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

1.1 Introduction

- ✓ Power quality is any abnormal behavior on a power system arising in the form of voltage or current, which affects the normal operation of electrical or electronic equipment.
- ✓ Power quality is any deviation of the voltage or current waveform from its normal sinusoidal wave shape.
- ✓ Power quality has been defined as the parameters of the voltage that affect the customer’s supersensitive equipment.
- ✓ Power quality problems are
    - Voltage sag
    - Voltage swell
    - Voltage Flicker
    - Harmonics
    - Over voltage
    - Under voltage
    - Transients
- ✓ Voltage sags are considered the most common power quality problem. These can be caused by the utility or by customer loads. When sourced from the utility, they are most commonly caused by faults on the distribution system. These sags will be from 3 to 30 cycles and can be single or three phase. Depending on the design of the distribution system, a ground fault on 1 phase can cause a simultaneous swell on another phase.
- ✓ Power quality problems are related to grounding, ground bonds and neutral to ground voltages, ground loops, ground current or ground associated issues.

- ✓ Harmonics are distortions in the AC waveform. These distortions are caused by loads on the electrical system that use the electrical power at a different frequency than the fundamental 50 or 60 Hz.

1.2 Terms and Definitions:

1.2.1 Power Quality:

It is any deviation of the voltage or current waveform from its normal sinusoidal wave shape.

1.2.2 Voltage quality:

Deviations of the voltage from a sinusoidal waveform.

1.2.3 Current quality:

Deviations of the current from a sinusoidal waveform.

1.2.4 Frequency Deviation:

An increase or decrease in the power frequency.

1.2.5 Impulsive transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is unidirectional in polarity.

1.2.6 Oscillatory transients:

A sudden, non power frequency change in the steady state condition of voltage or current that is bidirectional in polarity.

1.2.7 DC Offset:

The presence of a DC voltage or current in an AC power system.

1.2.8 Noises:

An unwanted electric signal in the power system.

1.2.9 Long duration Variation:

A variation of the RMS value of the voltage from nominal voltage for a time greater than 1 min.

1.2.10 Short Duration Variation:

A variation of the RMS value of the voltage from nominal voltage for a time less than 1 min.

1.2.11 Sag:

A decrease in RMS value of voltage or current for durations of 0.5 cycles to 1 min.

1.2.12 Swell:

A Temporary increase in RMS value of voltage or current for durations of 0.5 cycles to 1 min.

1.2.13 Under voltage:

10% below the nominal voltage for a period of time greater than 1 min.

1.2.14 Over voltage:

10% above the nominal voltage for a period greater than 1 min.

1.2.15 Voltage fluctuation:

A cyclical variation of the voltage that results in flicker of lightning.

1.2.16 Voltage imbalance:

Three phase voltages differ in amplitude.

1.2.17 Harmonic:

It is a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental power frequency.

1.2.18 Distortion:

Any deviation from the normal sine wave for an AC quantity.

1.2.19 Total Harmonic Distortion:

The ratio of the root mean square of the harmonic content to the RMS value of the fundamental quantity.

$$\mathrm{THD} = \frac{\sqrt{\sum_{h>1}^{h_{\max}} {M_h}^2}}{M_1}$$

1.2.20 Interruption:

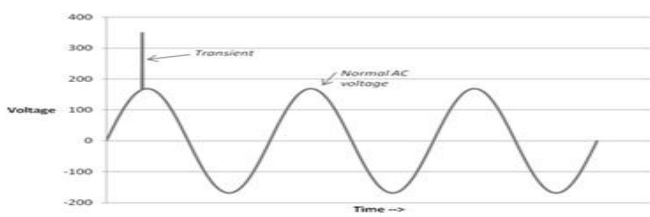
The complete loss of voltage on one or more phase conductors for a time greater than 1 min.

