

Power System Quality and Reliability

ECEg-6312

WEEK 1

Electric Power Quality Phenomena

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Course Description

Week 1: Electric power quality phenomena

Week 2: Voltage variations, sources, impacts, and mitigation mechanism

Week 3: Origin Transients, Its impact and mitigation and control mechanism

Week 4: Sources, Definitions & Standards of Harmonics

Week 5: Mitigation and Control of harmonics in Power System

Week 6: Power Quality Conditioners (PQC) (Active and Passive Harmonic Filters)

Week 7: Power Quality Conditioners (PQC) (DSTATCOM, DVR, and UPQC)

Week 8: Power Quality Case Studies and Mitigation using PQC

Course Description...

Week 9: Introduction to Power System Reliability

Week 10: Generator System Reliability Analysis

Week 11: Transmission System Reliability Model Analysis

Week 12: Multi-plant Multi-load System

Week 13: Introduction to System Modes of Failure

Week 14: Reliability Case Studies Project and Performance Evaluation

Week 15: Course Assessment/Evaluation

Week 16: Final Exam

Course Objectives

On successful completion of this course the students will be able:

1. To avail the knowledge about the power quality problems and their corrective measures.
2. Students will get the knowledge how the power quality problems will occur in the travelling lines and how it affects the power system.
3. Analyze the reliability of generation systems
4. Analyze the reliability of transmission systems

Electric Power Quality Phenomena

On this week we will cover the following key points:

1. Definitions of power quality (IEC & IEEE standards)
2. Classification of power quality (PQ) disturbances
3. Voltage fluctuations, Transients, Voltage unbalance, and Waveform distortion
4. Power frequency variations

Electric Power Quality Phenomena

After this topic, students should be able to:

- Define power quality based on international standards
- Classify major power quality (PQ) disturbances
- Analyze voltage fluctuations, transients, and waveform distortion
- Quantify voltage unbalance and frequency variations
- Relate disturbances to physical sources and system impacts

1. Definitions of Power Quality

- **Two major standard bodies to define power quality phenomena:**
 - IEEE and IEC standards
 - Specifically IEEE 1159 & IEC 61000 series
- **According to IEEE 1159 power quality is defined as:**
 - *Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment [1].*

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- **IEEE 1159** classifies power quality disturbances into [1], [2]:
 - Transients
 - Short-duration RMS voltage variations
 - Long-duration RMS voltage variations
 - Voltage imbalance
 - Waveform distortion (Harmonics, Interharmonics, and DC offset)
 - Voltage fluctuations (flicker)
 - Power frequency variations

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Definition of Power Quality (IEC 61000 Perspective)

- According to the IEC 61000 framework, power quality refers to:
 - The characteristics of the electricity at a given point in a power system, evaluated against a set of reference technical parameters such as **voltage magnitude, frequency, waveform shape, and continuity of supply** [2]-[4].

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- **The IEC 61000 standards classify power quality disturbances such as [2]-[4]:**
 - Voltage variations (Voltage sag (dip), Voltage swell, Interruptions)
 - Harmonics and interharmonics,
 - Voltage flicker
 - Frequency variations
 - Voltage unbalance
 - Transient disturbances
 - Electromagnetic interference

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- **In general, Power Quality (PQ) refers to:**
 - *The degree to which the voltage, current, and frequency of a power system conform to established standards and enable proper operation of equipment.*
- **Deviations from:**
 - Rated voltage
 - Rated frequency
 - Waveform purity
 - Symmetry

2. Power Quality Disturbances

- **Based on both IEEE 1159 and IEC 61000 PQ disturbances are classified as:**
 - Transients (μs – ms)
 - Short-duration voltage variations: Instantaneous (0.5 cycle to 30 cycles), Momentary (30 cycles to 3 seconds), Temporary (3 seconds to 1 minute)
 - Long-duration voltage variations (> 1 minute)
 - Voltage imbalance
 - Waveform distortion
 - Voltage fluctuations (flicker)
 - Frequency variations

Cont'd...

