POWER QUALITY (UNIT-I)

Power quality is a term which is ultimately a consumer driven issue that has different things to different people.

Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment."

A simpler and perhaps more concise definition might state: "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." This definition embraces two things that we demand from an electrical device: performance and life expectancy.

Any power problem manifested in voltage, current or frequency deviations that results in failure or misoperation of customer equipment will consider as power quality issue.

What is Electric Power Quality?

- To maintain the power distribution bus voltages to near sinusoidal waveform at rated voltage magnitude & frequency.
- It is a measure of how well electric power can be utilized by customers.

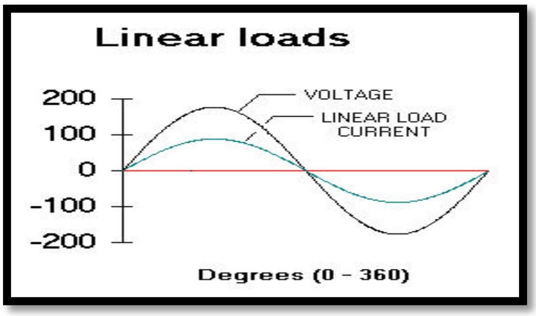
Need for Power Quality:

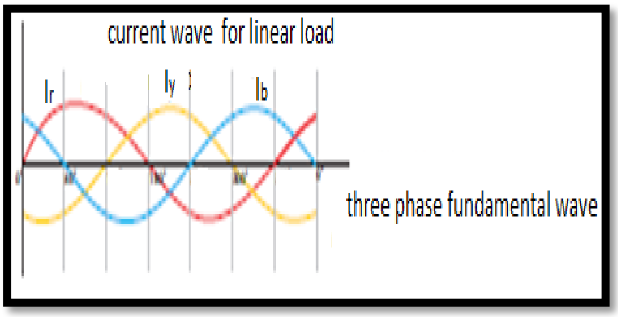
- ➢ In the recent years, power quality (PQ) has become a significant issue for both power suppliers and customers.
- ➢ There have been three important changes in relation to power quality.
- First of all, the characteristics of load have become so complex that the voltage and current of the power line connected with these loads are easy to be distorted.
- Lately, non-linear loads with power electronic interface that generate large harmonic current have been greatly increased in power system.
- Next, the end-user equipments have become more sensitive to power quality than before.

CLASSIFICATION OF LOADS

LINEAR LOAD

- **The voltage and current waveforms in electrical circuits with linear loads look alike i. e. no distortion.**
- **Example: Motors operating from sinusoidal supply mains with unsaturated magnetic circuit.**
- A linear element in a power system is a component in which the current is proportional to the voltage. This means that the current wave shape will be the same as the voltage as shown in fig.1. Typical examples of linear loads include motors, heaters and incandescent lamps.
- AC electrical loads where the voltage and current waveforms are sinusoidal. The current at any time is proportional to voltage. Linear Loads are: power factor improvement capacitors, indecent lamps, heaters etc. Applies to those ac loads where the current is not proportional to the voltage. Foremost among loads meeting their definition is gas discharge lighting having saturated ballast coils and thyristor (SCR) controlled loads.



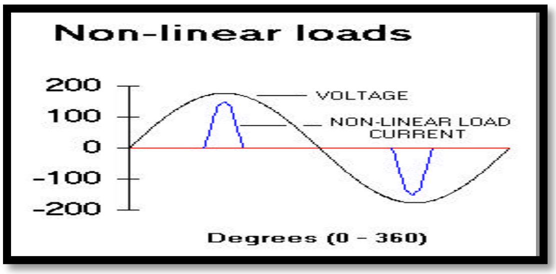


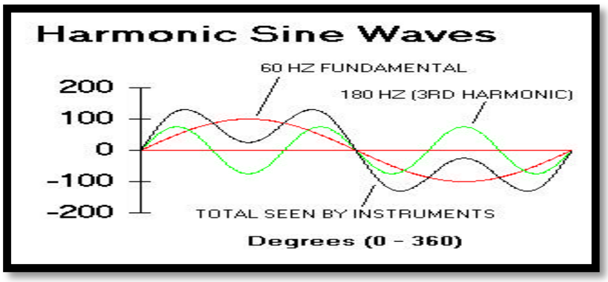
(1)Voltage and current waveforms for linear

