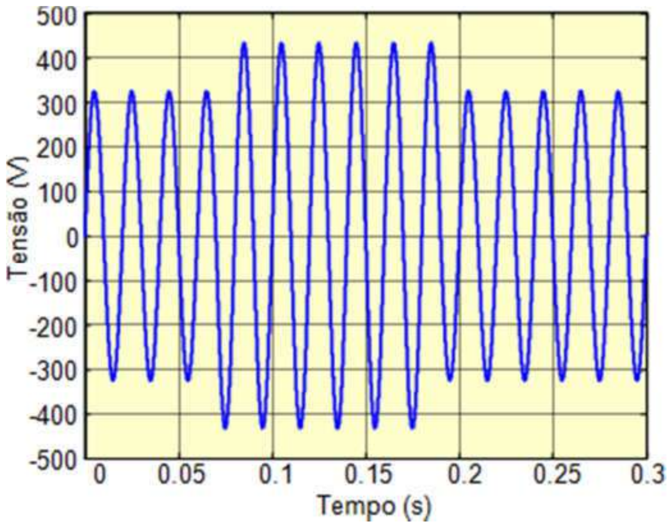
Unit – I

Introduction to Power Quality

Part – A

1. **Define voltage swell.**
   Swell is an event in which the RMS voltage increases between 1.1 and 1.8 PU at the power frequency. It lasts for durations of 0.5 cycles to 1 min.

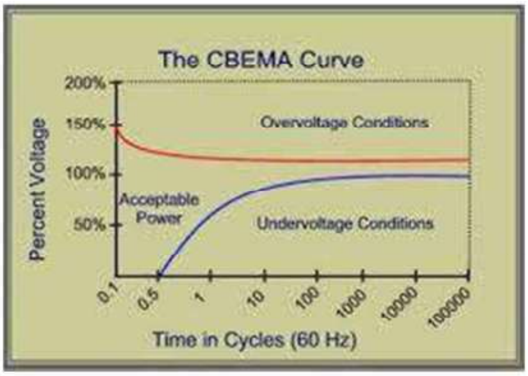


2. **What are the reasons for voltage imbalances?**

- Single phase fault will cause sag on one phase and swell on other phase.
- Capacitor bank anomalies such as a blown fuse on one phase of a three phase bank.

3. **List the major electric power quality issues.**
   Harmonics
   Voltage sag
   Voltage swell
   Flicker
   Noise
   Under voltage
   Over voltage.

4. **Draw the CBEMA curve of power quality.**



5. **Define sag.**
Voltage sag is an event in which the RMS voltage decreases between 0.1 and 0.9 p.u at the power frequency. It lasts for durations of 0.5 cycles to 1 minute.

6. **Find the total harmonic distortion of a voltage waveform with the following harmonic frequency make up: fundamental=114v, 3rd harmonic=4v, 5th harmonic=2v, 7th harmonics=1.5v and 9th harmonic=1v.**

$$\frac{\sqrt{V_3^2+V_5^2+V_7^2+V_9^2}}{V1}=(4.8218/114)=4.23\%$$

7. **Define voltage imbalance.**
Voltage unbalance is a steady state quantity defined as the maximum deviation from the average o the three phase voltages or currents, divided by the average of the three phase voltages or currents expressed in percent.

8. **What is the need for power quality standards?**

- These standards clarify our responsibilities and those of our electric customers in maintaining high-quality electric service.
- It also helps to determine what voltage range is required to operate equipment effectively, which is essential to the efficient and reliable operation of sensitive electronic loads.
Provides guidelines, recommendations and assure compatibility between end use equipment and system.
- Installation and mitigation guidelines are also given in standards.

9. **List any four primary types of waveform distortion.**

- DC offset
- Harmonics
- Flicker
- Inter harmonics

10. **Distinguish between swell and over voltage.**

S.no	Voltage Swell	Over voltage
1	Voltage increases between 1.1 and 1.8 per unit.	RMS voltage increases between 1.1 and 1.2 P.U
2	Occurs for durations of 0.5 cycles to 1 minute.	Occurs for more than one minute

11. Define Total Demand Distortion.

The total demand distortion is defined as the square root of the sum of the squares of the RMS value of the currents from 2nd to the highest harmonic (say 25th maximum in power system) divided by the peak demand load current and is expressed as a percent.

Unit - I

Introduction To Power Quality

Part – B

1. Discuss the following electrical power quality issues with examples.
(i) Voltage sag (ii)Voltage Interruption
Definiton:
Voltage sag is an event in which the RMS voltage decreases between 0.1 and 0.9 p.u at the power frequency. It lasts for durations of 0.5 cycles to 1 minute.
Types of Sag
1. Instantaneous Sag
2. Momentary Sag
3. Temporary sag

Instantaneous Sag
It is defined as the sag with RMS voltage value between 0.1 and 0.9 per unit for time duration of 0.00833 secon to 0.5 second.
Momentary Sag
Momentary sag is said to occur when the RMS voltage decreases between 0.1 and 0.9 per unit for the time duration of 0.5 sec to 3 sec.
Temporary sag
Temporary sag is said to occur when the RMS voltage decreases between 0.1 and 0.9 per unit for time duration of 3 to 60 seconds.

Causes of Sag
1. System faults cause (especially LG fault)causes voltage sag
2. Switching of heavy loads
3. Starting of motors(e.g Induction Motor)

Table

	Event Duration		Event voltage mag in per unit
Sag	Cycles	Milli seconds	
Instantaneous Sag	0.4166-25	0.00833-0.5	0.1-0.9
Momentary Sag	25-150	500-300	0.1-0.9
Temporary Sag	150-3000=	300-60000	0.1-0.9

(i) Voltage interruption

Definition

Voltage Interruptions are defined as zero voltage events that typically occur for short duration less than 60 seconds.

Types of Interruption

1. Momentary Interruption
2. Temporary Interruption
3. Sustained Interruption

Momentary Interruption

Momentary interruption is said to occur when the RMS voltage decreases less than 0.1 per unit for the time duration of 0.00833 second to 3 second.

Temporary Interruption

Temporary interruption is said to occur when the RMS voltage decreases less than 0.1 per unit for time duration of 3 second to 60 seconds.