1. Transients

- According to IEEE 1159 [1], transients are **sudden/fast, non–power-frequency** disturbances in voltage or current that occur over a very short duration.
- They are typically characterized by **high amplitude** and **short duration**,
- They may cause malfunction, insulation failure, or damage to electrical and electronic equipment.
- Two types: **Impulsive** and **Oscillatory** transients

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Types of Transients:

A. Impulsive Transients: They are sudden, unidirectional spikes in voltage or current.

- **Characteristics:**

- Very fast rise time (nanoseconds to microseconds)
- High peak magnitude but Short duration

- **Common causes**

- Lightning strikes
- Electrostatic discharge
- Switching of inductive loads

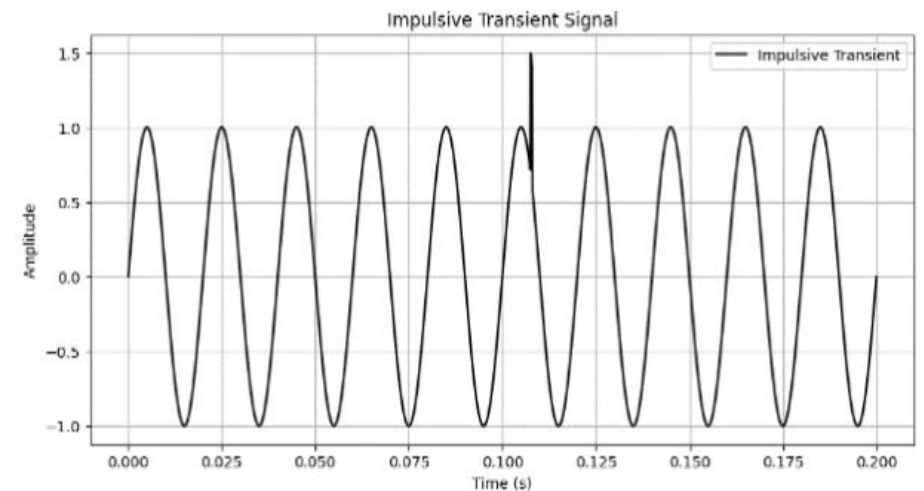


Figure 1: Impulsive Transients [5]

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B. Oscillatory Transients: They are disturbances where voltage or current oscillates around the nominal value before returning to steady state.

- **Characteristics:**

- Bidirectional waveform oscillation
- Decaying amplitude over time
- Frequency ranges from a few hundred Hz to several MHz

- **Common causes:**

- Capacitor bank and Power electronic switching
- Transformer energization

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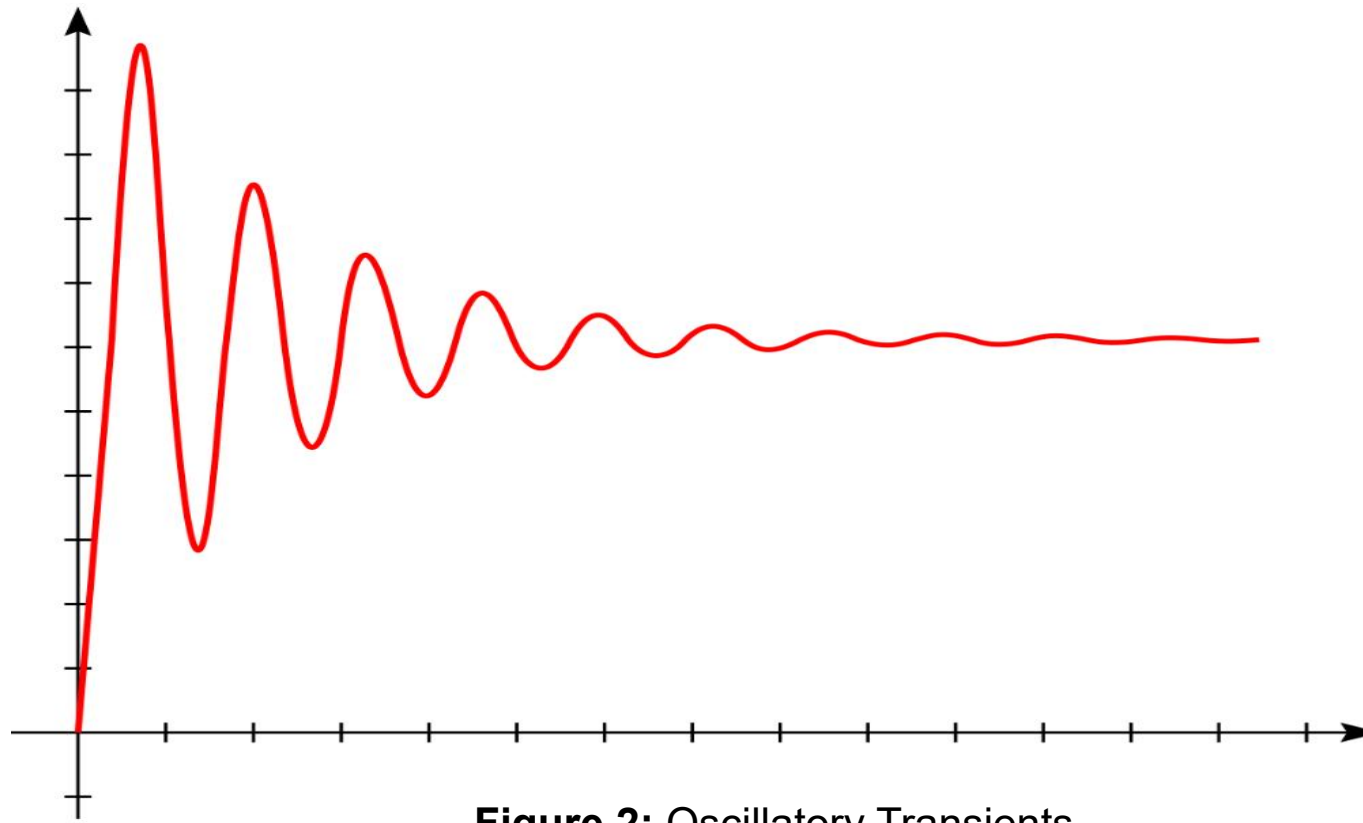