NON-LINEAR LOAD

- **The current waveform does not resemble the applied voltage waveform.**
- **Example: Motors operating from power converters**
- The nature of non-linear loads is to generate harmonics in the current waveform. This distortion of the current waveform leads to distortion of the voltage waveform. Under these conditions, the voltage waveform is no longer proportional to the current. Non Linear Loads are: computer, laser printers, sumps, rectifier, plc, electronic ballast, refrigerator, TV etc. The current wave shape on a non-linear load is not the same as the voltage as shown in figure. Typical examples of non-linear loads include rectifiers (power

supplies, UPS units, discharge lighting), adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment. The current drawn by non-linear loads is not sinusoidal but it is periodic, meaning that the current wave looks the same from cycle to cycle. Periodic waveforms can be described mathematically as a series of sinusoidal waveforms that have been summed together as shown in fig. The sinusoidal components are integer multiples of the fundamental where the fundamental, in the United States, is 60 Hz. The only way to measure a voltage or current that contains harmonics is to use a true-RMS reading meter. If an averaging meter is used, which is the most common type, the error can be significant.





(a) Voltage and current waveforms for non-linear loads (b) Waveform with symmetrical harmonic components

Each term in the series is referred to as a harmonic of the fundamental. The third harmonic would have a frequency of three times 60 Hz or 180 Hz Symmetrical waves contain only odd harmonics and un-symmetrical waves contain even and odd harmonics. A symmetrical wave is one in which the positive portion of the wave is identical to the negative portion of the wave. An un-symmetrical wave contains a DC component (or offset) or the load is such that the positive portion of the wave is different than the negative portion. An example of un-symmetrical wave would be a half wave rectifier.

DEFFERANCE BETWEEN LINEAR LOADS AND NON-LINEAR LOADS

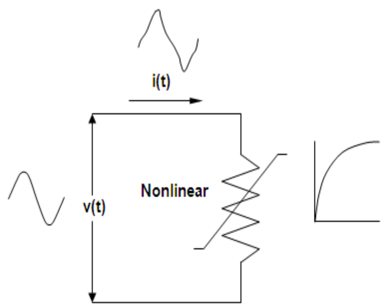
Table: Difference between linear loads and non-linear loads

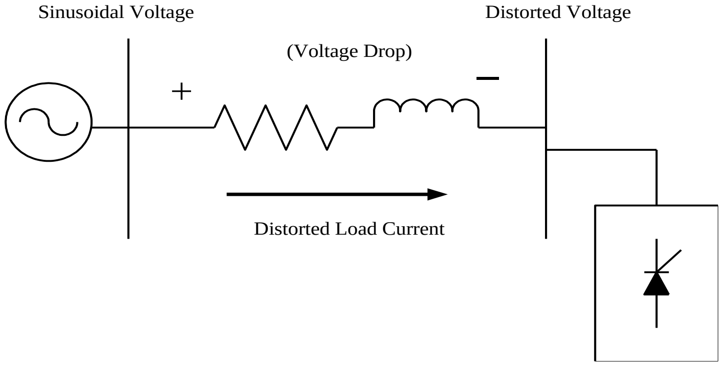
S. No.	LINEAR LOADS	NONLINEAR LOADS
1	Ohms law is applicable	Ohms law is not applicable
2	Crest Factor = √2=1.41	Crest Factor could be 3 to 4
3	Power factor = Cos ϕ	Power factor ≠ Cos ϕ = Displacement factor X Distortion Factor
4	Load current does not contain harmonics.	Load current contains all ODD harmonics.
5	Could be inductive or capacitive.	Can’t be categorized. As leading or lagging Loads.
6	Resistive, Inductive or capacitive	Usually an equipment with Diode and Capacitor
7	Zero neutral current if 1 Ph. loads are equally balanced on 3Ph. Mains (Vector sum of line current)	Neutral current could be 2.7 times the line current even if 1Ph. loads are equally balanced on 3 Ph. Mains
8	May not demand high inrush currents while starting.	Essentially very high inrush current (20 time of I Normal) is drawn while starting for approx. One cycle.