Sustained Interruption

The interruption with RMS voltage 0.0 per unit for time duration of greater than 60 seconds.

Causes

1. Utility Recloser operation 2. Faulty circuit breakers
3. Bad wiring connections

Effects

1. Lost data
2. Destruction of files
3. Damaged hard disk.

Event Type	Event Duration		Event voltage mag in per unit
Interruption	Cycles	Milli seconds	
Momentary Interruption	0.4166-150	8.333-500	<0.1
Temporary Interruption	150-3000	500-300	<0.1
Sustained Interruption	>2500	300-60000	Equal to 0

2. Briefly explain some of the important electrical power quality issues.

The various power quality issues are discussed below

Voltage Swell

Swell is an event in which the RMS voltage increases between 1.1 and 1.8 PU at the power frequency. It lasts for durations of 0.5 cycles to 1 min.

Voltage Sag

Voltage sag is an event in which the RMS voltage decreases between 0.1 and 0.9 p.u at the power frequency. It lasts for durations of 0.5 cycles to 1 minute.

Voltage Interruption

Voltage Interruptions are defined as zero voltage events that typically occur for short duration less than 60 seconds.

Voltage Imbalance

Voltage unbalance is a steady state quantity defined as the maximum deviation from the average o the three phase voltages or currents, divided by the average of the three phase voltages or currents expressed in percent.

Transients

Transients are the disturbance that occurs for a very short duration. It is classified into Impulsive transient and Oscillatory Transient.

Under voltage

The voltage decreases between 0.8 and 0.9 per unit at the power frequency for a period of time greater than 1 minute is defined as Under Voltage.

Over Voltage

It is an event in which the RMS voltage increases between 1.1 and 1.2 per unit at the power frequency for a period of time greater than 1 minute.

Harmonics

Harmonics are defined as the sinusoidal currents and voltages with frequencies that are integer multiples of fundamental frequency that is 50 HZ.

DC Offset

The presence of a DC voltage or current in an ac power system is termed as DC offset.

Inter Harmonics

Voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate.

Voltage Flicker

Voltage Flicker is rapidly occurring voltage sags caused by sudden and large increases in load current.

It is mostly caused by rapidly varying load like arc furnaces, electric welders, rock crushers and wood chippers.

Noises

Noise is defined as unwanted electric signals with broadband spectral contents lower than 200 KHZ superimposed upon the power system voltage or current in phase conductors.

Notching

Notching is a periodic voltage disturbance caused by the normal operation of power electronics devices when current is commutated from one phase to another.

3. Discuss the sources and effect of different categories of long duration voltage variations.

Long Duration Variations

The variation of the RMS value of the voltage from its nominal values for a time greater than 60 seconds is called long duration variation.

Types

1. Under Voltage
2. Over Voltage
3. Sustained Interruption

Under Voltage

It is an event in which the RMDS voltage decreases between 0.8 and 0.9 per unit at the power frequency for a period of time greater than 1 minute.

Event Type	Event Duration		Event voltage mag in per unit
Under Voltage	Cycles	Milli seconds	
-	>3000	>60000	0.8-0.9

Causes

1. Load switching i.e switching ON a large load and switching on a large inductor
2. Overload circuits can also lead to under voltage
3. Faulty connections or wiring and loose or corroded connections

Over Voltage

It is an event in which the RMS voltage increases between 1.1 and 1.2 per unit at the power frequency for a period of time greater than 1 minute.

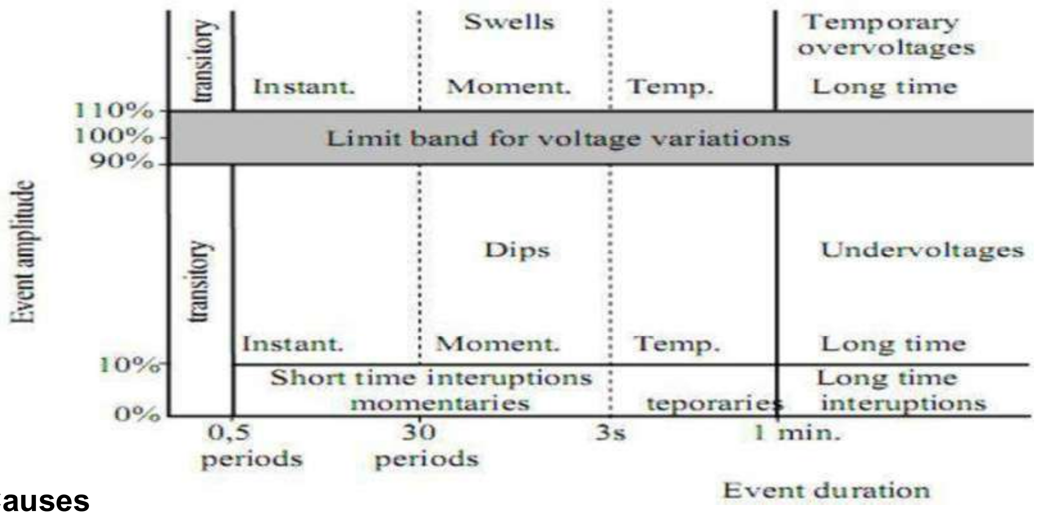
Event Type	Event Duration		Event voltage mag in per unit
Over Voltage	Cycles	Milli seconds	
-	>3000	>60000	1.1-1.2

Causes

1. Load switching i.e switching OFF a large load and switch ON a large capacitor bank.
2. Incorrect tap settings on transformers.

Sustained Interruption

Sustained interruption is said to occur when the RMS voltage decreases 0.0 per unit for the time duration greater than 60 seconds.



Causes

1. Due to the operation of protective devices such as breakers and fuses.

Event Type	Event Duration		Event voltage mag in per unit	
Sustained Interruption	Cycles	Milli seconds		2. 3
-	>2500	300-60000	Equal to 0	5

3. Explain the following electrical power quality issues with examples.

Voltage swell

Definiton:

Voltage swell is an event in which the RMS voltage increases between 1.1 and 1.8 p.u at the power frequency. It lasts for durations of 0.5 cycles to 1 minute.

