# UNIT-1

# INTRODUCTION

**Basic terms and definitions**

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| active filter | Any of a number of sophisticated power electronic devices for eliminating harmonic distortion. |
| CBEMA curve | A set of curves representing the withstand capabilities of computers in terms of the magnitude and duration of the voltage disturbance.<br>Developed by the Computer Business Equipment Manufacturers Association (CBEMA) |
| crest factor | A value reported by many power quality monitoring instruments representing the ratio of the crest value of the measured waveform to the root mean square of the fundamental. For example, the crest factor of a sinusoidal wave is 1.414. |
| critical load | Devices and equipment whose failure to operate satisfactorily jeopardizes the health or safety of personnel, and/or results in loss of function, financial loss, or damage to property deemed critical by the user. |
| current distortion | Distortion in the ac line current |
| differential mode voltage | The voltage between any two of a specified set of active conductors |
| distortion | Any deviation from the normal sine wave for an ac quantity. |
| distributed generation (DG) | DG typically refers to units less than 10 megawatts (MW) in size that are interconnected with the distribution system rather than the transmission system. |
| dropout | A loss of equipment operation (discrete data signals) due to noise, sag, or interruption. |
| dropout voltage | The voltage at which a device will release to its deenergized position (the voltage at which a device fails to operate). |
| electromagnetic compatibility | The ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. |
| fast tripping | Refers to the common utility protective relaying practice in which the circuit breaker or line recloser operates faster than a fuse can blow. Also called fuse saving. |
| Fault | A short circuit on the power system usually induced by lightning, tree branches, or animals, which can be cleared by momentarily interrupting the current. |
| ferroresonance | An irregular, often chaotic type of resonance that involves the nonlinear characteristic of iron-core (ferrous) inductors |
| flicker | An impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution |

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| | fluctuates with time |
| frequency deviation | An increase or decrease in the power frequency. Duration of a frequency deviation can be from several cycles to several hours. |
| frequency response | In power quality usage, it refers to the variation of impedance of the system, or a metering transducer, as a function of frequency. |
| fundamental (component) | The component of order 1 (50 to 60 Hz) of the Fourier series of a periodic quantity |
| ground | A conducting connection, whether intentional or accidental, by which an electric circuit or electrical equipment is connected to the 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 | A system of interconnected bare conductors arranged in a pattern over a specified area and on or buried below the surface of the earth. The primary purpose of the ground grid is to provide safety for workers by limiting potential differences to safe levels in case of high currents. |
| harmonic (component) | A component of order greater than 1 of the Fourier series of a periodic quantity |
| harmonic content | The quantity obtained by subtracting the fundamental component from an alternating quantity. |
| harmonic distortion | Periodic distortion of the sine wave. |
| harmonic filter | On power systems, a device for filtering one or more harmonics from the power system. Most are passive combinations of inductance, capacitance, and resistance. Newer technologies include active filters |
| harmonic number | The integral number given by the ratio of the frequency of a harmonic to the fundamental frequency. |
| harmonic resonance | A condition in which the power system is resonating near one of the major harmonics being produced by nonlinear elements in the system, thus increasing the harmonic distortion. |
| impulsive transient | A sudden, non power frequency change in the steady state condition of voltage or current that is unidirectional in polarity (primarily either positive or negative). |
| instantaneous reclosing | A term commonly applied to reclosing of a utility breaker as quickly as possible after an interrupting fault current. Typical times are 18 to 30 cycles. |
| interharmonic (component) | A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is designed to operate (e.g., 50 or 60 Hz). |
| momentary interruption | A type of short-duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time period between 30 cycles and 3 s. |
| Sustained interruption | A type of long-duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time greater |