Figure 2: Oscillatory Transients

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2. Short-duration Voltage Variations

- Short-duration voltage variations are changes in RMS voltage magnitude that occur for a short period, typically ranging from **0.5 cycles to 1 minute**.
- These disturbances are commonly caused by system faults, motor starting, transformer energization, or sudden load changes.
- Short-duration voltage variations are divided into three main categories: voltage **sag (dip)**, voltage **swell**, and **interruption**.

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3. Long-duration Voltage Variations

- They are RMS voltage deviations from the nominal value that persist for longer than **1 minute**.
- These variations are typically associated with sustained load changes, incorrect voltage regulation, or system configuration issues in power networks.
- Long-duration voltage variations are classified into three main types: **overvoltage**, **undervoltage**, and **sustained** interruption.

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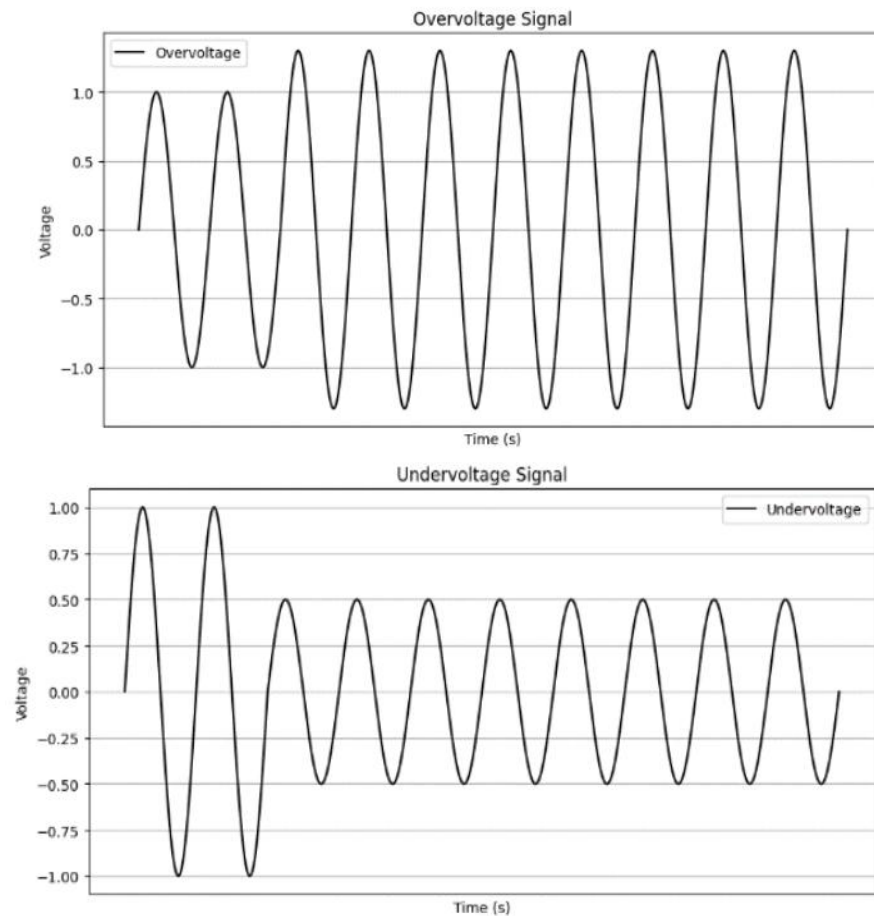