Main Power Quality Problems/Issues:

1. Harmonic distortion
2. Momentary Interruptions
3. Temporary Interruptions
4. Long Term outage
5. Noise
6. Voltage Sag
7. Voltage Swell
8. Voltage Spikes
9. Undervoltages

Voltage based Power Quality Problems:	Current based Power Quality Problems:	Sources of Power Quality Problems:
• Voltage sag • Voltage swell • Voltage Interruption • Under/over Voltage • Voltage Flicker • Harmonic Distortion • Voltage Notching • Transient Disturbance • Outage and frequency variation	• Reactive Power Compensation • Voltage Regulation • Current Harmonic Compensation • Load Unbalancing (for 3-phase systems) • Neutral Current Compensation (for 3-phase 4-wire systems)	• Power electronic devices • IT and office equipments • Arching devices • Load switching • Large motor starting • Embedded generation • Sensitive Equipment • Storm and environmental related damage





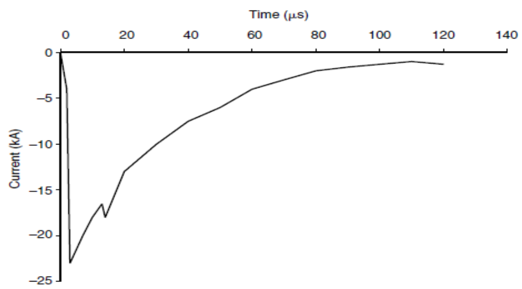
TRANSIENTS

- **A transient can be unidirectional impulse of either polarity or a domped oscillatory wave with first peak occuring in either polarity.**
- **Other definitions in common use are broad in scope and simply state that a transient is "that part of the change in a variable that disappears during transition from one steady state operating condition to another."**
- **Transients can be classified into two categories: *impulsive and oscillatory. These terms reflect the waveshape of a current* or voltage transient.**

Impulsive transient

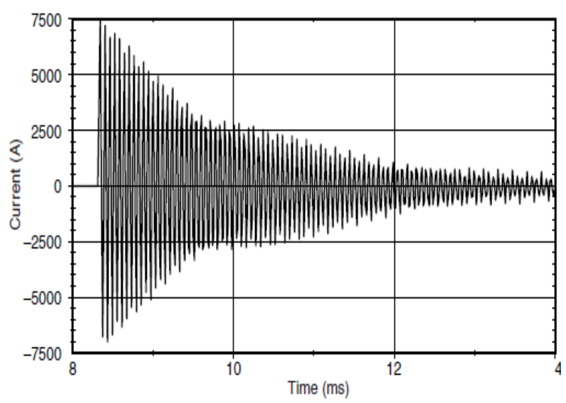
An *impulsive transient is a sudden, non–power frequency change in the* steady-state condition of voltage, current, or both that is unidirectional in polarity (primarily either positive or negative).

- Impulsive transients are normally characterized by their rise and decay times, which can also be revealed by their spectral content. The most common cause of impulsive transients is lightning.



Oscillatory transient

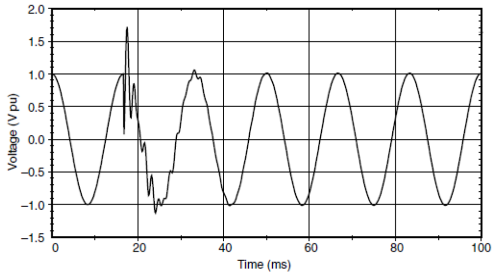
- An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values.
- An oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapidly.
- Oscillatory transients with a primary frequency component greater than 500 kHz and a typical duration measured in microseconds (or several cycles of the principal frequency) are considered *high-frequency transients. These transients are often the result of a local system* response to an impulsive transient.



