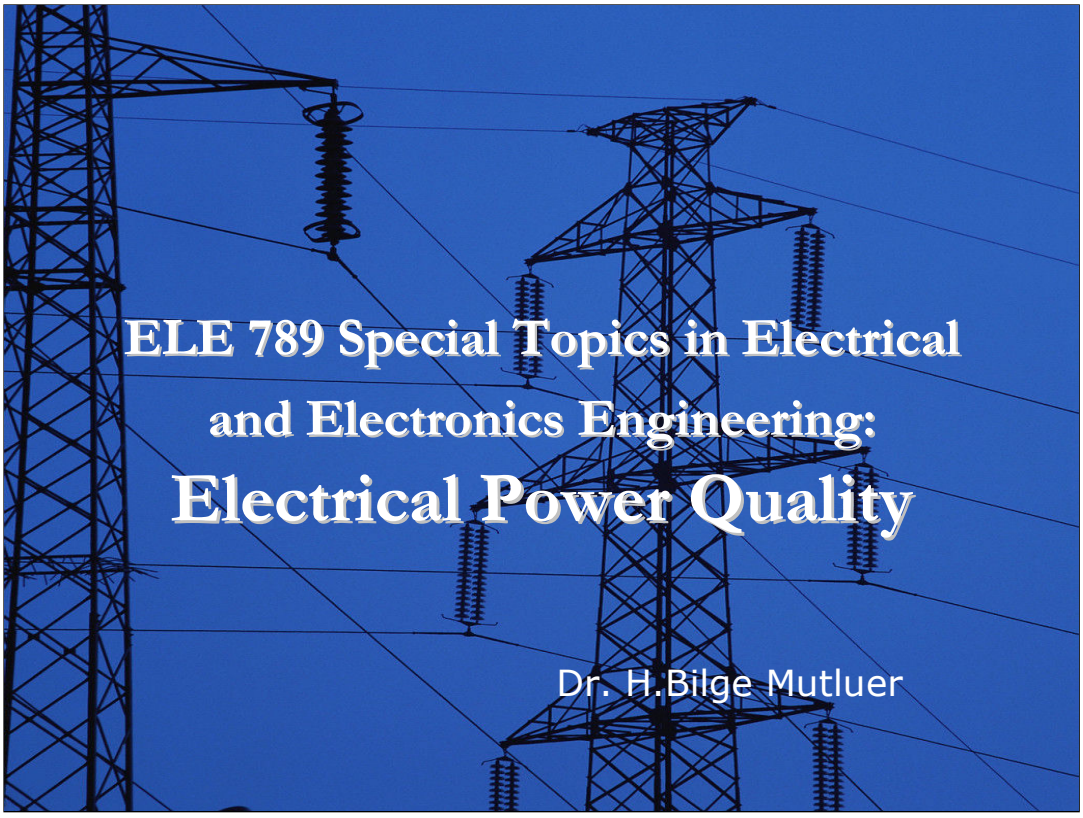
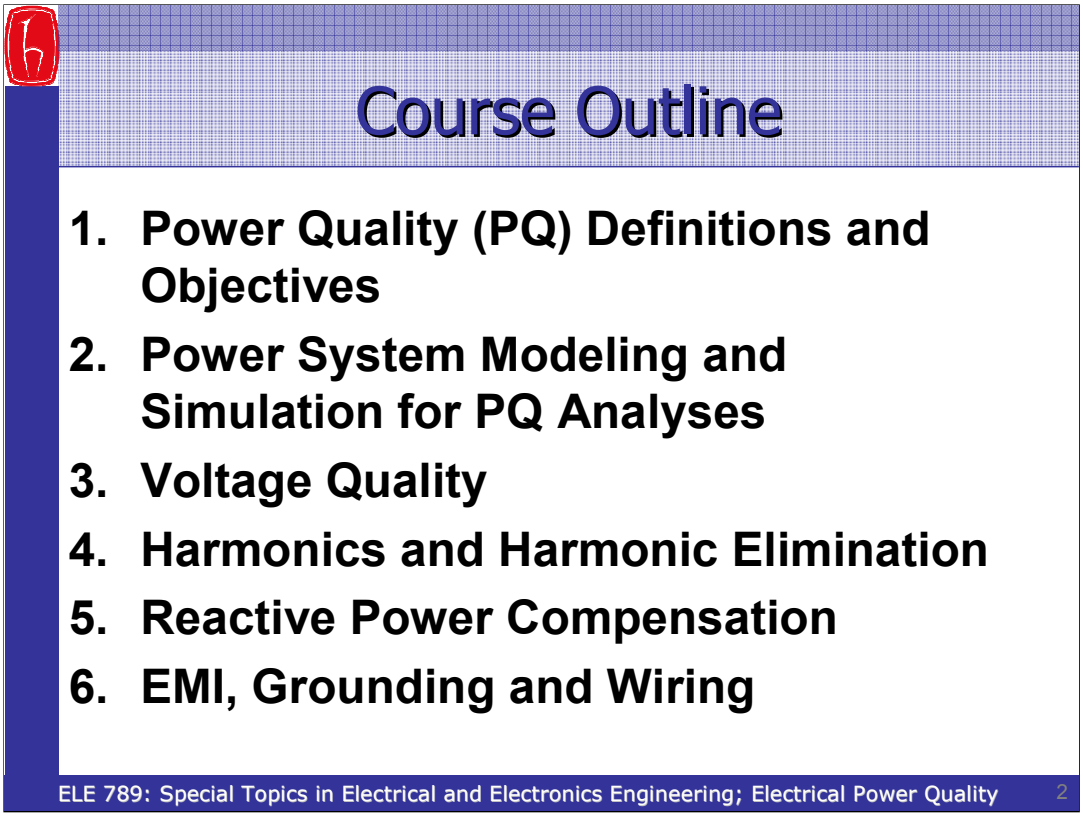
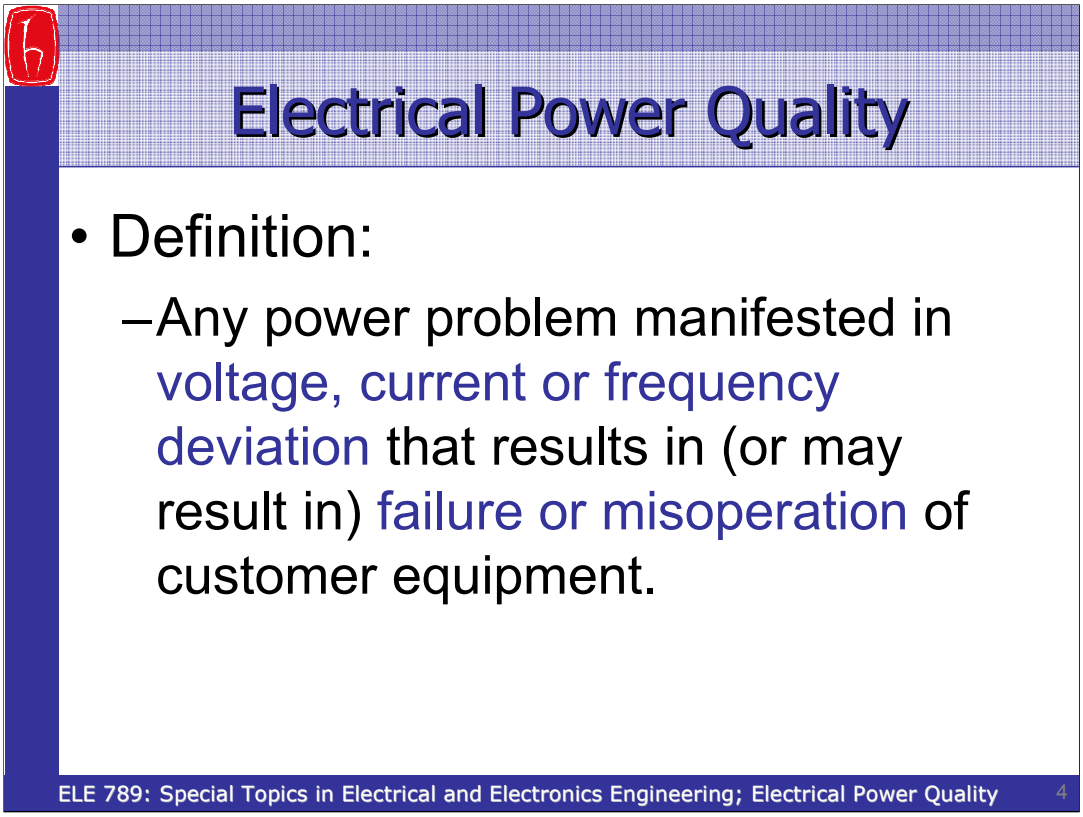