1.3 Concepts of transients:

- ✓ Transient over voltages in electrical transmission and distribution networks result from the unavoidable effects of lightning strike and network switching operations.\
- ✓ Response of an electrical network to a sudden change in network conditions.
- ✓ Oscillation is an effect caused by a transient response of a circuit or system. It is a momentary event preceding the steady state (electronics) during a sudden change of a circuit.
- ✓ An example of transient oscillation can be found in digital (pulse) signals in computer networks. Each pulse produces two transients, an oscillation resulting from the sudden rise in voltage and another oscillation from the sudden drop in voltage. This is generally considered an undesirable effect as it introduces variations in the high and low voltages of a signal, causing instability.
- ✓ Types of transient:
  - o Impulsive transient
  - o Oscillatory transient

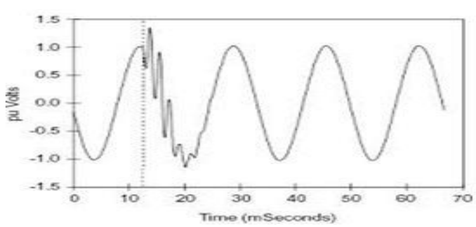
1.3.1 Impulse transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is unidirectional in polarity.



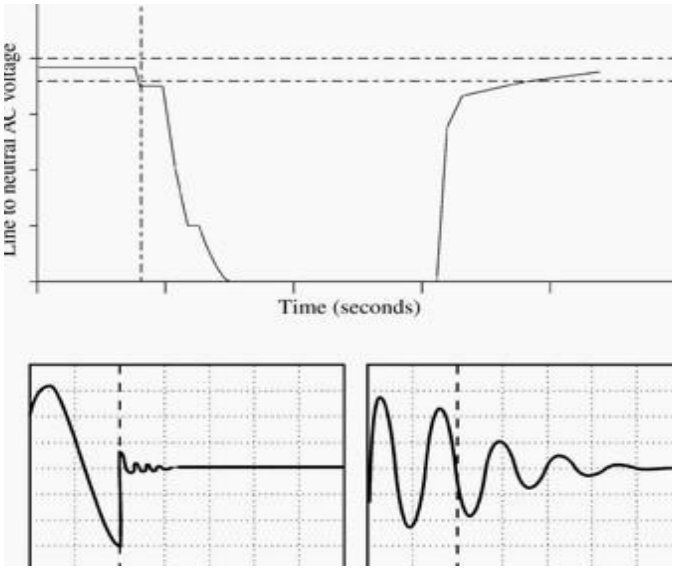
1.3.2 Oscillatory transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is bidirectional in polarity.



1.3.3 Short duration variations – Interruption

The complete loss of voltage on one or more phase conductors for a time less than 1 min.