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| | than 1 min. |
| temporary interruption | A type of short-duration variation. The complete loss of voltage (<0.1 pu) on one or more phase conductors for a time period between 3 s and 1 min. |
| inverter | A power electronic device that converts direct current to alternating current of either power frequency or a frequency required by an industrial process. |
| islanding | Refers to a condition in which distributed generation is isolated on a portion of the load served by the utility power system. |
| isolation | Separation of one section of a system from undesired influences of other sections. |
| ITI curve | A set of curves published by the Information Technology Industry Council (ITI) representing the withstand capabilities of computers connected to 120-V power systems in terms of the magnitude and duration of the voltage disturbance. The ITI curve replaces the curves originally developed by the ITI's predecessor organization, the Computer Business Equipment Manufacturers Association (CBEMA). |
| linear load | An electrical load device that, in steady-state operation, presents an essentially constant load impedance to the power source throughout the cycle of applied voltage. |
| long-duration variation | A variation of the rms value of the voltage from nominal voltage for a time greater than 1 min. |
| low-side surges | A term coined by distribution transformer designers to describe the current surge that appears to be injected into the transformer secondary terminals during a lightning strike to grounded conductors in the vicinity. |
| noise | Unwanted electrical signals that produce undesirable effects in the circuits of the control systems in which they occur. |
| nominal voltage (Vn) | A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class |
| nonlinear load | Electrical load that draws current discontinuously or whose impedance varies throughout the cycle of the input ac voltage waveform. |
| notch | A switching (or other) disturbance of the normal power voltage waveform, lasting less than a half-cycle, which is initially of opposite polarity than the waveform and is thus subtracted from the normal waveform in terms of the peak value of the disturbance voltage. This includes complete loss of voltage for up to a half-cycle. |
| oscillatory transient | A sudden, non power frequency change in the steady state condition of voltage or current that includes both positive- or negative polarity value. |
| overvoltage | a specific type of long-duration variation which refers to a voltage having a value of at least 10 percent above the nominal voltage for a period of time greater than 1 min. |
| passive filter | A combination of inductors, capacitors, and resistors designed |

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| | to eliminate one or more harmonics. |
| phase shift | The displacement in time of one voltage waveform relative to other voltage waveform(s). |
| true factor | The ratio of active power (watts) to apparent power (volt amperes). |
| pulse | An abrupt variation of short duration of a physical quantity followed by a rapid return to the initial value. |
| pulse-width modulation (PWM) | A common technique used in inverters to create an ac waveform by controlling the electronic switch to produce varying width pulses. Minimizes power frequency harmonic distortion |
| reclosing | The common utility practice used on overhead lines of closing the breaker within a short time after clearing a fault |
| recovery time | The time interval needed for the output voltage or current to return to a value within the regulation specification after a step load or line change. |
| recovery voltage | The voltage that occurs across the terminals of a pole of a circuit-interrupting device upon interruption of the current. |
| rectifier | A power electronic device for converting alternating current to direct current. |
| resonance | A condition in which the natural frequencies of the inductances and capacitances in the power system are excited and sustained by disturbing phenomena. This can result in excessive voltages and currents. |
| sag | A decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycle to 1 min. |
| shielding | Shielding is the use of a conducting and/or ferromagnetic barrier between a potentially disturbing noise source and sensitive circuitry. Shields are used to protect cables (data and power) and electronic circuits. They may be in the form of metal barriers, enclosures, or wrappings around source circuits and receiving circuits. |
| shielding (of utility lines) | The construction of a grounded conductor or tower over the lines to intercept lightning strokes in an attempt to keep the lightning currents out of the power system. |
| short-duration variation | A variation of the rms value of the voltage from nominal voltage for a time greater than one-half cycle of the power frequency but less than or equal to 1 min. |
| swell | A temporary increase in the rms value of the voltage of more than 10 percent of the nominal voltage, at the power frequency, for durations from 0.5 cycle to 1 min. |
| sympathetic tripping | When a circuit breaker on an unfaulted feeder section trips unnecessarily due to back feed into a fault elsewhere. Most commonly occurs when sensitive ground fault relaying is employed. |
| synchronous closing | Generally used in reference to closing all three poles of a capacitor switch in synchronism with the power system to minimize transients. |