ELE 789 Special Topics in Electrical
and Electronics Engineering:
Electrical Power Quality
Dr. H.Bilge Mutluer


Course Outline
1. Power Quality (PQ) Definitions and Objectives
2. Power System Modeling and Simulation for PQ Analyses
3. Voltage Quality
4. Harmonics and Harmonic Elimination
5. Reactive Power Compensation
6. EMI, Grounding and Wiring
ELE 789: Special Topics in Electrical and Electronics Engineering; Electrical Power Quality
2

Outline

Power Quality (PQ) Definitions and Objectives

- CHAPTER 1
  - What is Electrical Power Quality
  - General Terms and Definitions



What is Electrical Power Quality (Sankaran)

"Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy."

IEEE1100

Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment."

Electrical Power Quality

- Economical Aspects
- Life-time of the equipment and systems
- Reliability
- Advantages to utility
- Advantages to the customer

Electrical Power Quality

- Historical Background:
  - The first EMC law by German Reich (1892)
  - Development of Standards
    - VDE 0838, VDE 0839, EN 61000, IEC 1000
    - TS EN 61000-3-2 (1998), 3.3.2003
  - Legislations
    - Arz Güvenilirliği ve Kalitesi, EPDK
    - Elektrik Piyasası Şebeke Yönetmeliği

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Sankaran:

Since the discovery of electricity 400 years ago, the generation, distribution, and use of electricity have steadily evolved.

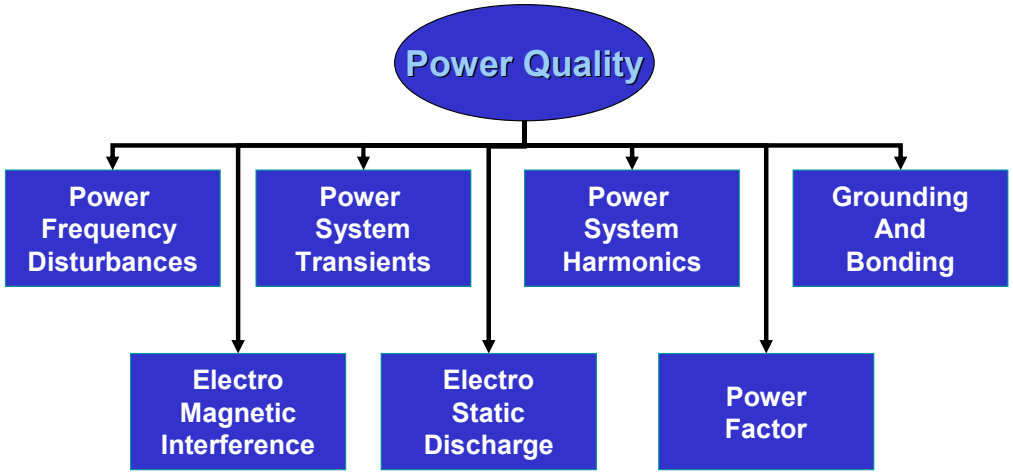
Wikipedia:

English physician William Gilbert made a careful study of electricity and magnetism, distinguishing the lodestone effect from static electricity produced by rubbing amber.[6] He coined the New Latin word *electricus* ("of amber" or "like amber", from *ήλεκτρον* [*elektron*], the Greek word for "amber") to refer to the property of attracting small objects after being rubbed

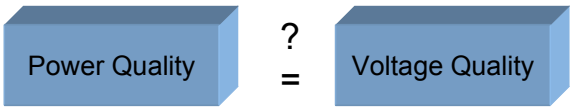
The first EMC law by German Reich (1892):

Electrical systems shall, if a disturbance in operation of one line by another has occured, or may occur, at expense of that part which due to the latter system or a subsequent change to its existing system causes this disturbance, or the danger of same, where possible be designed so that they do not have a disturbing effect

Electrical Power Quality Concerns



Utility and Load Side Approach



Short circuit at load => Voltage Sag
Excessive load current harmonics => Voltage harmonics
Lightning based impulse voltages => Short circuit currents

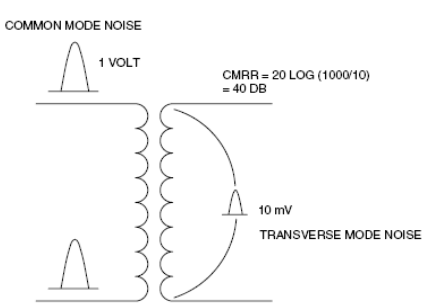
Terminology

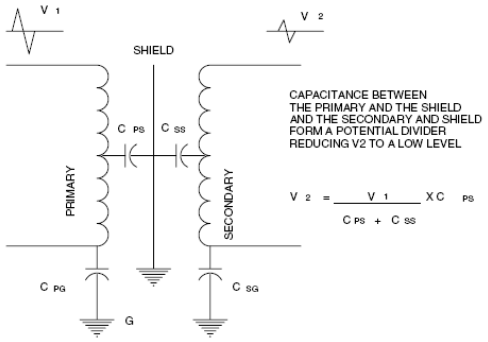
- To prevent
  - Confusion
  - Ambiguity
- To create a general understanding
- Development of Standards