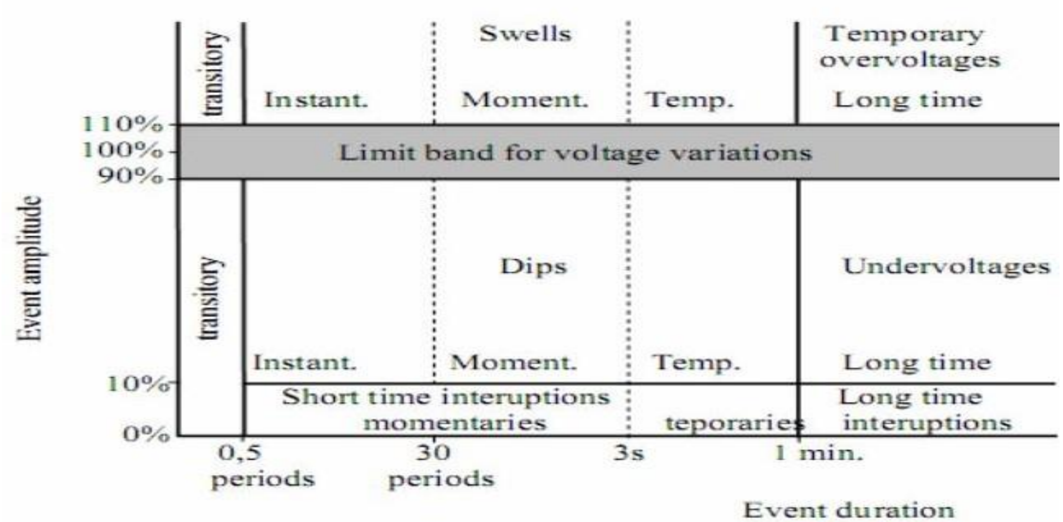


1.3.3.1 Types of Short Duration interruption:

- ✓ Momentary Interruption < 1 min , <0.1 pu
- ✓ Temporary Interruption < 1 min , <0.1 pu

1.3.4 Long duration variations – Sustained interruption

The complete loss of voltage on one or more phase conductors for a time greater than 1 min.



1.4 Sags and Swells:

1.4.1 Voltage sag:

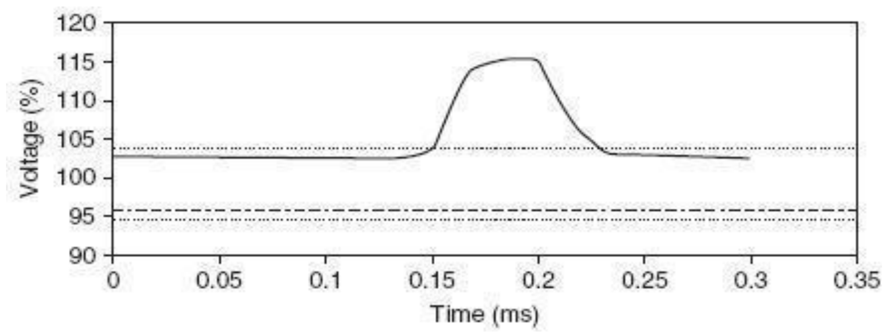
- ✓ A **voltage sag** or **voltage dip** is a short duration reduction in RMS voltage which can be caused by a short circuit, overload or starting of electric motors.
- ✓ Voltage sag happens when the RMS voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.
- ✓ Some references define the duration of sag for a period of 0.5 cycles to a few seconds, and longer duration of low voltage would be called "sustained sag".

There are several factors which cause voltage sag to happen:

- ✓ Since the electric motors draw more current when they are starting than when they are running at their rated speed, starting an electric motor can be a reason of voltage sag.
- ✓ When a line-to-ground fault occurs, there will be voltage sag until the protective switch gear operates.
- ✓ Some accidents in power lines such as lightning or falling an object can be a cause of line-to-ground fault and voltage sag as a result.
- ✓ Sudden load changes or excessive loads can cause voltage sag.
- ✓ Depending on the transformer connections, transformers energizing could be another reason for happening voltage sags.
- ✓ Voltage sags can arrive from the utility but most are caused by in-building equipment. In residential homes, we usually see voltage sags when the refrigerator, air-conditioner or furnace fan starts up.

1.4.2 Voltage Swell:

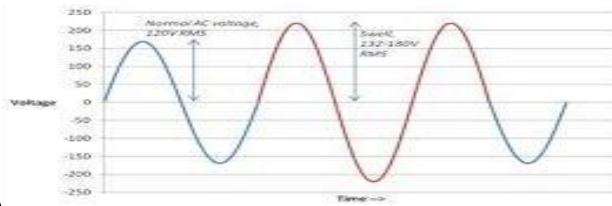
- ✓ Swell - an increase to between 1.1pu and 1.8 pu in rms voltage or current at the power frequency durations from 0.5 to 1 minute
- ✓ In the case of a voltage swell due to a single line-to-ground (SLG) fault on the system, the result is a temporary voltage rise on the un faulted phases, which last for the duration of the fault. This is shown in the figure below:



Instantaneous Voltage Swell Due to SLG fault

- ✓ Voltage swells can also be caused by the deenergization of a very large load.
- ✓ It may cause breakdown of components on the power supplies of the equipment, though the effect may be a gradual, accumulative effect. It can cause control problems and hardware failure in the equipment, due to overheating that could eventually result to shutdown. Also, electronics and other sensitive equipment are prone to damage due to voltage swell.