Types of Swell

1. Instantaneous Swell
2. Momentary Swell
3. Temporary Swell

Instantaneous Swell

It is defined as the swell with RMS voltage value between 1.1 and 1.8 per unit for time duration of 0.00833 secon to 0.5 second.

Momentary Swell

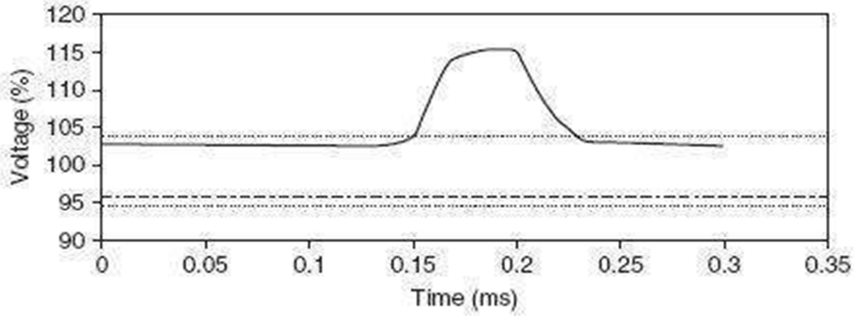
Momentary swell is said to occur when the RMS voltage increases between 1.1 and 1.4 per unit for the time duration of 0.5 sec to 3 sec.

Temporary Swell

Temporary swell is said to occur when the RMS voltage increases between 0.1 and 0.9 per unit for time duration of 3 to 60 seconds.

Causes of Swell

1. System faults cause (especially LG fault)causes voltage sag on one phase and swell on another two phases.
2. Switching of a large load
3. switching on a large capacitor bank.



Table

Event Type	Event Duration		Event voltage mag in per unit
Swell	Cycles	Milli seconds	
Instantaneous Swell	0.4166-25	8.333-500	1.1-1.8
Momentary Swell	25-150	500-300	1.1-1.4
Temporary Sag	150-3000	300-60000	1.1-1.2

4. Define the power quality. Explain the reasons for increased concern in powerquality.

Power Quality Definition

Power Quality is any abnormal behavior on a power system arising in the form of voltage and/or current, which adversely affects the normal operation of electrical or electronic equipment.

Power Quality Concern

There are four major reasons for the increases concern in power quality.

1. Newer-generation load equipment, with Processor-based control and power electronics converter is more sensitive to PQ variations than earlier equipment used.
2. The increasing importance on overall power system efficiency has resulted in continued growth in the application of devices such as Adjustable Speed Drives(ASDs) and shunt capacitors for power factor correction to reduce losses. This results in harmonics.
3. Customers have an increases awareness of PQ issues. Utility customers are becoming better informed about such as interruptions, sags and switching transients and are challenging the utilities to improve the quality of power delivered.
4. Many things are now interconnected in a network; integrated processes mean that the failure of any component has much more important consequences.

5.Discuss the detail about the Computer Business Equipment Manufactures Associations(CBEMA) Curve.

Computer Business Equipment Manufactures Associations (CBEMA) Curve

- The information technology Industry Council Curve (ITIC) was formerly known as CBEMA.It was developed in collaboration with Electric Power Research Institute‵s (EPRI) and Power electronics application Center.
- The curve is designed for computer equipment to to describe the tolerance of mainframe computer equipment to the magnitude and duration of voltage variations on the power system.

- The horizontal axis represents the duration for which an event lasts and the vertical axis represents the voltage magnitude of the event as a percent of the nominal voltage for the duration of event.
- 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.

- 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.

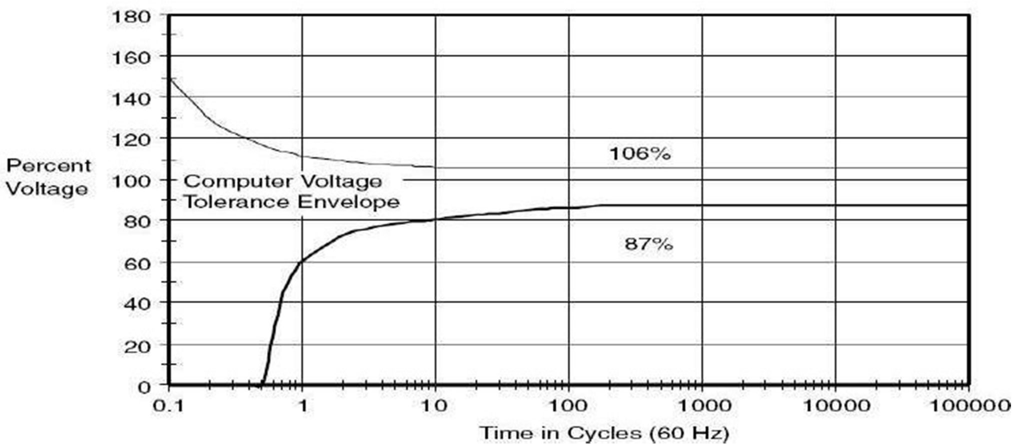


Fig 1.5 A portion of the CBEMA curve commonly used as a design target for equipment And a format for reporting power quality variation data.

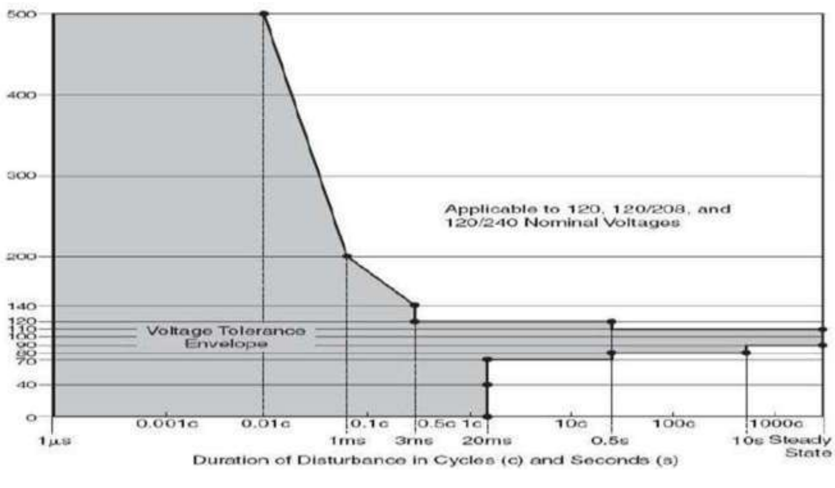


Fig 1.6 ITI curve for susceptibility of 120-V computer equipment.