References:
1. Dugan
2. Sankaran

Common Mode Voltage

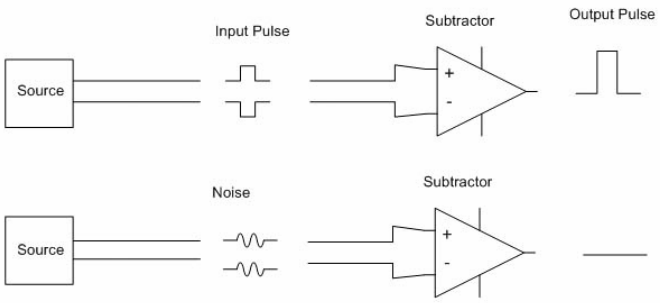
- The noise voltage that appears equally from current-carrying conductor to ground
- CMMR: Common Mode Rejection Ratio





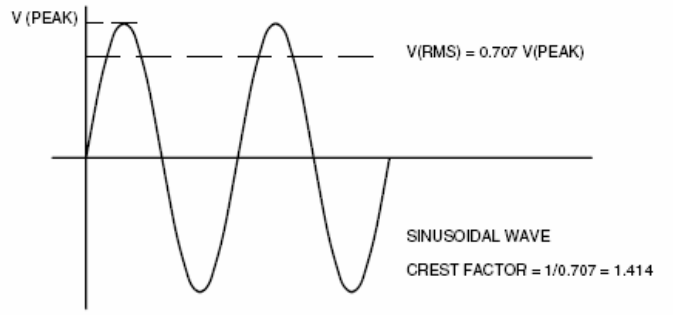
Differential Mode Voltage

- The voltage between any two of a specified set of active conductors.



Crest Factor

- Ratio of the crest (peak) value of the measured waveform to RMS of the fundamental

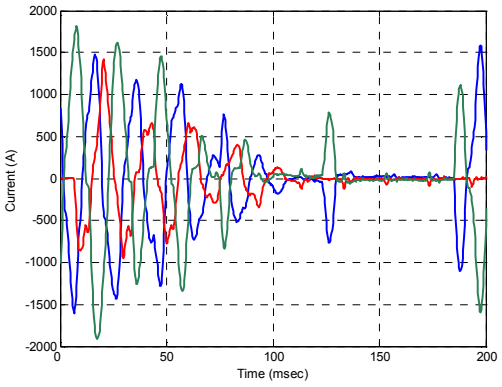


Sankaran:

Crest factor is one indication of the distortion of a periodic waveform from its ideal characteristics.

(Waveform) Distortion

- Any **deviation from the normal sine** wave of an AC quantity
- Common Types:
  - DC offset
  - Harmonics
  - Interharmonics
  - Notching
  - Noise



Sankaran:

— Qualitative term indicating the deviation of a periodic wave from its ideal waveform characteristics.

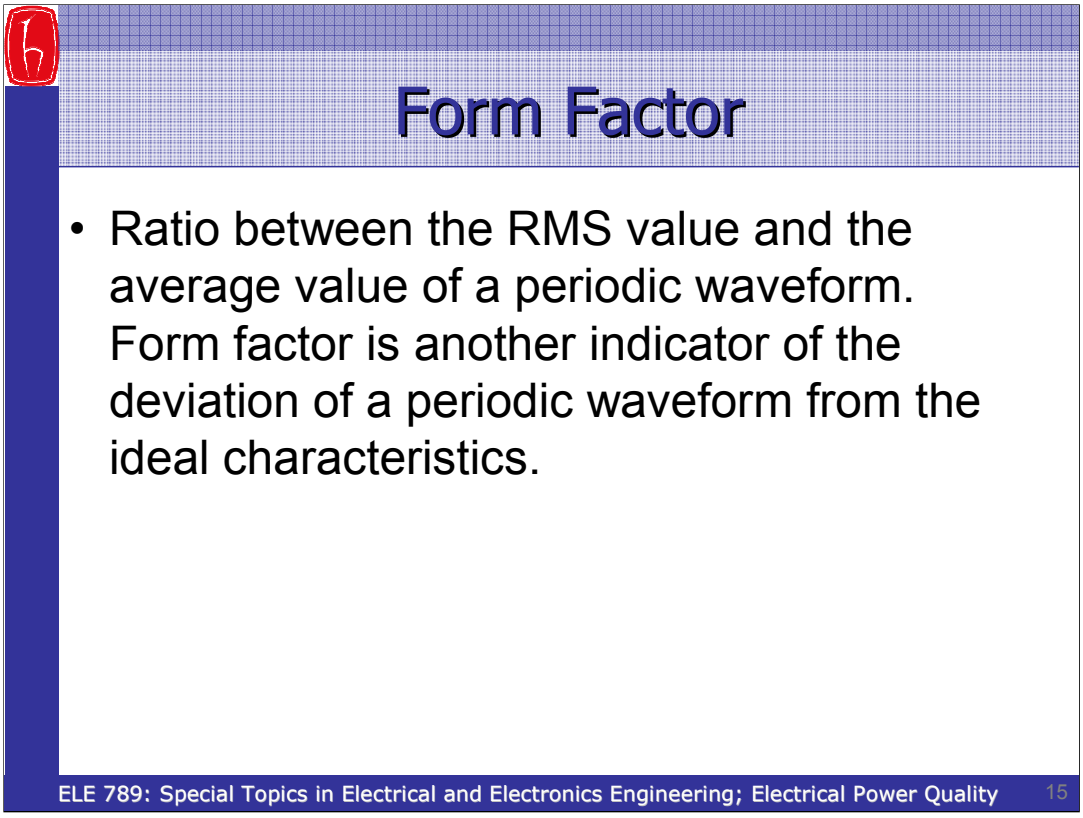
The distortion introduced in a wave can create waveform deformity as well as phase shift.

Distortion Factor

- Ratio of the RMS of the harmonic content of a periodic wave to the RMS of the fundamental content of the wave, expressed as a percent. This is also known as the Total Harmonic Distortion
- THD, TDD (IEEE 519-1992)

$$THD = \frac{\sqrt{V_2^2 + V_3^2 \ldots + V_n^2}}{V_1} \times 100\%$$

THD: The ratio of the root mean square of the harmonic content to the rms value of the fundamental quantity, expressed as the percent of the fundamental



For example, the average value of a pure sinusoidal wave averaged over a cycle is 0.637 times the peak value. The RMS value of the sinusoidal wave is 0.707 times the peak value. The form factor, *FF* , is calculated as *FF* = 0.707/0.637 = 1 .11.

Periodic

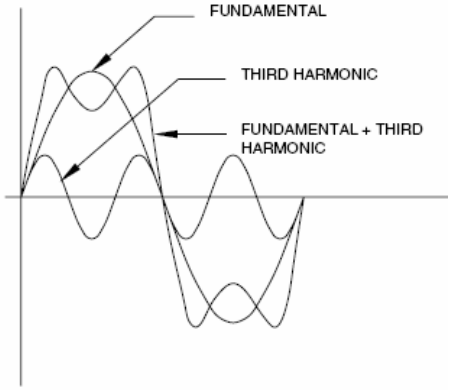
- A voltage or current is periodic if the value of the function at time t is equal to the value at time $t + T$, where T is the period of the function.

Fundamental

- The component of order 1 (50Hz or 60Hz) of the Fourier Series of a periodic quantity.