Voltage Swell	Magnitude	Duration
Instantaneous	1.1 to 1.8 pu	0.5 to 30 cycles
Momentary	1.1 to 1.4 pu	30 cycles to 3 sec
Temporary	1.1 to 1.2 pu	3 sec to 1 min



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1.4.3 Voltage unbalance:

- ✓ In a balanced sinusoidal supply system the three line-neutral voltages are equal in magnitude and are phase displaced from each other by 120 degrees (Figure 1). Any differences that exist in the three voltage magnitudes and/or a shift in the phase separation from 120 degrees is said to give rise to an unbalanced supply (Figure 2)

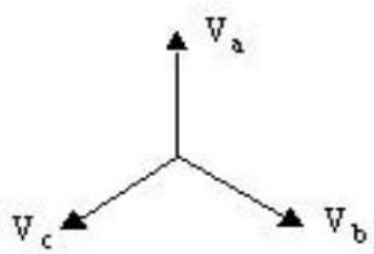


Figure 1 A balanced system

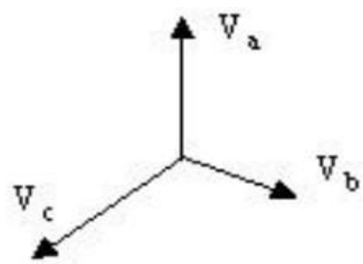
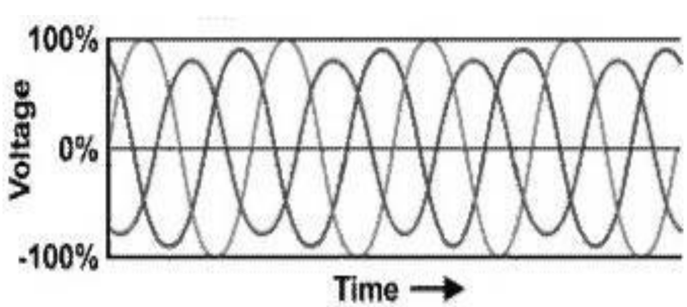


Figure 2 An unbalanced system

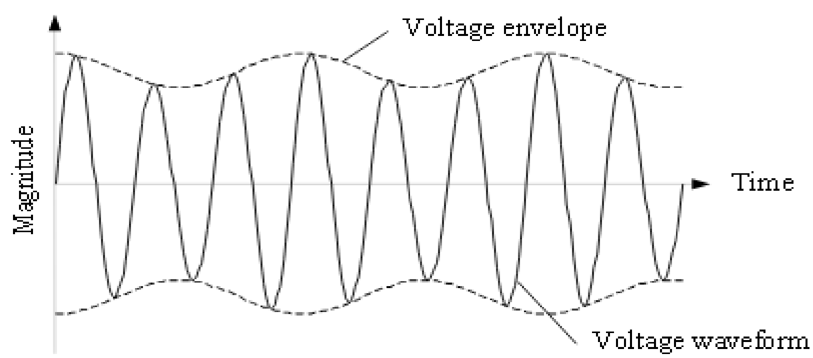


- ✓ The utility can be the source of unbalanced voltages due to malfunctioning equipment, including blown capacitor fuses, open-delta regulators, and open-delta transformers. Open-delta equipment can be more susceptible to voltage unbalance than closed-delta since they only utilize two phases to perform their transformations.
- ✓ Also, voltage unbalance can also be caused by uneven single-phase load distribution among the three phases - the likely culprit for a voltage unbalance of less than 2%. Furthermore, severe cases (greater than 5%) can be attributed to

single-phasing in the utility's distribution lateral feeders because of a blown fuse due to fault or overloading on one phase.