Table 1. Long-duration voltage variation

Type	Duration	Voltage Magnitude
Overvoltage	>1 minute	1.1-1.2 p.u
Undervoltage	>1 minute	0.8-0.9 p.u
Interruption	>1 minute	0.0 p.u

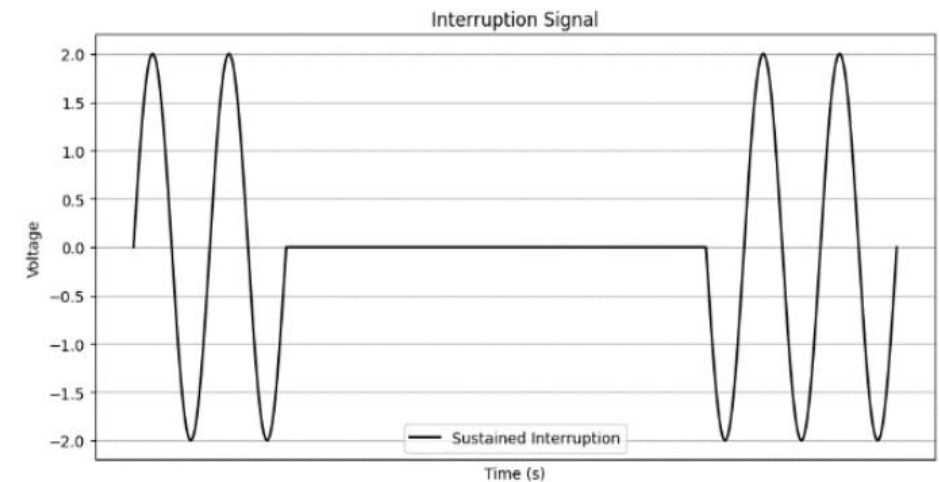


Figure 3. Long-duration Voltage Variation Waveforms [5]

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4. Voltage Imbalance (Voltage Unbalance):

- Voltage imbalance is the condition in a three-phase system where the magnitudes and/or phase angles of the phase voltages are unequal.
 - Voltage Unbalance is quantified using voltage measurement.

$$\% V_{unbalance} = \frac{\text{Maximum deviation from average voltage}}{\text{Average voltage}} \times 100$$

– Acceptable Limits

- $\leq 1\%$ → Ideal system, $\leq 2\%$ → Acceptable for most systems, $> 3\%$ → Risk of motor overheating, $> 5\%$ → Serious operational concern

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Causes of Voltage Imbalance:

– **Distribution-Level Causes:**

- Uneven single-phase loads
- Asymmetrical feeder impedance
- Open conductor
- Blown fuse in capacitor bank