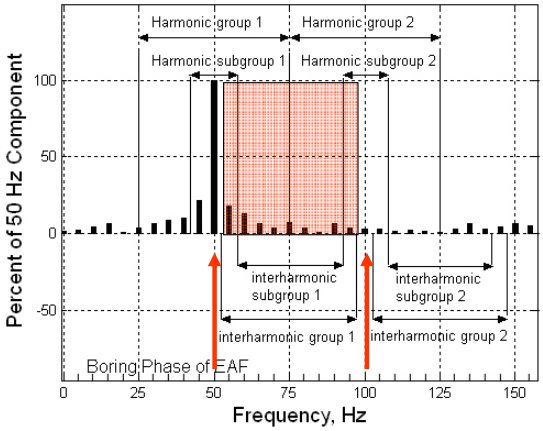
Harmonic (Component)

- A component of order greater than 1 of the fourier series of a periodic quantity



Interharmonic

- A frquency component of a periodic quantity that is **not an integer multiple of the supply frequency**
- Static frequency converters, cycloconverters, inductio furnaces, arc and laddle furnaces

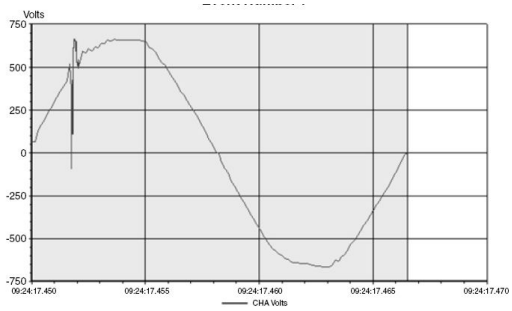


Impulse

- A pulse that, for a given application, approximates a unit pulse or a dirac function.

$$\delta_a(x) = \frac{1}{a\sqrt{\pi}} e^{-x^2/a^2}$$

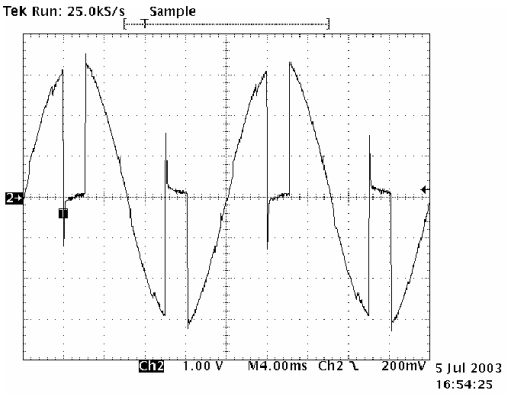
$$\delta(x) = \begin{cases} +\infty, & x = 0 \\ 0, & x \neq 0 \end{cases}$$



Traditionally used to indicate a short duration overvoltage event with certain rise and fall characteristics. Standards have moved toward including the term *impulse* in the category of transients

Notch

- Disturbance of the normal power voltage waveform lasting less than a half cycle; the disturbance is initially of **opposite polarity** than the waveform and, thus, subtracts from the waveform.



Triplen (harmonics)

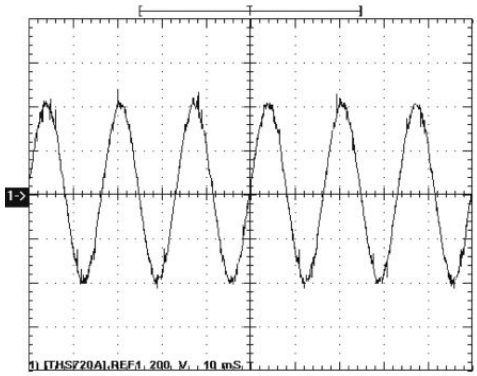
- Odd multiples of the third harmonic (including itself)
- Natural tendency to be zero sequence

Electro Magnetic Compatibility

- The ability of a device, equipment or system to **function satisfactorily** in its electromagnetic environment **without introducing intolorable electromagnetic disturbances** to anything in that environment.

Noise

- Electrical noise is unwanted electrical signals that produce undesirable effects in the circuits of control systems in which they occur



Coupling

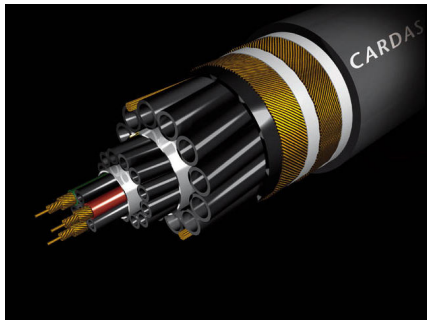
- A circuit element, or elements or network that may be considered **common to the input mesh and output mesh** and through which **energy may be transferred** from one another.

Sankaran:

Process by which energy or electrical noise in one circuit can be transferred to another circuit that may or may not be electrically connected to it.

Shield

- Conductive sheath (usually metallic) applied, over the insulation of a conductor, for the purpose of providing means to reduce coupling between the conductors.
- Prevents / reduces unwanted electrostatic / electromagnetic fields (noise)

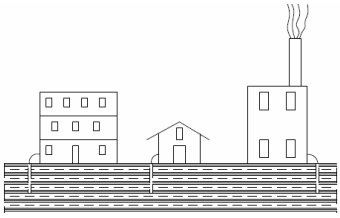


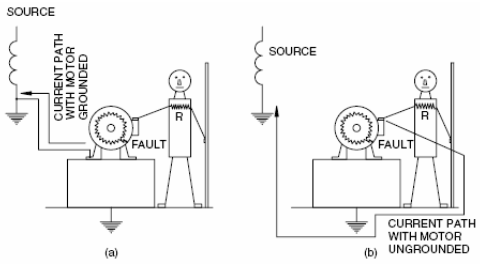
Shielding

- Usage of a conducting and/or ferromagnetic barrier between a potentially disturbing noise source and sensitive circuitry
- Protect data/ power cables

Ground (Earth, Grounding)

- A conducting connection (intentional or accidental) by which an electrical circuit is connected to earth, or to some conducting body of relatively large extent

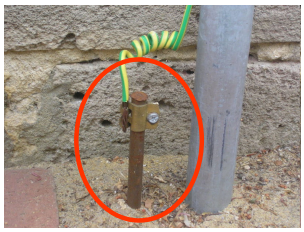




It is used for establishing and maintaining the potential of earth and conducting ground currents to and from earth.