1.4.4 Voltage Fluctuation:

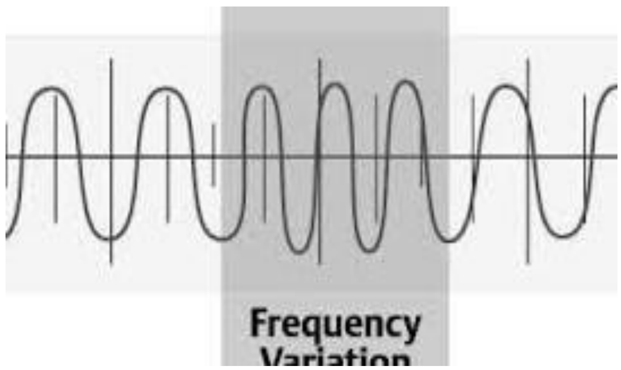
- ✓ Voltage fluctuations can be described as repetitive or random variations of the voltage envelope due to sudden changes in the real and reactive power drawn by a load. The characteristics of voltage fluctuations depend on the load type and size and the power system capacity.
- ✓ Figure 1 illustrates an example of a fluctuating voltage waveform. The voltage waveform exhibits variations in magnitude due to the fluctuating nature or intermittent operation of connected loads.
- ✓ The frequency of the voltage envelope is often referred to as the flicker frequency. Thus there are two important parameters to voltage fluctuations, the frequency of fluctuation and the magnitude of fluctuation. Both of these components are significant in the adverse effects of voltage fluctuations.



- ✓ Voltage fluctuations are caused when loads draw currents having significant sudden or periodic variations. The fluctuating current that is drawn from the supply causes additional voltage drops in the power system leading to fluctuations in the supply voltage. Loads that exhibit continuous rapid variations are thus the most likely cause of voltage fluctuations.
- ✓ Arc furnaces
- ✓ Arc welders
- ✓ Installations with frequent motor starts (air conditioner units, fans)
- ✓ Motor drives with cyclic operation (mine hoists, rolling mills)
- ✓ Equipment with excessive motor speed changes (wood chippers, car shredders)

1.5 Power frequency variations:

- ✓ Power frequency variations are a deviation from the nominal supply frequency. The supply frequency is a function of the rotational speed of the generators used to produce the electrical energy.
- ✓ At any instant, the frequency depends on the balance between the load and the capacity of the available generation.
- ✓ A frequency variation occurs if a generator becomes un-synchronous with the power system, causing an inconsistency that is manifested in the form of a variation.
- ✓ The specified frequency variation should be within the limits $\pm 2.5\%$ Hz at all times for grid network.



1.6 International Standards of power quality:

1.6.1 IEEE Standards:

- ✓ IEEE power quality standards: Institute Of Electrical and Electronics Engineer.
- ✓ IEEE power quality standards: International Electro Technical Commission.
- ✓ IEEE power quality standards: Semiconductor Equipment and Material International.
- ✓ IEEE power quality standards: The International Union for Electricity Applications
- ✓ IEEE Std 519-1992: IEEE Recommended practices and requirements for Harmonic control in Electric power systems.
- ✓ IEEE Std 1159-1995: IEEE Recommended practices for monitoring electrical power
- ✓ IEEE std 141-1993, IEEE Recommended practice for electric power distribution for industrial plants.
- ✓ IEEE std 1159-1995, IEEE recommended practice for Monitoring electrical power quality.

1.6.2. IEC Standards:

- ✓ Definitions and methodology 61000-1-X
- ✓ Environment 61000-2-X
- ✓ Limits 61000-3-X
- ✓ Tests and measurements 61000-4-X
- ✓ Installation and mitigation 61000-5-X
- ✓ Generic immunity and emissions 61000-6-X

1.7 CBEMA and ITI Curves:

- ✓ 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 4469 that we typically use in our analysis of power quality monitoring results is shown in Fig. 1.5.
- ✓ 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.
- ✓ 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 cycles 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.
- ✓ The CBEMA organization has been replaced by ITI, and a modified curve has been developed that specifically applies to common 120-V computer equipment (see Fig. 1.6). 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.