– **Transmission-Level Causes:**

- Untransposed lines
- Unbalanced faults
- Unequal transformer impedances

– **DER-Related Causes:**

- Single-phase PV connections
- Uneven EV charging distribution

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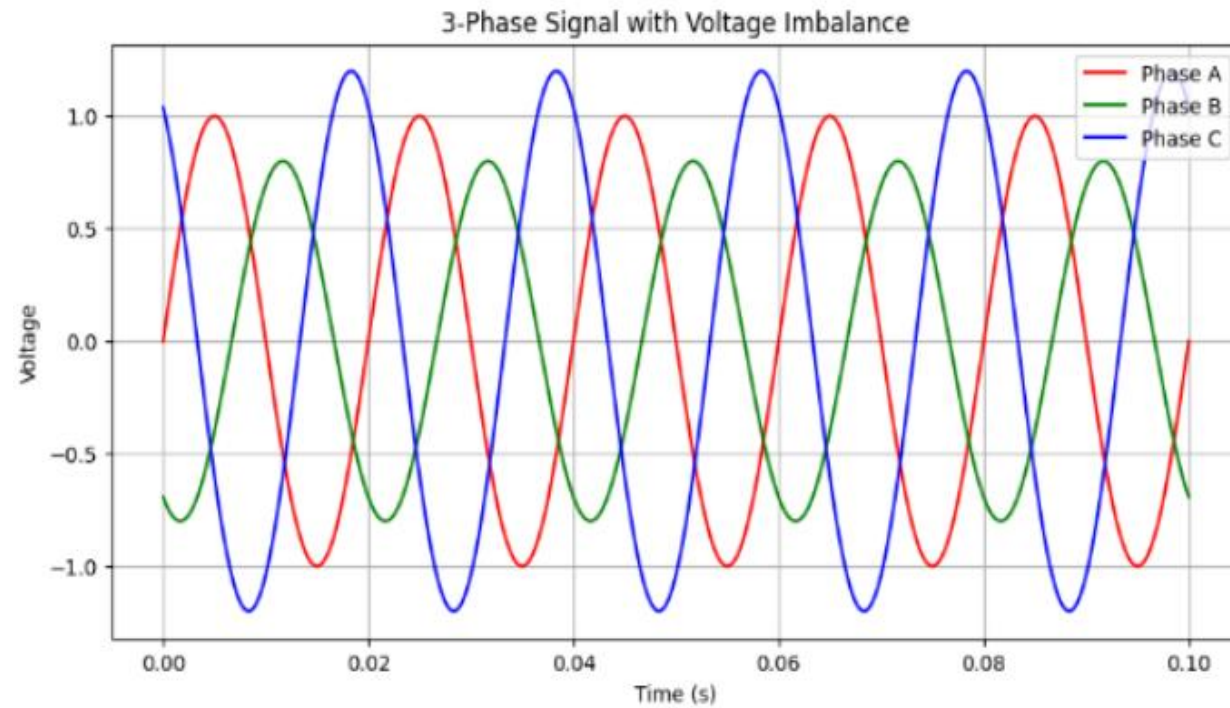


Figure 4: Three phase imbalance

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Mitigation Techniques of Voltage Unbalance

– System-Level:

- Phase load balancing
- Feeder reconfiguration
- Proper line transposition
- Equal impedance design

– Equipment-Level:

- Phase balancing transformers
- Static VAR compensators
- DSTATCOM with unbalance compensation
- Smart inverter phase control

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5. Voltage Fluctuations / Flicker

- Voltage fluctuation is defined as:
 - A **series** of voltage changes or a **cyclical** variation of the voltage envelope whose magnitude does not normally exceed the **voltage range** specified for normal operation.
- When these voltage variations affect lighting intensity and become perceptible to the human eye, the phenomenon is called **flicker**.

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Causes of Voltage Fluctuations

- Voltage fluctuations are mainly caused by loads that draw rapidly varying current, including:
 - Electric arc furnaces and Welding machines
 - Large motor starting and Rolling mills
 - Variable speed drives
 - Switching of large loads
- These loads cause continuous changes in the system current, which leads to corresponding voltage variations across network impedances.

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Effects of Flicker

- The primary effects of flicker include:
 - Visible light intensity variations in lamps
 - Annoyance or discomfort to consumers
 - Reduced power quality perception
 - Possible malfunction of sensitive electronic equipment
- Typical Flicker Frequency Range is **0.5-30 Hz**.
- Within this range, the **human eye** is most sensitive to variations in light intensity.

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6. Power Frequency Variations

- Power frequency variation is the deviation of the system's fundamental frequency from its nominal value due to a mismatch between generation and load.
 - 50 Hz (used in most of the world)
 - 60 Hz (used in North America and a few other regions)
- Ideally, the frequency should remain constant. However, small deviations occur when generation and load are not balanced.