Ground Electrode

- A conductor or group of conductors in intimate contact with the earth for the purpose of providing a connection with the ground

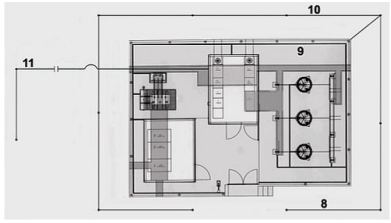


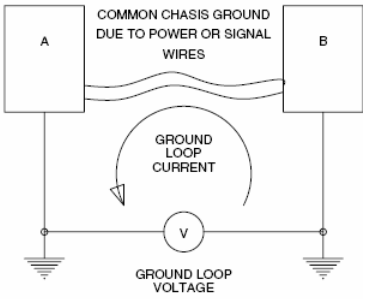
Ground Grid

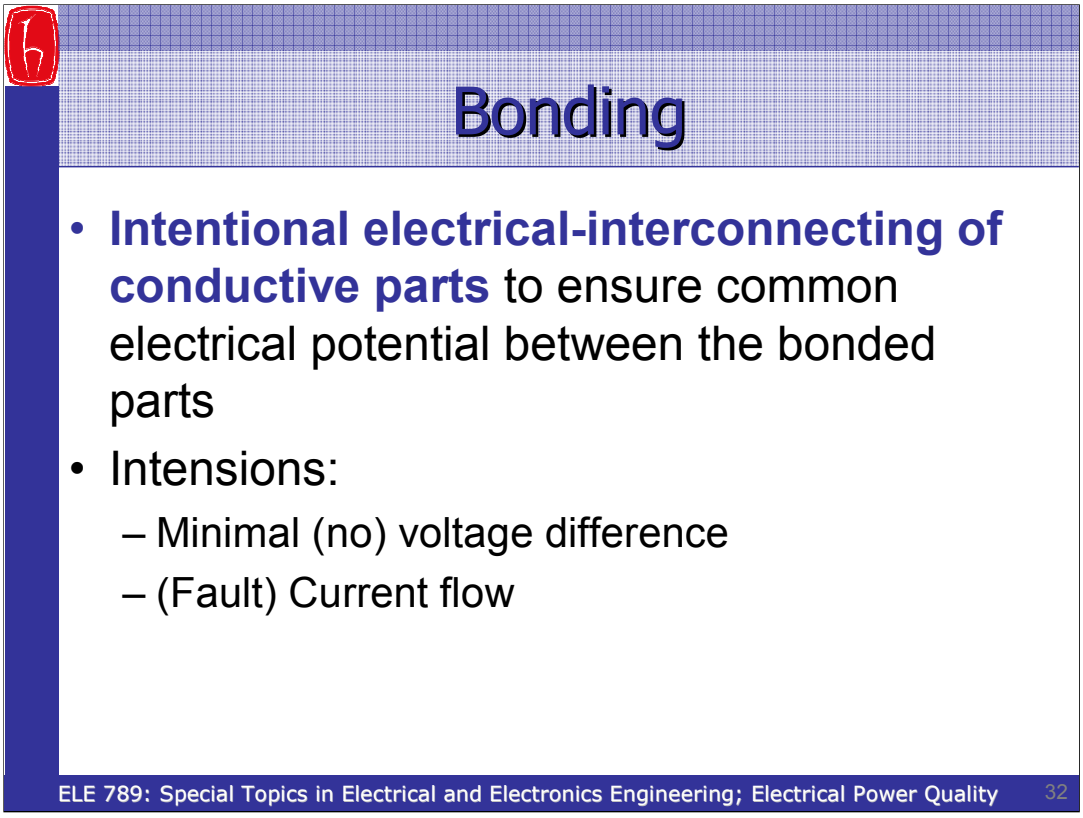
- System of interconnected bare conductors arranged in a pattern over a specified area and buried below the surface of the earth.

Ground Loop

- Potentially detrimental loop formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same ground potential







Sankaran:

Intentional electrical-interconnecting of conductive parts to ensure common electrical potential between the bonded parts. Bonding is done primarily for two reasons. Conductive parts, when bonded using low impedance connections, would tend to be at the same electrical potential, meaning that the voltage difference between the bonded parts would be minimal or negligible. Bonding also ensures that any fault current likely imposed on a metal part will be safely conducted to ground or other grid systems serving as ground

Isolation

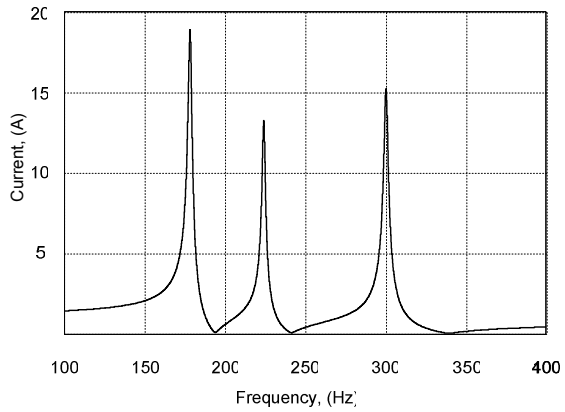
- Seperation of one section of a system from undesired influences of other sections.

Linear / Nonlinear Load

- Electrical load which in steady-state operation presents essentially constant impedance to the power source throughout the cycle of applied voltage.
- A purely linear load has only the fundamental component of the current present.

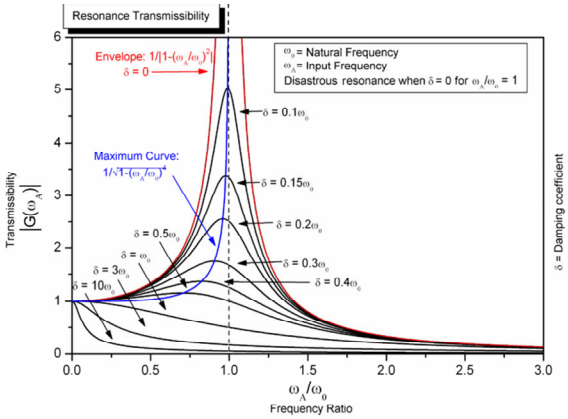
Frequency Response

- Variation of impedance of system, or a metering transducer as a function of frequency



Resonance

- A condition in which natural frequencies of the inductances and capacitances in the power system are excited and sustained by disturbing phenomena

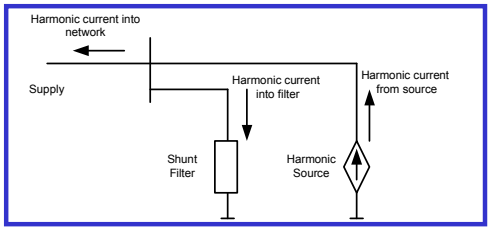


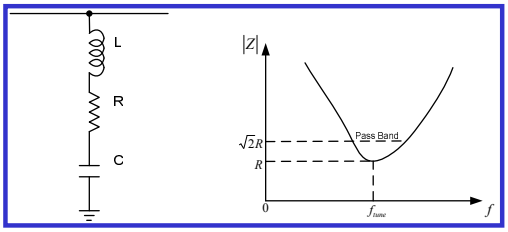
Ferroresonance

- An irregular, often chaotic type of resonance that involves the non-linear characteristic of iron-core (ferrous) inductors.