6. **Explain briefly about the international standards of power quality.**

The international standards of power quality are
(i)IEEE standard
(ii) IEC standards

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.

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

7. **Write a short note on the following power quality issues.**

Power frequency variations

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(+ or – 0.05 Hz) at all times

for grid network.

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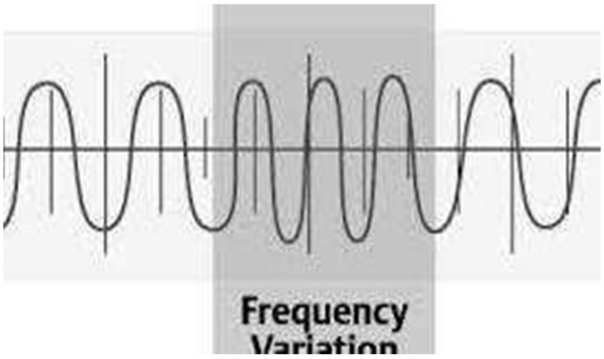


8. **What is the impact of transient in power quality? Classify the transient that occurs in power system.**

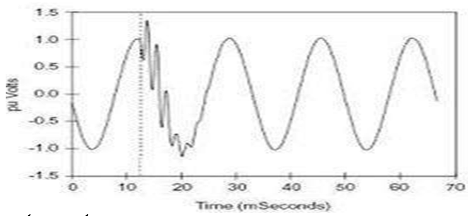
Concepts of transients:

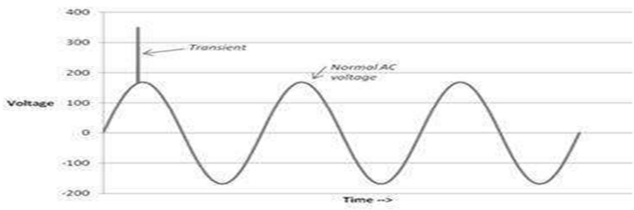
- Transient over voltages in electrical transmission and distribution networks result from the unavoidable effects of lightning strike and network switching operations.
- Response of an electrical network to a sudden change in network conditions.
- Oscillation is an effect caused by a transient response 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

Impulse transient:

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





Oscillatory transient:

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

Unit – II

Voltage Sag and Interruptions

Part – A

1. What is Voltage Sag? .

A sag or dip, as defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, is a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage. Typical values are between 0.1 pu and 0.9 pu.

2. What are the causes of sag? .

- Voltage sags are usually associated with system faults
- It can also be caused by energization of heavy load
- Starting of large motors

3. What are three levels of possible solutions to voltage sag and momentary interruption problems?

- Power System Design
- Equipment Design
- Power Conditioning Equipment

4. List some IEEE Standards Associated with Voltage Sags.

- IEEE 1250-1995, ―IEEE guide for service to equipment sensitive to momentary voltage disturbances‖
- IEEE 493-1990, ―Recommended practice for the design of reliable industrial and commercial power systems
- IEEE 1100-1999. ―IEEE recommended practice for powering and grounding electronic equipment‖.
- IEE 446-1995, ―IEEE recommended practice for emergency and standby power systems for industrial and commercial applications range of sensibility loads‖.

5. What are the sources of sags and Interruption?.

- A sudden increase in load results in a Corresponding sudden drop in voltage.
- Any sudden increase in load, if large enough, will cause a voltage sag in 1.Motors
- Faults.
- Switching

6. Name the different motor starting methods.

1. Resistance and reactance starters

2. Autotransformer starters

3. Star-Delta starters

7. Name any four types of sag mitigation devices.

1. Dynamic Voltage Restorer (DVR)
2. Active Series Compensators (Transformer less series injection) 3.Solid State (static) Transfer Switches (SSTS)

8. Define active series compensation devices.

1. One of the important new options is a device that can boost the voltage by injecting avoltage in series with the remaining voltage during a voltage sag condition. These arereferred to as active series compensation devices.

2. They are available in size ranges from small single-phase devices to very largedevices that can be applied on the medium-voltage systems.

9. What is the main function of DSTATCOM?

Voltage regulation and compensation of reactive power

Correction of power factor

Elimination of current harmonics

Unit – II

Voltage Sag and Interruptions

Part – B

1. Briefly explain the sources of voltage sag and interruptions.

Sources of sags and interruptions:

- A sudden increase in load results in a corresponding sudden drop in voltage.
- Any sudden increase in load, if large enough, will cause a voltage sag in:
  - Motors
  - Faults cause the voltage sag.
- Switching operation
- 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.

2. Discuss the methodology of estimating voltage sag performance.

Estimating Voltage sag Performance:

It is important to understand the expected voltage sag performance of the supply system so that facilities can be designed and equipment specifications developed to assure the optimum operation of production facilities.

The following is a general procedure for working with industrial customers to assure compatibility between the supply system characteristics and the facility operation:

- Determine the number and characteristics of voltage sags that result from transmission system faults.
- Determine the number and characteristics of voltage sags that result from distribution system faults (for facilities that are supplied from distribution systems).
- Determine the equipment sensitivity to voltage sags. This will determine the actual performance of the production process based on voltage sag performance

calculated in steps 1 and 2.

- Evaluate the economics of different solutions that could improve the performance, either on the supply system or within the customer facility.