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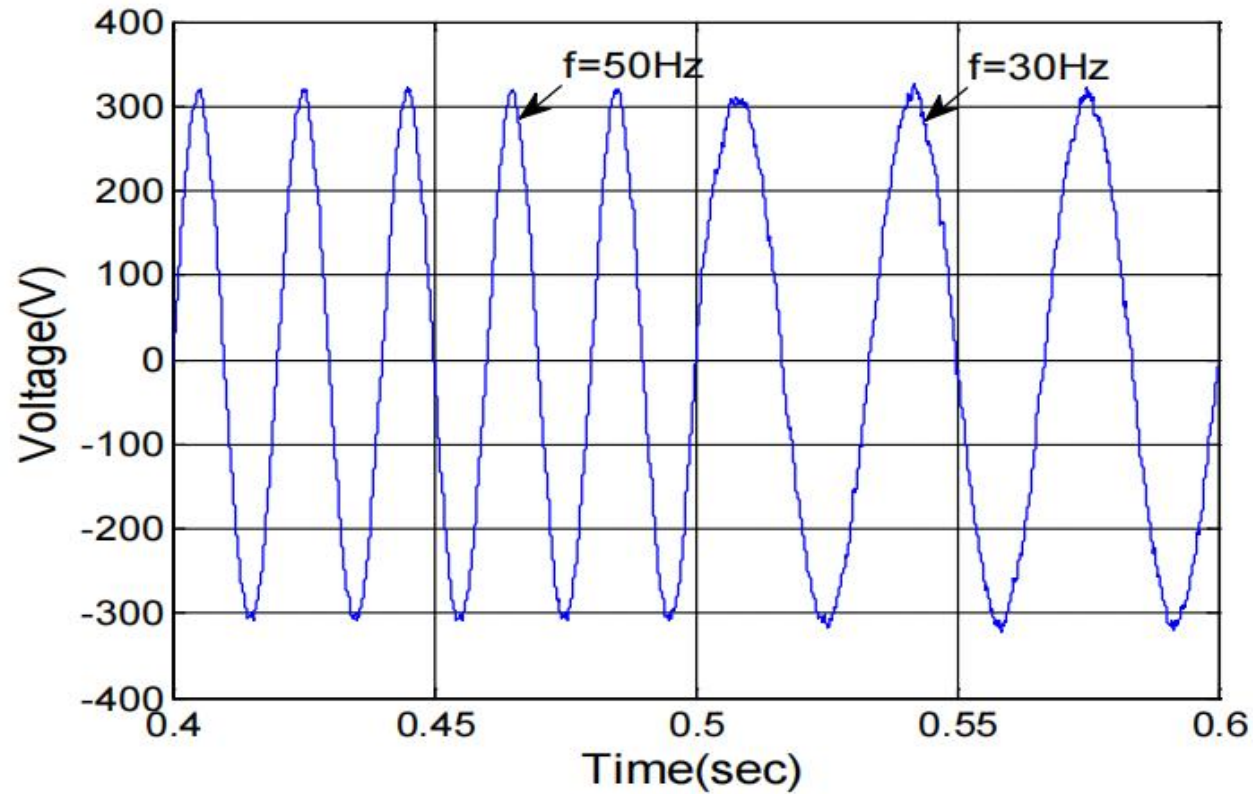


Figure 5: Frequency Variation of Voltage

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- **Causes of Frequency Variation**
 - Sudden loss of generation or tripping of generators
 - Abrupt load changes (increase or decrease)
 - Operation of isolated or weak networks
 - Faults or disturbances in the transmission or distribution system
 - Insufficient or slow governor and automatic generation control (AGC) response
- Frequency variations are more pronounced in small-scale systems or microgrids where inertia is limited.

Summary

- In general, power quality disturbances can be broadly classified into several types, each affecting voltage and current in different ways.
- Power quality disturbances are categorized as:
 1. Transients: Impulsive transients and Oscillatory transients
 2. Voltage variations: Short-duration variations and Long-duration variations
 3. Voltage imbalance
 4. Voltage fluctuations and Waveform distortion
 5. Power frequency variations

Brainstorming Questions

1. What types of equipment are most sensitive to short-duration voltage sags?
2. How can impulsive and oscillatory transients be mitigated in industrial networks?
3. Why is voltage imbalance more critical in motor-heavy facilities?
4. What monitoring strategies can detect long-duration voltage variations effectively?
5. How can renewable energy integration affect voltage variations and unbalance?

References

- [1]. Institute of Electrical and Electronics Engineers, Recommended Practice for Monitoring Electric Power Quality, IEEE 1159, IEEE Power and Energy Society, New York, USA.
- [2]. M. H. J. Bollen, Understanding Power Quality Problems: Voltage Sags and Interruptions. New York, USA: IEEE Press, 2000.
- [3]. International Electrotechnical Commission, Electromagnetic Compatibility (EMC) – Part 4-30: Testing and Measurement Techniques – Power Quality Measurement Methods, IEC Standard 61000-4-30, Geneva, Switzerland.

References...

[4]. International Electrotechnical Commission, Electromagnetic Compatibility (EMC) – Part 2: Environment – Compatibility Levels for Low-Frequency Conducted Disturbances, IEC 61000 Series, Geneva, Switzerland.

[5]. B. F. Khaldi, F. Z. Dekhandji, and A. Recioui, “Power quality disturbances: A review of detection, classification, optimization, and mitigation techniques,” Algerian Journal of Signals and Systems, vol. 9, no. 4, pp. —, Dec. 2024.

Thank You!