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| total demand distortion(TDD) | The ratio of the root mean square of the harmonic current to the rms value of the rated or maximum demand fundamental current, expressed as a percent. |
| total harmonic distortion (THD) | The ratio of the root mean square of the harmonic content to the rms value of the fundamental quantity, expressed as a percent of the fundamental. |
| transient | 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. A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity. |
| triplen harmonics | A term frequently used to refer to the odd multiples of the third harmonic, which deserve special attention because of their natural tendency to be zero sequence. |
| undervoltage | When used to describe a specific type of long-duration variation, refers to a measured voltage having a value at least 10 percent below the nominal voltage for a period of time greater than 1 min. |
| voltage change | A variation of the root mean square or peak value of a voltage between two consecutive levels sustained for definite but unspecified durations |
| voltage distortion | Distortion of the ac line voltage |
| voltage fluctuation | A series of voltage changes or a cyclical variation of the voltage envelope. |
| voltage imbalance (unbalance) | A condition in which the three-phase voltages differ in amplitude or are displaced from their normal 120 degree phase relationship or both. Frequently expressed as the ratio of the negative sequence or zero-sequence voltage to the positive-sequence voltage, in percent. |
| voltage interruption | Disappearance of the supply voltage on one or more phases. |
| voltage regulation | The degree of control or stability of the rms voltage at the load. Often specified in relation to other parameters, such as input-voltage changes, load changes, or temperature changes. |
| voltage magnification | The magnification of capacitor switching oscillatory transient voltage on the primary side by capacitors on the secondary side of a transformer. |
| waveform distortion | A steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation. |

**Concepts**

**Classification of Power Quality issues:**

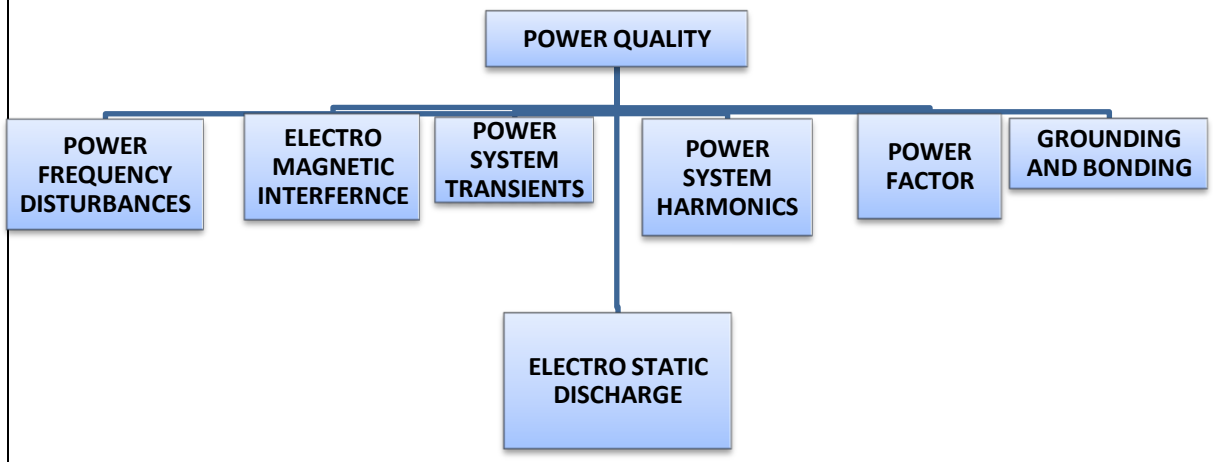


Fig 1.1 Classification of Power quality issues

- **Power Frequency Disturbances** are low frequency phenomena that result in voltage sags or swells. These may be source or load generated due to faults or switching operations.