Area of vulnerability

- The concept of an *area of vulnerability* has been developed to help evaluate the likelihood of sensitive equipment being subjected to voltage lower than its *minimum voltage sag ride-through capability.*
- The latter term is defined as the minimum voltage magnitude a piece of equipment can withstand or tolerate without mis operation or failure.
- An area of vulnerability is determined by the total circuit miles of exposure to faults that can cause voltage magnitudes at an end-user facility to drop below the equipment minimum voltage sag ride-through capability.
- Figure 2.5 shows an example of an area of vulnerability diagram for motor contactor and adjustable-speed-drive loads at an end-user facility served from the distribution system.
- The loads will be subject to faults on both the transmission system and the distribution system.
-

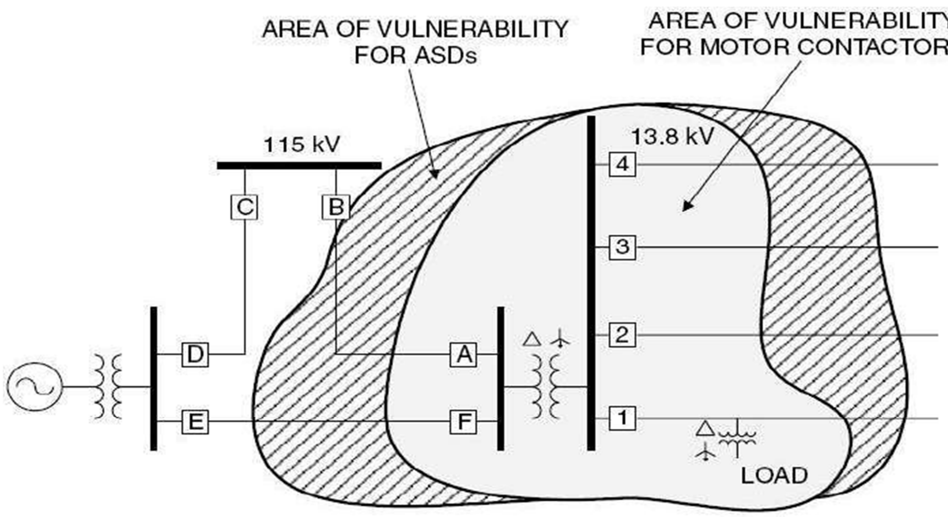


Fig 1.1 Illustration of an area of vulnerability

Equipment sensitivity to voltage sags

Equipment sensitivity to voltage sags can be divided into three categories:

1. **Equipment sensitive to only the magnitude of a voltage sag.**

2. **Equipment sensitive to both the magnitude and duration of a voltage sag.**

3. **Equipment sensitive to characteristics other than magnitude and duration.**

Equipment sensitive to only the magnitude of a voltage sag*:*
This group includes devices such as under voltage relays, process controls, motor drive controls, and many types of automated machines (e.g., semiconductor manufacturing equipment). Devices in this group are sensitive to the minimum (or maximum) voltage magnitude experienced during a sag (or swell). The duration of the disturbance is usually of secondary importance for these devices.

Equipment sensitive to both the magnitude and duration of a voltage sag:
- This group includes virtually all equipment that uses electronic power supplies.
- Such equipment misoperates or fails when the power supply output voltage drops below specified values.
- Thus, the important characteristic for this type of equipment is the duration that the rms voltage is below a specified threshold at which the equipment trips.

Equipment sensitive to characteristics other than magnitude and duration*:*

Some devices are affected by other sag characteristics such as the phase unbalance during the sag event, the point-in-the wave at which the sag is initiated, or any transient oscillations occurring during the disturbance.

These characteristics are more subtle than magnitude and duration, and their impacts are much more difficult to generalize.

As a result, the rms variation performance indices defined here are focused on the more common magnitude and duration characteristics.

For end users with sensitive processes, the voltage sag ride-through capability is usually the most important characteristic to consider. These loads can generally be impacted by very short duration events, and virtually all voltage sag conditions last at least 4 or 5 cycles (unless the fault is cleared by a current-limiting fuse).

Thus, one of the most common methods to quantify equipment susceptibility to voltage sags is using a magnitude-duration plot as shown in Fig. 2.6. It shows the voltage sag magnitude that will cause equipment to misoperate as a function of the sag duration.

The curve labeled CBEMA represents typical equipment sensitivity characteristics. The curve was developed by the CBEMA and was adopted in IEEE 446 (Orange Book). Since the association reorganized in 1994 and was subsequently renamed the Information Technology Industry Council (ITI), the CBEMA curve was also updated and renamed the ITI curve. Typical loads will likely trip off when the voltage is below the CBEMA, or ITI, curve.

The curve labeled ASD represents an example ASD voltage sag ride through capability for a device that is very sensitive to voltage sags. It trips for sags below 0.9 pu that last for only 4 cycles. The contactor curve represents typical contactor sag ride-through characteristics. Ittrips for voltage sags below 0.5 pu that last for more than 1 cycle.

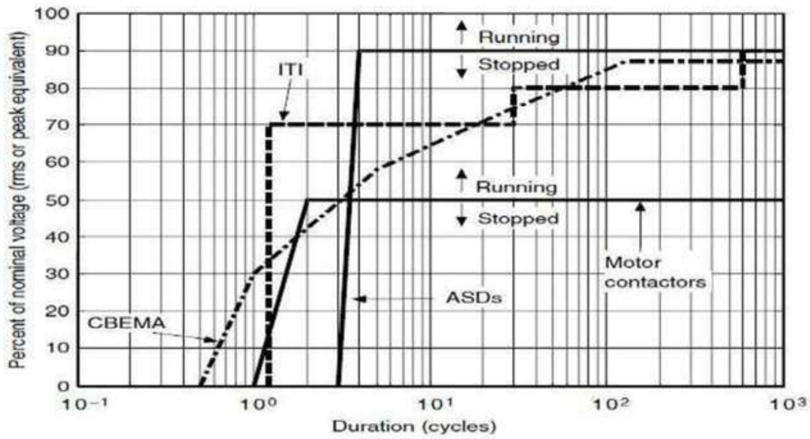


Fig 2.6 Typical equipment voltage sag ride through capability curves.