- ✓ Both curves are used as a reference in this book to define the withstand capability of various loads and devices for protection from power quality variations.
- ✓ For display of large quantities of power quality monitoring data, we frequently add a third axis to the plot to denote the number of events within a certain predefined cell of magnitude and duration.

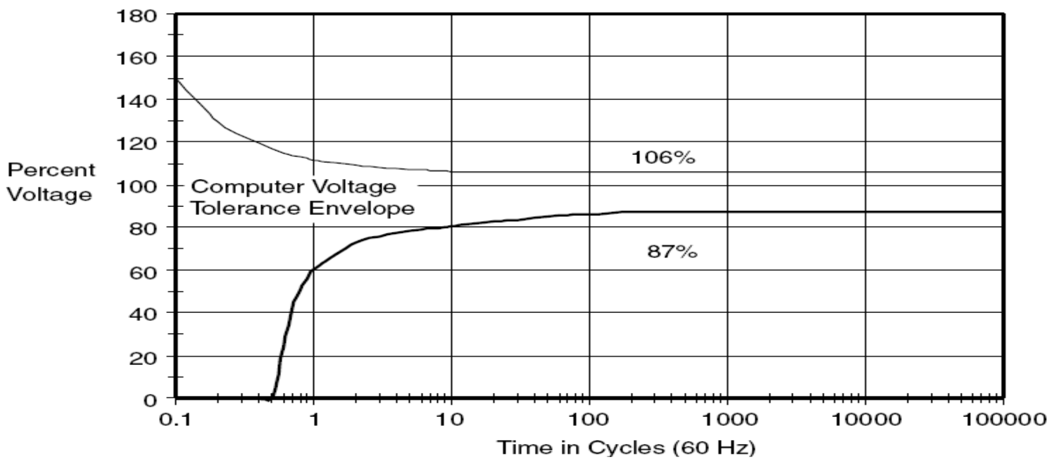


Fig 1.5 A portion of the CBEMA curve commonly used as a design target for equipment And a format for reporting power quality variation data.

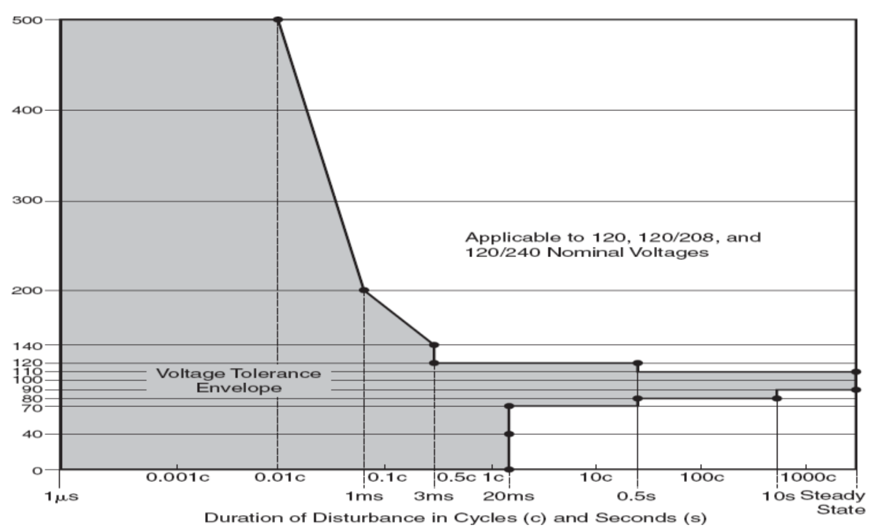


Fig 1.6 ITI curve for susceptibility of 120-V computer equipment.