- 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.*
- 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 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.

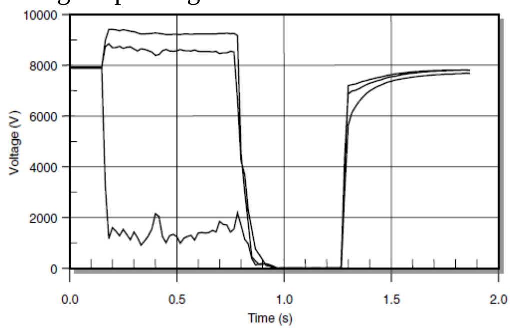


Short-Duration Voltage Variations:

- Short-duration voltage variations are: voltage dips and short interruptions. Each type of variation can be designated as instantaneous, momentary, or temporary, depending on its duration as shown below:

Instantaneous		
Interruption	0.5-30 cycles	<0.1p.u
Sag (dip)	0.5-30 cycles	0.1-0.9p.u
Swell	0.5-30 cycles	1.1-1.4p.u
Momentary		
Interruption	30cycles-3s	<0.1p.u
Sag (dip)	30cycles-3s	0.1-0.9p.u
Swell	30cycles-3s	1.1-1.4p.u
Temporary		
Interruption	3s-1min	<0.1p.u
Sag (dip)	3s-1min	0.1-0.9p.u
Swell	3s-1min	1.1-1.4p.u

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).*



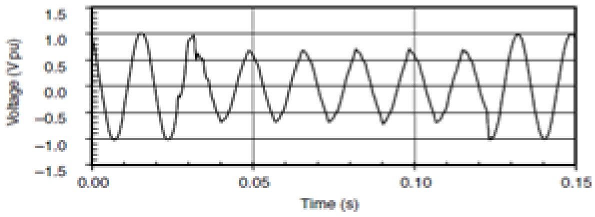
Interruption

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.

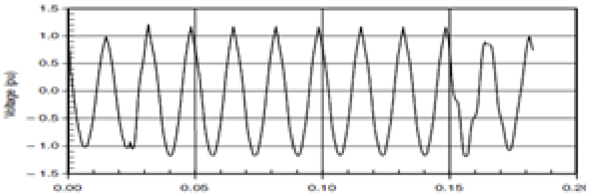
Sags (dips)

A *sag is a decrease to between 0.1 and 0.9 p.u in rms voltage or current* at the power frequency for durations from 0.5 cycle to 1 min. Voltage sags are usually associated with system faults but can also be caused by energization of heavy loads or starting of large motors. Sags starve a machine of the electricity it needs to function, causing computer crashes or equipment lock-ups.

Causes: Equipment start-up such as elevators, heating & air-conditioning equipment, compressors, and copy machines or nearby short ckts on the utility system.



(a) Voltage Sag


(b) Voltage Swell

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 ar a voltage swell caused by an SLG fault. Swells can also be caused by switching off a large load or energizing a large capacitor bank. e usually associated with system fault conditions. Voltage swells may lead to damage of sensitive equipment.

Causes: Due to start/stop of heavy loads and poorly regulated transformers.

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.

Waveform Distortion

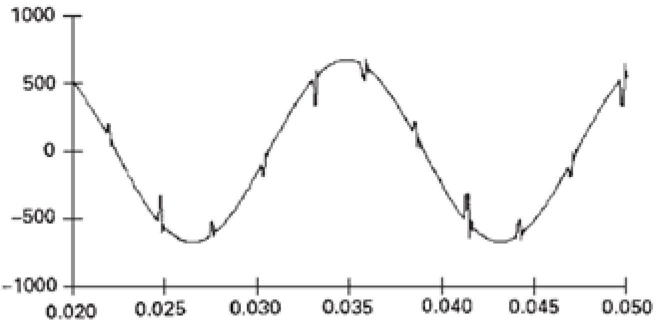
Waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation. There are five primary types of waveform distortion:

■ DC offset
■ Harmonics
■ Interharmonics
■ Notching
■ Noise

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.