3. Briefly explain any two voltage sag mitigation techniques with necessary circuit diagram and waveforms.

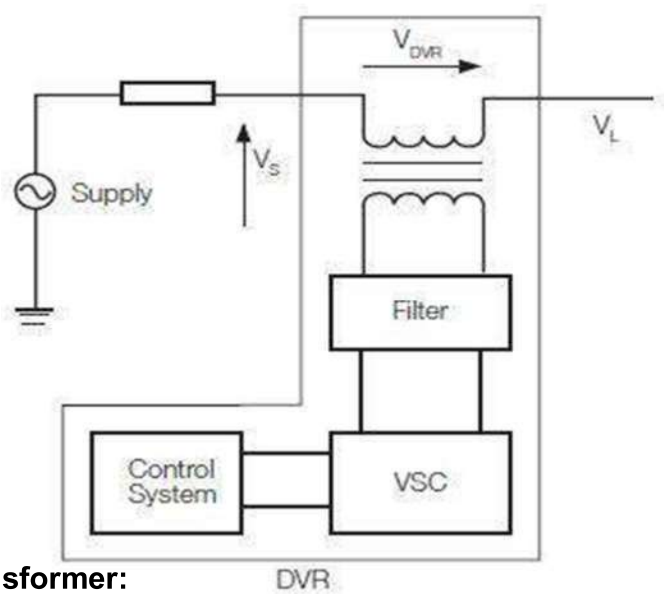
Mitigation of Voltage Sags:

- When a customer or installation suffers from voltage sag, there is a number of mitigation methods are available to solve the problem.
- These responsibilities are divided into three parts that involves utility, customer and equipment manufacturer.
- Different mitigation methods are
- Dynamic voltage restorer
- Active series Compensators
- Distribution static compensator (DSTATCOM)
- Solid state transfer switch (SSTS)
- Static UPS with energy storage
- Backup storage energy supply (BSES)
- Ferro resonant transformer
- Flywheel and Motor Generator set
  - Static Var Compensator (SVC)

Dynamic Voltage Restorer: (DVR)

- Dynamic Voltage Restorers (DVR) are complicated static devices which work by adding the ‗missing' voltage during a voltage sag.
- Basically this means that the device injects voltage into the system in order to bring the voltage back up to the level required by the load.

  - Injection of voltage is achieved by a switching system coupled with a transformer which is connected in series with the load.
- There are two types of DVRs available; those with and without energy storage. Devices without energy storage are able to correct the voltage waveform by
- drawing additional current from the supply.
- Devices with energy storage use the stored energy to correct the voltage waveform. The difference between a DVR with storage and a UPS is that the
- DVR only supplies the part of the waveform that has been reduced due to the voltage sag, not the whole waveform.
- In addition, DVRs generally cannot operate during interruptions. Figure 10 shows a schematic of a DVR.
- The basic DVR consists of an injection/booster transformer, a harmonic filter, a voltage source converter (VSC) and a control system.
- DVR systems have the advantage that they are highly efficient and fast acting. It is claimed in that the DVR is the best economic solution for mitigating voltage sags based on its size and capabilities.
- Another advantage of DVR systems is that they can be used for purposes other than just voltage sag mitigation.

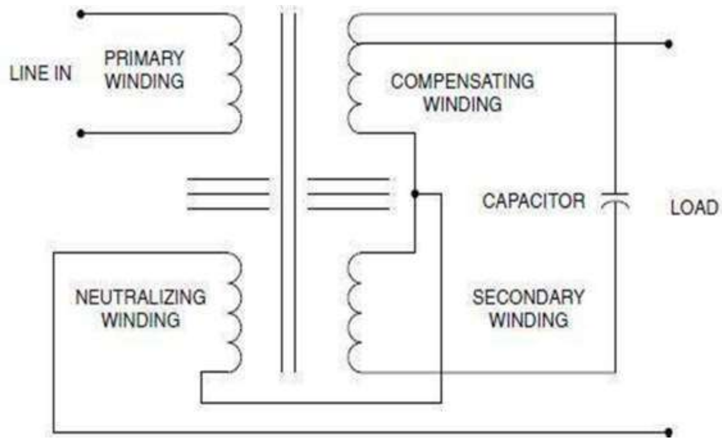


Ferro Resonant Transformer:

- A Ferro resonant transformer, also known as a constant voltage transformer (CVT), is a transformer that operates in the saturation region of the transformer B-H curve.
- Voltage sags down to 30 % retained voltage can be mitigated through the use of Ferro resonant transformers.
- Figure shows a schematic of a Ferro resonant transformer. The effect of operating the transformer in this region is that changes in input voltage only have a small impact on the output voltage.
- Ferro resonant transformers are simple and relatively maintenance free devices which can be very effective for small loads. Ferro resonant transformers are

available in sizes up to around 25 KVA.

- On the down side, the transformer introduces extra losses into the circuit and is highly inefficient when lightly loaded. In some cases they may also introduce distorted voltages.
- In addition, unless greatly oversized, Ferro resonant transformers are generally not suitable for loads with high inrush currents such as direct-on-line motors.



4. Explain the solid state transfer switch with the transfer operation.

Static Transfer Switches:

- The static transfer switch (STS) is an electrical device that allows instantaneous transfer of power source to the load. If one power source fails, the STS to backup power source.
- A static transfer switch used to switch between a primary supply and a backup supply in the event of a disturbance. The controls would switch back to the primary supply after normal power is restored.

Classification of STS

- Low voltage STS (Vt Up to 600Vt, Ct rating from 200 amps to 4000 amps)
- Medium voltage STS (Vt from 4.61 KV to 34.5 KV)

- Fast acting STS's that can transfer between two power source in four to zero milliseconds are increasingly being applied to protect large loads and entire load facilities from short duration power disturbance.
- These products use solid state power electronics or static switches as compared to electromechanical switches, which are slow for the application.

The basic STS unit consists of three major parts

- Control and Metering
- Silicon controlled rectifier
- Breakers/ Bus assembly

Fast Transfer Switch (FTS)

- FTS is used to obtain the minimum time of switch between two sources of power. This can be achieved by analyzing the phase shift between sine waves of two power sources.
- 33FTS permits to control zero phase shifts between input signals of power sources. These signals are passed through A/D converter and then to PLB form the control signal for solid state relay to secure the moment of zero phase shifts between input signals.
- It increases the speed of connecting the load to the power sources with optimal parameters.