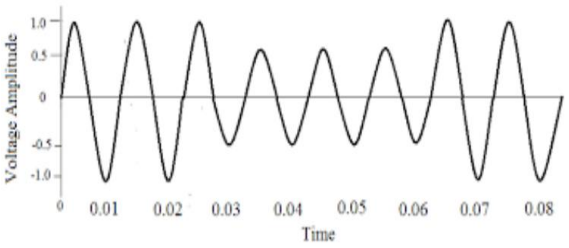


Fig 1.2 voltage sag

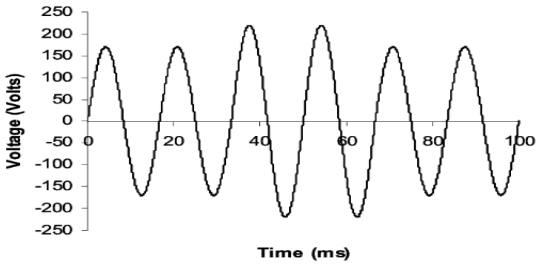


Fig 1.3 voltage swell

- Power System Transients are fast, short duration events that produce distortions such as notching, ringing and impulse. The mechanisms by which transient energy is propagated in power lines, transferred to other electrical circuits and eventually dissipated are different from the factors that affect power frequency disturbances.
- Power system harmonics are low- frequency phenomena characterized by waveform distortion which introduces harmonic frequency components. Voltage and current harmonics have undesirable effects on power system operation and power system components. In some instances, interaction between harmonics and power system parameters (R-L-C) can cause harmonics to multiply with severe consequences.
- Grounding and Bonding is one of the critical issues in power quality studies. Grounding is done for three reasons.
  - ✓ Fundamental objective of grounding is safety.
  - ✓ Second objective of grounding and bonding is to provide low impedance path for the flow of fault current. Thus protective device could isolate the faulted circuit from power source.

- ✓ Third use of grounding is to create a ground reference plane for sensitive electrical equipment. This is known as Signal Reference Ground (SRG). Configuration of SRG may vary from user to user and from facility to facility.

- Electromagnetic Interference (EMI) refers to the interaction between electric and magnetic fields and sensitive electronic circuits and devices. EMI is a high frequency phenomenon. EMI is different from power frequency disturbances and electrical transients.
- Radio Frequency Interference (RFI) is the interaction between conducted or radiated radio frequency fields and sensitive data and communication equipment. RFI is different from EMI.
- Electro Static Discharge (ESD) is very familiar and unpleasant occurrence. At high levels ESD is harmful to electronic equipment causing malfunction and damage.
- Power Factor is an economic issue in the operation of a power system. As utilities are increasingly faced with power demands that exceed generation capability, the penalty of low power factor is expected to increase.

$$PF = Cos\theta$$

$$PF = \frac{Active\ power\ (watts)}{Apparant\ power\ (VA)}$$

**Magnitude versus Duration plot:**

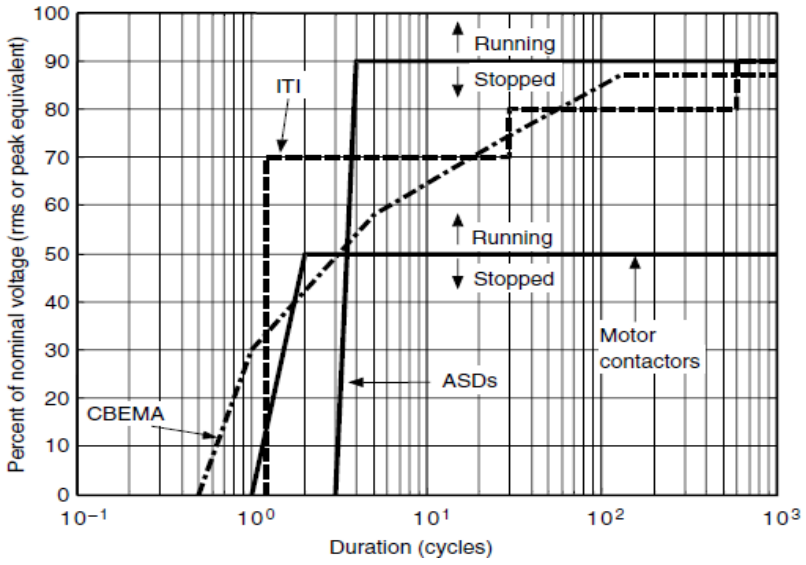


Fig 1.4 Magnitude versus Duration plot/ Equipment voltage sag ride- through capability curves

- One of the most common methods to quantify equipment susceptibility to voltage sags is using a magnitude-duration plot as shown in Fig 1.4.
- It shows the voltage sag magnitude that will cause equipment to misoperate as a function of the sag duration.
- The curve shown in Fig 1.4 shows voltage sag ride through capability for a ASD that is very sensitive to voltage sags.
- It trips for sags below 0.9 p.u that last for only 4 cycles. The contactor curve represents typical contactor sag ride-through characteristics. It trips for voltage sags

below 0.5 p.u that last for more than 1 cycle.