Harmonic Filter

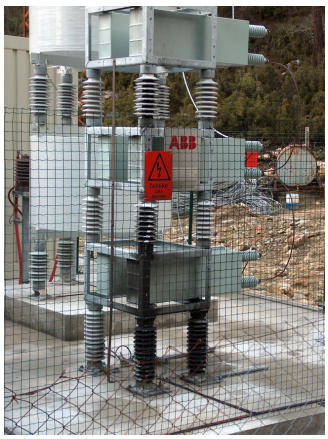
- A device filtering one or more harmonic from the power system
- Active / passive
- Shunt / series connection





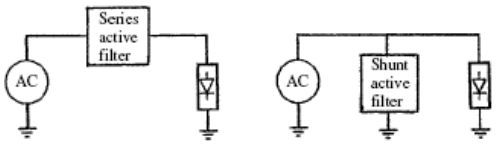
Passive Filter

- A combination of inductors, capacitors and resistors designed to eliminate one or more harmonics.



Active Filter

- Any of a number of sophisticated **power electronic devices for eliminating harmonic distortion**.



Inverter

- A power electronic device that converts DC to AC for:
  - Power Frequency
  - Variable frequency
- Different modulation techniques and topologies
  - Synchronous, Resonant, PWM, SPWM, SHEM

Event Duration

- Instantaneous
  - One half cycle – 30 cycles
- Momentary
  - 30 cycles – 3 seconds
- Temporary
  - 3 seconds – 1 minute
- Short Duration Variation (Voltage)
  - <= 1 minute
- Long Duration Variation (Voltage)
  - > 1 minute

Critical Load

- Devices and equipment **whose failure to operate jeopardizes the health or safety** of personel and/or results in **loss of function, financial loss or damage** to the property deemed critical by the user.

Distributed Generation

- Generation dispersed throughout the power system as opposed to large, central station power plants.
- Typically refers to units less than 10 MW, interconnected to Distribution (Not Transmission)

Technology	Recip Engine: Diesel	Recip Engine: NG	Microturbine	Combustion Gas Turbine	Fuel Cell
Size (Typ.)	30kW - 6+MW	30kW - 6+MW	30-400kW	0.5 - 30+MW	100-3000kW

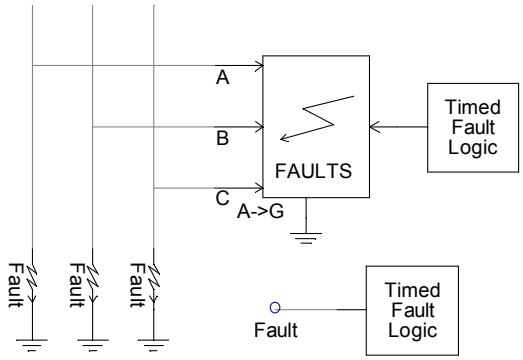
Islanding

- A condition in which distributed generation is isolated on a portion of the load served by the utility power system.

It is usually an undesirable situation, although there are situations where controlled islands can improve the system reliability

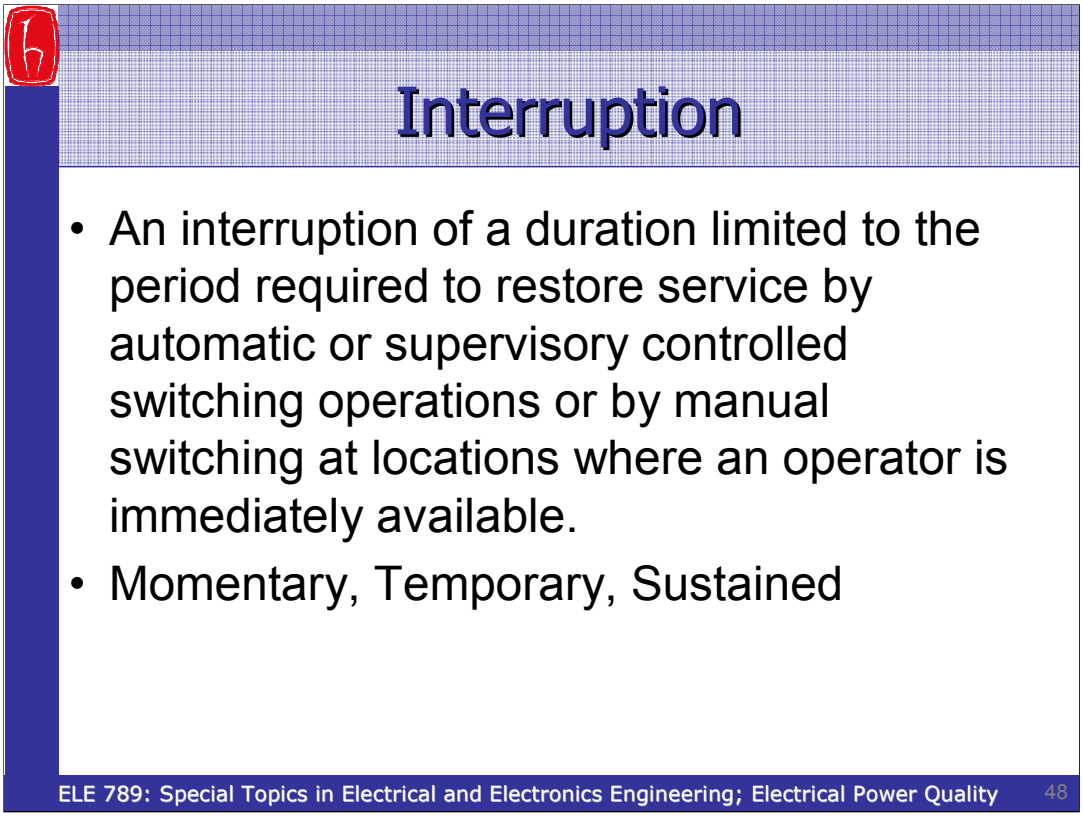
Fault

- Generally refers to a short circuit on the power system.



Dropout

- A loss of equipment operation due to noise, sag or interruption
- Dropout voltage:
  - At which a device will release to its de-energised position



Momentary interruption:

Complete loss of voltage (<0.1p.u.) on one or more phase conductors for a time period between 30 cycles and 3 s.

Temporary interruption:

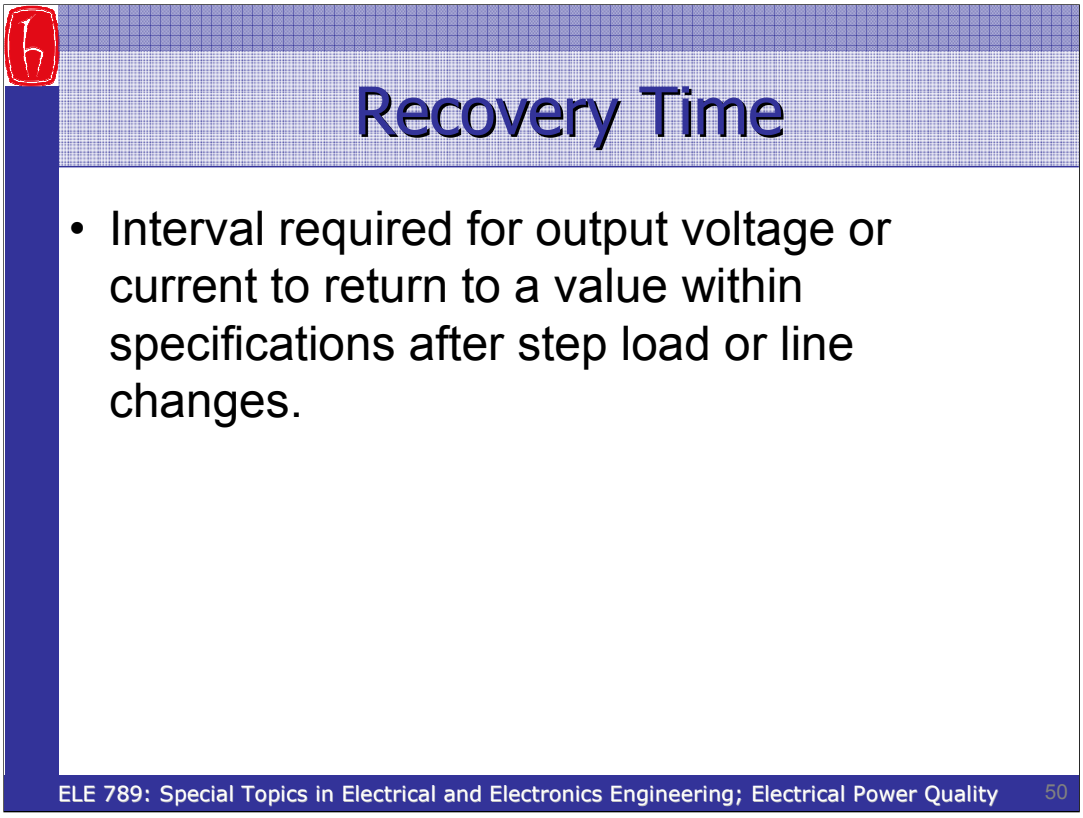
Complete loss of voltage (<0.1p.u.) on one or more phase conductors for a time period between 3 s and 1 min.

Sustained interruption:

Complete loss of voltage (<0.1p.u.) on one or more phase conductors for a time period >1min.

Ride Through

- Measure of the ability of control devices to sustain operation when subjected to partial or total loss of power of a specified duration



Also may indicate the time interval required to bring a system back to its operating condition after an interruption or dropout

Frequency Deviation

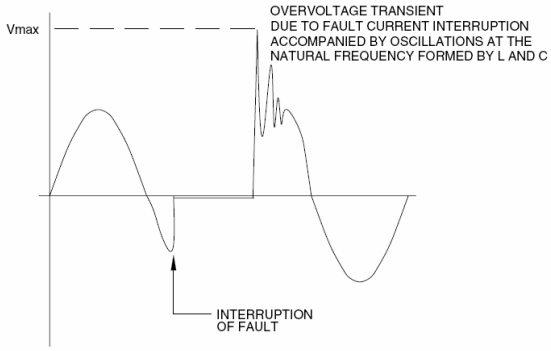
- An increase or decrease in the power frequency
- Duration can be from several cycles to several hours

(Power) Disturbance

- Any deviation from the nominal value of the input AC characteristics

Transient

- 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.
- Can be a unidirectional impulse or damped oscillatory wave

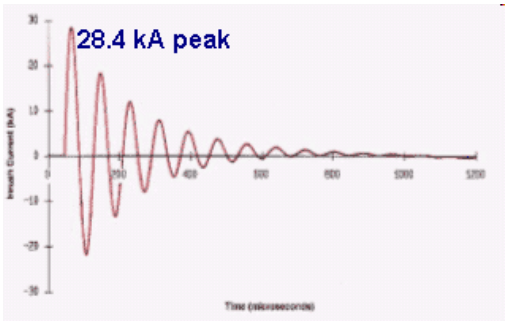


Sankaran:

Subcycle disturbance in the AC waveform evidenced by a sharp, brief discontinuity of the waveform. This may be of either polarity and may be additive or subtractive from the nominal waveform. Transients occur when there is a sudden change in the voltage or the current in a power system. Transients are short-duration events, the characteristics of which are predominantly determined by the resistance, inductance, and capacitance of the power system network at the point of interest. The primary characteristics that define a transient are the peak amplitude, the rise time, the fall time, and the frequency of oscillation

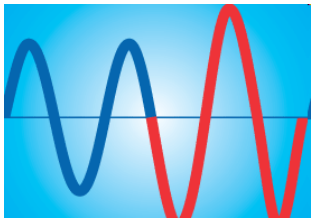
Inrush

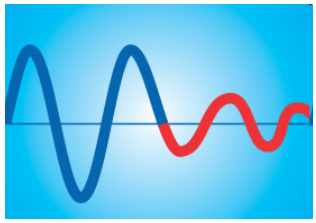
- Large current that a load draws when initially turned on.



Overvoltage / Undervoltage

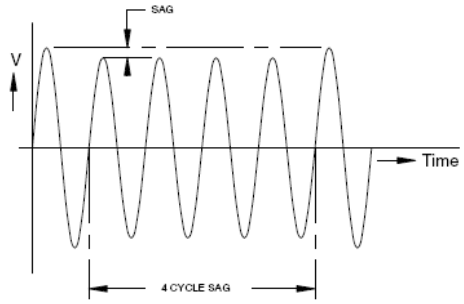
- Long duration variation **(>1 min)**
  - Overvoltage: > +10% ,
  - Undervoltage: < -10%





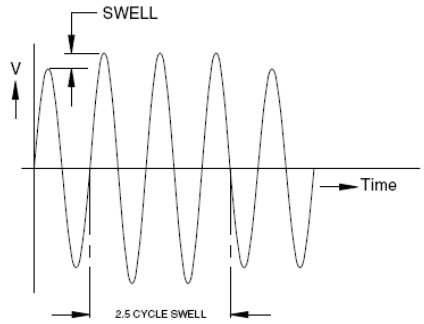
Sag

- A decrase to 0.1 and 0.9 p.u. in rms voltage at the power frequency
- 0.5 cycle to 1 min.



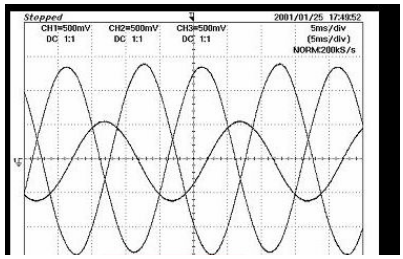
Swell

- An increase more than 0.1 p.u. in rms voltage at the power frequency
- 0.5 cycle to 1 min.