Performance of Fast Transfer Switches:

- Under normal condition the voltage and frequency of power sources1 and power sources2 are inside suitable range of tolerance and load get power from PS1 through closed SSR1.
- ZD1 and ZD2 form menders from input sine wave signal. Generate the control signal from PLB the unit of ADC converter input voltage from PS1, PS2.
- In PLB, the measured the value with reference minimum and maximum value of input output voltage are compared.
- If any measured value of signal from PS1 is out of tolerance then should be formed the signal to the switch the load to PS2.
- The same procedure is used t control the frequency of input signal and phase shift between PS1 and PS2.
- If any parameter of signal power source is changed then ADC would form the value of code and this value goes to PLB.
- After comparing the measurement value of input voltage with minimum and maximum accepted values.
- If the signal will be formed to switch off the SSR1 means signal to switch on the SSR2 will form is according with synchronism and phase shift between signals from PS1 and PS2.
- In general any case failure of one commercial source of power, the switch transfers the load to another source in very short time.
- It is also achieve by synchronized phase control of signal from both power sources. It makes possible to choose the power source during the time interval less than 1ms.

5. Draw and explain the topology for illustrating the operations of the active series compensator.

Advances in power electronic technologies and new topologies for these devices have resulted in new options for providing voltage sag ride through support to critical loads. One of the important new options is a device that can boost the voltage by injecting a voltage in series with the remaining voltage during a voltage sag condition.

These are referred to as active series compensation devices. They are available in size ranges from small single-phase devices (1 to 5 KVA) to very large devices that can be applied on the medium-voltage systems (2 MVA and larger).

Figure shows an example of a small single-phase compensator that can be used to provide ride-through support for single-phase loads.

A one-line diagram illustrating the power electronics that are used to achieve the compensation is shown in Fig. When a disturbance to the input voltage is detected, a fast switch opens and the power is supplied through the series-connected electronics.

This circuit adds or subtracts a voltage signal to the input voltage so that the output voltage remains within a specified tolerance during the disturbance.

The switch is very fast so that the disturbance seen by the load is less than a quarter cycle in duration. This is fast enough to avoid problems with almost all sensitive loads. The circuit can provide voltage boosting of about 50 percent, which is sufficient for almost all voltage sag conditions.

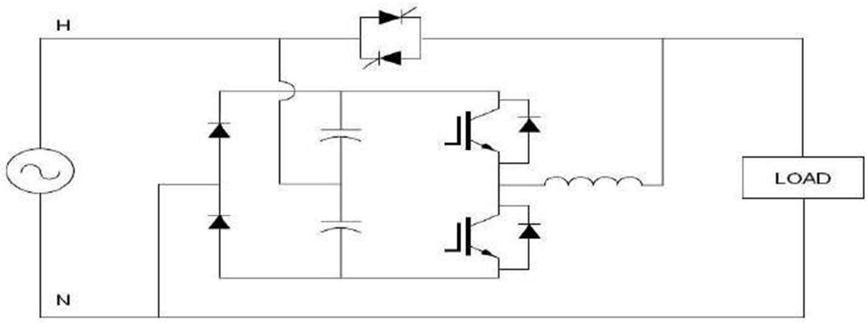
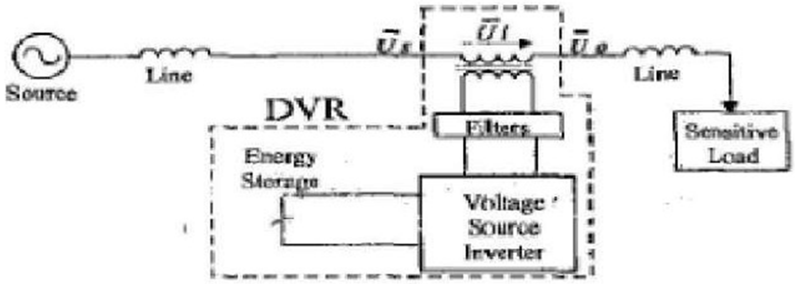


Fig Topology illustrating the operation of the active series compensator.

6. Describe the procedure for estimating the voltage sage severity.
Voltage sags due to Motor Starting:

- Voltage sag produced by induction motor starting current is one of the main causes of sensitive equipment dropout.
- The use of motor starter reduces the voltage sag depth but increases its duration.
- The subsequent connection to full voltage originates new sag separated from the first one by a few seconds.
- An induction motor will draw six to ten times its full load current while starting.
- This lagging current then causes a voltage drop across the impedance of the system.
- Generally induction motors are balanced 3 phase loads, voltage sags due to their starting are symmetrical.
- Each phase draws approximately the same in rush current. The magnitude of voltage sag depends on,
- Characteristics of the induction motor

- Strength of the system at the point where motor is connected.



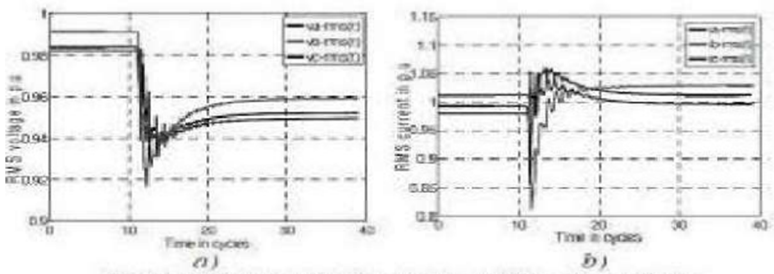


Figure 6. Voltage sag registered at node 890: a) rms voltage b) rms current

Estimation of the Sag Severity:

. If full-voltage starting is used, the sag voltage, in per unit of nominal system

voltage, is

$$V_{\text{Min}}(\text{pu}) = \frac{V(\text{pu}) \cdot \text{kVA}_{\text{SC}}}{\text{kVA}_{\text{LR}} + \text{kVA}_{\text{SC}}}$$

Where *V*(pu) = actual system voltage, in per unit of nominal, kVA_{LR} = motor locked rotor kVA

kVA_{SC} = system short-circuit kVA at motor

If the result is above the minimum allowable steady-state voltage for the affected equipment, then the full-voltage starting is acceptable. If not, then the sag magnitude versus duration characteristic must be compared to the voltage tolerance envelope of the affected equipment. The required calculations are fairly complicated and best left to a motor-starting or general transient analysis computer program.

The following data will be required for the simulation:

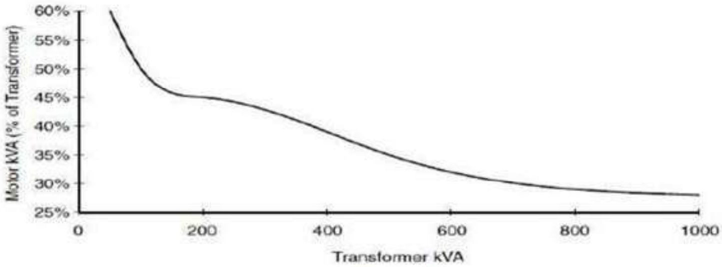


Fig Typical motor versus transformer size for full-voltage starting sags of 90 percent.