- Motor contactors having a minimum voltage sag ride-through capability of 0.5 pu would have tripped out when a fault causing a voltage sag with duration of more than 1 cycle occurs within the area of vulnerability. However, faults outside this area will not cause the voltage to drop below 0.5 pu.

**CBEMA and ITI Curves:**

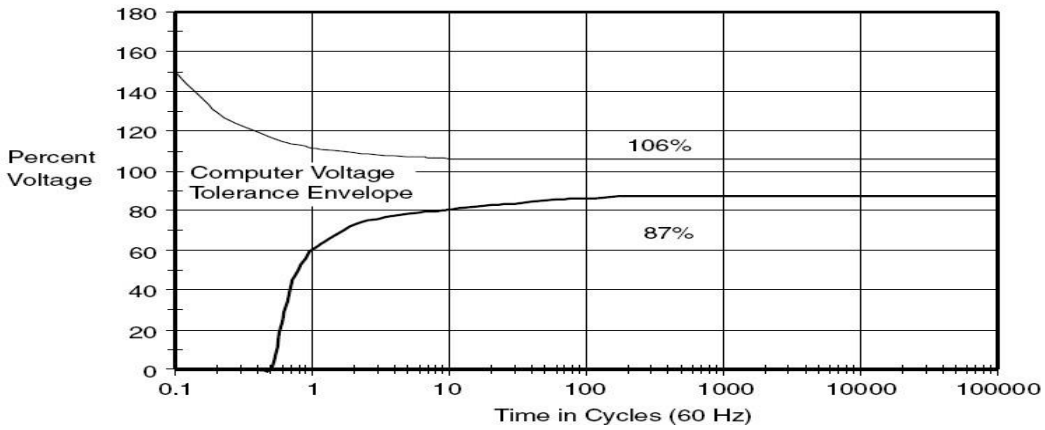


Fig 1.5 A portion of the CBEMA curve commonly used as a design target

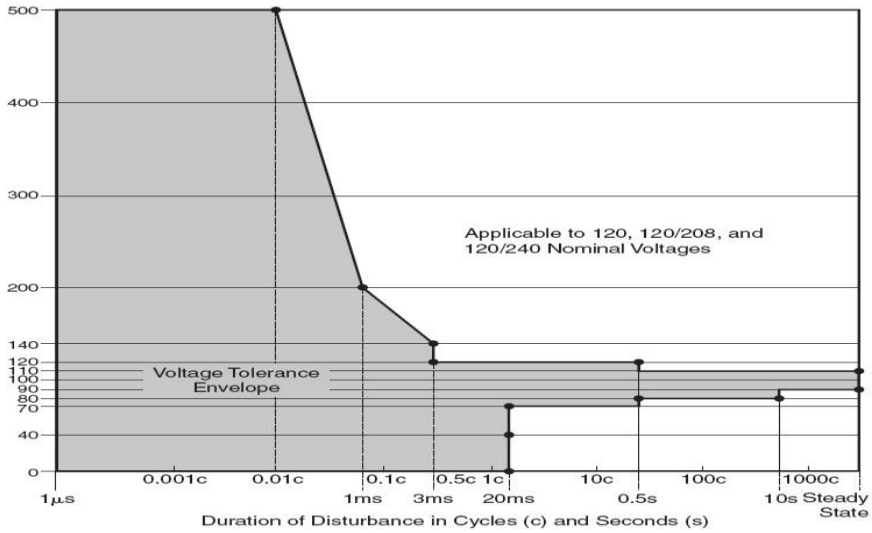


Fig 1.6 ITI curve for susceptibility of 120-V computer equipment.

- Fig 1.5 shows CBEMA curve. This curve is one of the most frequently employed displays of data to represent the power quality is the so-called 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.
- 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.
- 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.