Voltage Imbalance (Unbalance)

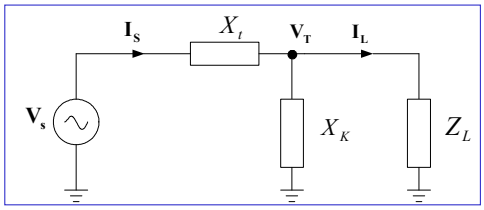
- Three phase differ in amplitude or are displaced from their normal 120 deg. phase relationship or both
- Expressed as the ratio of the negative and zero sequence to the positive sequence voltage, (%)

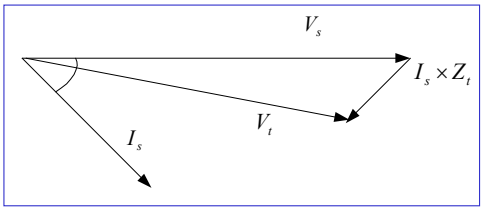


$$\begin{bmatrix} I^+ \\ I^- \\ I^0 \end{bmatrix} = 1/\sqrt{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_R \\ I_Y \\ I_B \end{bmatrix}$$

Voltage Regulation

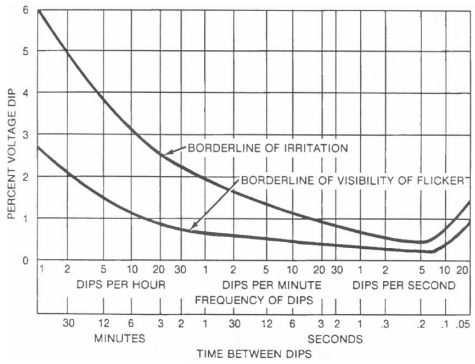
- The degree of control or stability of the rms voltage at the load.





Flicker

- An impression of unsteadiness of visual sensation induced by a **light stimulus whose luminance or spectral distribution fluctuates by time**



Variation of input voltage sufficient in duration to allow visual observation of a change in electric light source intensity. Quantitatively, flicker may be expressed as the change in voltage over nominal expressed as a percent.

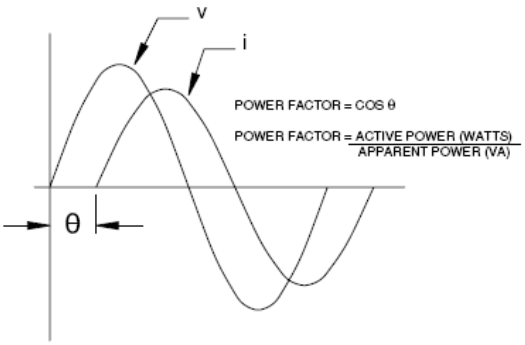
P_{st} and P_{lt}

- Defined by IEC 61000-4-15
- Pst :
  - Short term flicker severity level based on an observation of 10 min.
- Plt:
  - Long term flicker severity level based on an observation of 2h.

A Pst value greater than 1 corresponds to level of irritability for 50% of the persons subjected to the measured flicker

Power Factor (Displacement)

- Ratio between the active power (P) of the fundamental wave to the apparent power (S) of the **fundamental wave.**
- For a pure sinusoidal waveform, the **cosine of the displacement angle** between the V and I



Power Factor (True, Total)

- Ratio of the total active power (P) to the total apparent power (S) of the composite wave, **including all harmonic frequency components**.
- The **total power factor is less than the displacement power factor**, as the presence of harmonics tends to increase the displacement

Electromagnetic Phenomena (Classified by IEC)

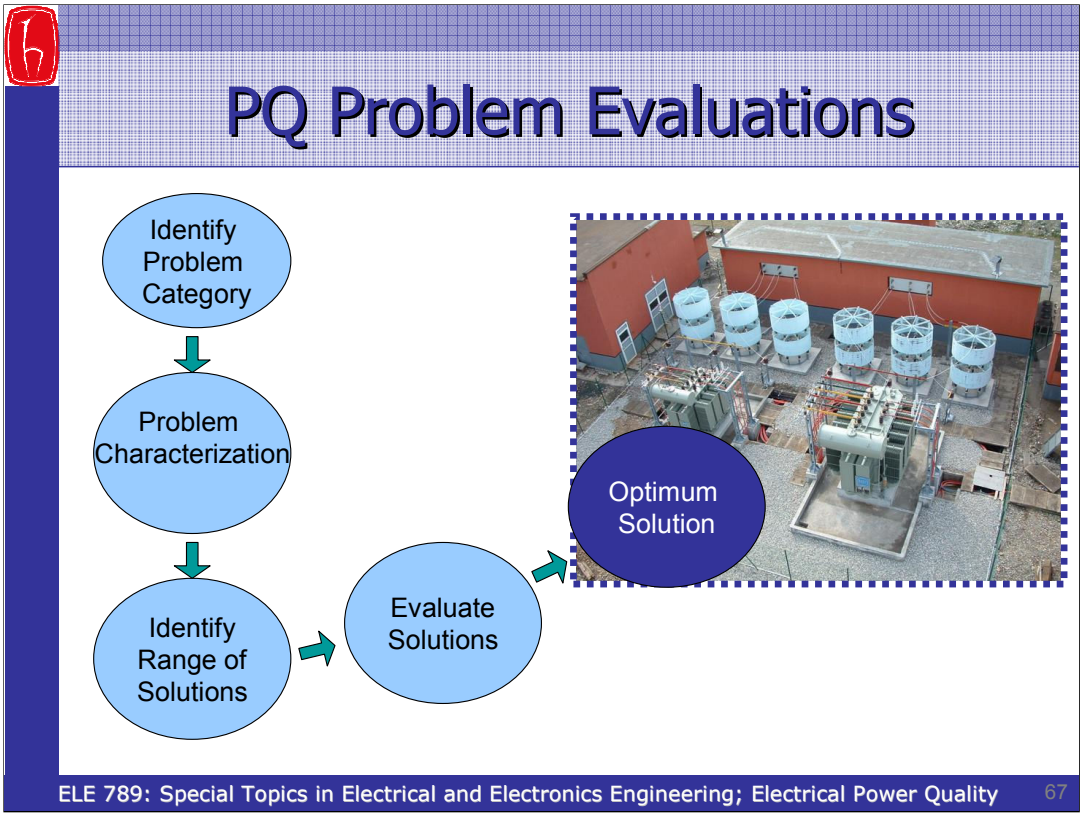
- Conducted Low Frequency Disturbances:
  - Harmonics, interharmonics
  - Signal systems (power line carrier)
  - Flicker
  - Dips and interruptions
  - Voltage imbalance
  - Power frequency variations
  - Induced low frequency
  - DC in AC networks

Electromagnetic Disturbances (Classified by IEC)

- Radiated Low Frequency:
  - Magnetic fields
  - Electrical fields
- Conducted High Frequency:
  - Induced continuous wave voltages & currents
  - Unidirectional transients
  - Oscillatory transients

Electromagnetic Disturbances (Classified by IEC)

- Radiated High Frequency:
  - Magnetic fields
  - Electrical fields
  - Electromagnetic fields
  - Continuous waves
  - Transients
- Electrostatic Discharge
- Nuclear Electromagnetic Pulse



Identify Problem Category
-Voltage Regulation / Unbalance
-Voltage Sags / Interruptions
-Flicker
-Transient
-Harmonic Distortion
Problem Characterization
Measurements / Data Collection
-Causes
-Characteristics
-Equipment Impacts
Identify Range of Solutions
-Transmission System
-Distribution System
-End Use Customer Interface
- End Use Customer System
-Equipment Design / Specifications
Evaluate Solutions
-Modeling Analysis
-Evaluate Technical Alternatives

-Evaluate Economics of Possible Solutions

Conclusions

- General Introduction:
  - Power Quality (PQ) Definition
  - General Classes of PQ
  - Terminology