Harmonics. *Harmonics* are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the sup-ply system is designed to operate (termed the *fundamental* frequency; usually 50 or 60 Hz).6 Periodically distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics. Harmonic distortion originates in the nonlinear characteristics of devices and loads on the power system. Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. It is also common to use a single quantity, the *total harmonic distortion* (THD), as a measure of the effective value of harmonic distortion.

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. Interharmonics can be found in networks of all voltage classes. The main sources of interharmonic waveform distortion are static frequency converters, cycloconverters, induction furnaces, and arcing devices. Power line carrier signals can also be considered as interharmonics.



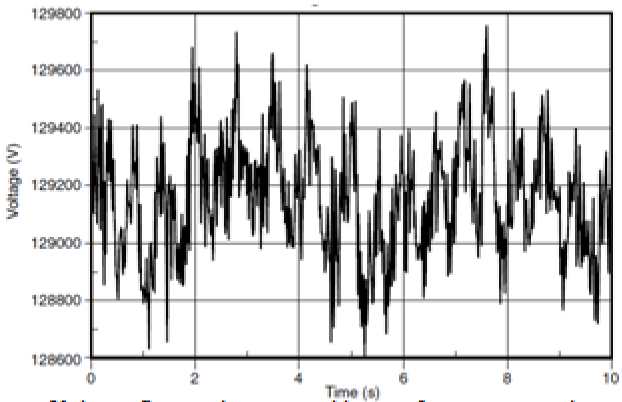
Voltage notching caused by a three-phase converter

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. Since notching occurs continuously, it can be characterized through the harmonic spectrum of the affected voltage. However, it is generally treated as a special case. The frequency components associated with notching can be quite high and may not be readily characterized with measurement equipment normally used for harmonic analysis. The notches occur when the current commutates from one phase to another. 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. Noise in power systems can be caused by power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies. Noise problems are often exacerbated by improper grounding that fails to conduct noise away from the power system. Basically, noise consists of any unwanted distortion of the power signal that cannot be classified as harmonic distortion or transients. Noise disturbs electronic devices such as microcomputer and programmable controllers. The problem can be mitigated by using filters, isolation transformers, and line conditioners.

Voltage Fluctuation

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 specified by ANSI C84.1 of 0.9 to 1.1 pu. IEC 61000-2-1 defines various types of voltage fluctuations. We will restrict our discussion here to IEC 61000-2-1 Type (d) voltage fluctuations, which are characterized as a series of random or continuous voltage fluctuations.

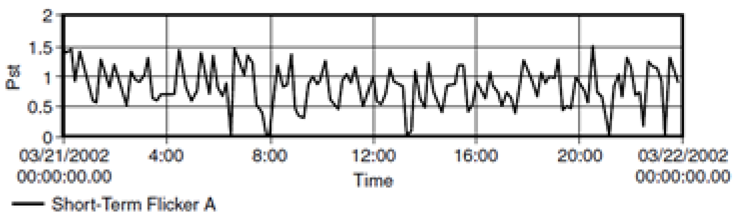


Voltage fluctuation caused by arc furnace operation

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. An example of a voltage waveform which produces flicker is shown in figure. This is caused by an arc furnace, one of the most common causes of voltage fluctuations on utility transmission and distribution systems. The flicker signal is defined by its rms magnitude expressed as a percent of the fundamental. Voltage flicker is measured with respect to the sensitivity of the human eye. Typically, magnitudes as low as 0.5 percent can result in percent of fundamental.

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. There are slight variations in frequency as the dynamic balance between load and generation changes. The size of the frequency shift and its duration depend on the load characteristics and the response of the generation control system to load changes. Figure illustrates frequency variations for a 24-h period on a typical 13-kV substation bus.



Flicker at 161 kV substation bus measured according to IEC Standard