**Responsibilities of Suppliers and Users of Electric Power:**

**Responsibilities of Suppliers of Electric power:**

- The realization of quality of electric power is the responsibility of both suppliers and users of electricity.
- Suppliers are in the business of selling electricity to widely varying customers. The needs of one user may not be same as the needs of other users.
- Most electrical equipment is designed to operate within the range of $\pm 5\%$ of nominal voltage. Voltages outside $\pm 5\%$ limit usually have a negative impact on loads such as motors and fluorescent lighting.
- Also the utility frequencies usually fall in the range of $\pm\ 0.1$ Hz of nominal frequency.

**Responsibilities of Users of Electric Power:**

- A power consumer should be concerned about energy conservation, harmonic current injection, power factor and surge current demands.
- It is the responsibility of power consumers to optimize the usage of electricity.
- Energy conservation is one means of ensuring an adequate supply of electrical power and also for maintaining ecological balance.
- Utilities should place restrictions on the amount of harmonic current that the user may inject into the power source.
- The power user should be concerned about the power factor, which is the ratio of $\frac{real\ power\ (watts)}{total\ apparant\ power\ (VA)}$ drawn from the source.
- The power will be converted into useful work and supply any losses associated with performing the work. As power factor ratio becomes smaller, the efficiency with which power is utilized also becomes less.
- Typically power suppliers expect a power factor of 0.95 or higher from industrial and commercial users. A penalty is imposed if power factor is below 0.95.
- Users should implement methods to improve power factor so that penalty can be avoided or minimized.
- Thus if both suppliers and users are responsible for power quality improvement.

**Power Quality Standards:**

**IEEE (Institute of Electrical and Electronic Engineers) Standards:**

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| IEEE 644 | Standard procedure for measurement of Power Frequency Electric and Magnetic Fields from AC power lines |
| IEEE C63.12 | Recommended practise for Electromagnetic Compatibility limits |
| IEEE 518 | Guide for the installation of Electrical Equipment to minimize electrical noise inputs to controllers from external sources |
| IEEE 519 | Recommended practise and requirements for Harmonic control in Electrical Power systems |
| IEEE 1100 | Recommended practise for Powering and Grounding Control in Electrical Power Systems |
| IEEE 1159 | Recommended practise for Monitoring Electrical Power Quality |
| IEEE 141 | Recommended practise for Electric Power Distribution for Industrial Plants |
| IEEE 142 | Recommended practise for Grounding of Industrial and Commercial Power System |
| IEEE 241 | Recommended practise for Electric Power Systems in Commercial buildings |
| IEEE 602 | Recommended practise for Electric Power Systems in Health Care Facilities |
| IEEE 902 | Guide for maintenance, operation and safety of industrial and commercial power systems |
| IEEE C57.110 | Recommended practise for Establishing Transformer Capability when supplying non-sinusoidal load. |
| IEEE P1433 | Power Quality definitions |
| IEEE P1453 | Voltage Flicker |
| IEEE P1564 | Voltage Sag Indices |

**IEC (International Electro technical Commission) Standards**

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| IEC/ TR3 61000-2-1 | Electromagnetic Compatibility - Environment |
| IEC/ TR3 61000-3-6 | Electromagnetic Compatibility - Limits |
| IEC 61000-4-7 | Electromagnetic Compatibility – Testing and Measurement Techniques- General guides on harmonics and interharmonics measurement and instrumentation |
| IEC 61642 | Industrial ac networks affected by harmonics – Application of filters and Shunt Capacitors |
| IEC SC77A | Low Frequency EMC phenomena |
| IEC TC77/ WGI | Terminology |
| IEC SC77A/WGI | Harmonics and other low frequency Disturbances |
| IEC SC77A/WG6 | Low Frequency Immunity Tests |
| IEC SC77A/WG2 | Voltage Fluctuations and other Low Frequency Disturbances |
| IEC SC77A/WG8 | Electromagnetic Interference related to the network Frequency |
| IEC SC77A/WG9 | Power Quality Measurement methods |

**Important Questions:**

1. Write short notes on CBEMA and ITI curves.
2. Discuss the responsibilities of suppliers and users of Electric power?
3. Depict Magnitude versus Duration plot.
4. Explain the classification of Power Quality issues in detail.
5. Discuss about the various IEEE and IEC standards for measuring power quality.