- Parameter values for the standard induction motor equivalent circuit: $R1$, $X1$, $R2$, $X2$, and

  XM.
- Number of motor poles and rated rpm (or slip).
- *WK*2 (inertia constant) values for the motor and the motor load.
- Torque versus speed characteristic for the motor load.

Unit - III

Over voltages

Part – A

1. **1.Define transient over voltages.**
A transient over voltage can be defined as the response of an electrical network to a sudden change in network conditions, either intended or accidental, (e.g. a switching operation or a fault) or network stimuli (e.g. lightning strike).

2. **2.Define voltage magnification phenomena?**
The highest transient voltages occur at the low voltage capacitor bank when the characteristic frequency of the switching transient is nearly equal to the resonant frequency of the low voltage system and when the switched capacitor is ten or more times the size of the low-voltage capacitor

3.Give the various aspects of equipment specific design and protection issues for The capacitor switching transients.

1.Phase-to-ground and phase-to-phase insulation switching withstand to voltage stresses 2.Controlled closing for circuit breakers (pre-insertion resistors/reactors or synchronous switching) 3.Capacitor bank and substation circuit breakers ANSI?IEEE C37 requirements
4.Current limiting reactor requirements 5.Surge arrester energy requirement

3. **4.What are the various Causes of over voltages?**
Over voltages, i.e. brief voltage peaks (transients, surges, spikes), can be attributed to the Following main causes:
1.Atmospheric discharges, i.e. lightning (LEMP – Lightning Electro-Magnetic Pulse)
2.Switching operations in the public grid and low-voltage mains
3.Electrostatic Discharges (ESD) 4.Ferro resonance

4. **5.What is the need of surge arrestors?**
1.A surge arrester is a protective device for limiting surge voltages on equipment by discharging or bypassing surge current.
2.Surge arresters allow only minimal flow of the 50Hz/60Hz power current to ground.

6.What is metal-oxide surge-arrester?

A metal-oxide surge-arrester (MOSA) utilizing zinc-oxide block provides the best performance, as surge voltage conduction starts and stops promptly at a precise voltage level, thereby improving system protection.

7. What is the role of surge arrestor on shielded and unshielded transmission line?

1. On shielded transmission lines or under-built distribution circuits, the arrester prevents tower-to-phase insulator back-flashovers during a lightning strike.
2. On unshielded sub transmission or distribution circuits, the arrester prevents phase

8. Define lightning phenomena.

1. Lightning is an electrical discharge in the air between clouds, between different charge centre within the same cloud, or between cloud and earth (or earthed object).

2. Even though more discharges occur between or within clouds, there are enough strokes that terminate on the earth to cause problems to power systems and sensitive electronic equipment

9. What is Ferro resonance?

Ferro resonance is a special case of series LC resonance where the inductance involved is nonlinear and it is usually related to equipment with iron cores. It occurs when line capacitance resonates with the magnetizing reactance of a core while it goes in the out of saturation.

10. Give the cable life equation as a function of impulses.

The cable life is an exponential function of the number of impulses of a certain magnitude that it receives, according to Hopkinton. The damage to the cable is related by Dc=P.Ve Where, Dc=constant, representing cable damage P=Number of impulses V=Magnitude of impulses E=empirical constant ranging from 10 to 15

11. What is the need of Computer analysis tools for transient studies?

Computer analysis simulation tool can simulate the time response of the transient phenomena in the power system with a very high degree of accuracy.

12. Give any two analysis examples available in PSCAD/EMTDC? Transient Studies.

1. Transient over voltage studies (TOV)

2. Line energizing (charging and discharging transients)

3. Capacitor bank back to back switching, selection of inrush and out-rush reactors

Unit – III

Over voltages

Part – B

13. Explain transient over voltage and classified transient.

- Transient over voltages in electrical transmission and distribution networks result from the unavoidable effects of lightning strikes and network switching operations.
- These over voltages have the potential to result in large financial losses each year due to damaged equipment and lost production.
- They are also known as surges or spikes.
- Transient over voltages can be classified as
  - o Impulsive transient
  - Oscillatory transient
- A transient is a natural part of the process by which the power system moves from one steady state to another.
- Its duration is in the range of microseconds to milliseconds.
- Low frequency transients are caused by network switching.
- High frequency transients are caused by lightning and by inductive loads turning off.
- Surge suppressors are devices that conduct across the power line when some voltage threshold is exceeded.
- Typically they are used to absorb the energy in high frequency transients.
- The devices are used for over voltage protection is,

o Surge arrester(crowbar & clamping device)

o Transient over voltage Surge suppresser

o Isolation transformer

o Low pass filter

o Low impedance power conditioners

o Pre-insertion resistors (transmission and distribution)

o Pre-insertion inductors (transmission)

o Synchronous closing (transmission and distribution)

Classification of transient over voltages:

Transient over voltages can be classified into two broad categories:

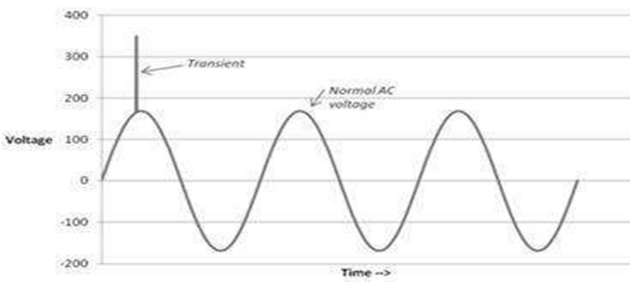
o Impulsive transient

o Oscillatory transient

Impulsive transient:

□ An impulsive transient is a sudden non power frequency change in the steady state condition of the voltage or current waveforms that is essentially in one

direction either positive or negative with respect to those waveforms.



Oscillatory transient:

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

□ An oscillatory transient is a sudden non power frequency change in the steady state condition of the voltage or current waveforms that is essentially in both