- One is the voltage-conditioning component that the pensates harmonics, fundamental negative-, and zero-sequence components of voltage, and regulates the fundamental component magnitude.

- The other voltage component (V_h = [$V_{ha,}$ $V_{hb,}$ $V_{hc,}$]) performs harmonic isolation and zero-sequence current damping, as well as damping of harmonic oscillations caused by the series resonance due to the series inductances and the shunt capacitor banks. V_b can also compensate for th oscillating instantaneous active and reactive powers.

- The reference active power forces the converter to inject a fundamental voltage component orthogonal to the load voltage. This will cause change in the power angle δ and mostly affects the active power flow. The reference reactive power will cause a compensation voltage in phase with the load voltage. This will change the magnitudes of the voltages and strongly affects the reactive power flow of the system.

- Signal i_h which provides harmonic isolation and damping for zero-sequence currents flowing through the series converter, is separated from the signal i_0 by a low-pass filter.

- The reference compensation voltages and a PWM control approach are relied on produce the gating signals of the series convertor.

The UPQC series control system may be simplified by eliminating the reference compensation currents. Voltage regulation is controlled by V_{ref}. The converter is designed to behave like a resistor at harmonic frequency to perform damping of harmonic oscillations. To do this, harmonic components of the line current to detected and multiplied by a damping coefficient.

KUBERUNATH BALANAGU

STUDENT NO: 372003863

ASSIGNMENT

SUBJECT: GO37

COURSE

ADVANCE DIPLOMA IN ELECTRICAL ENGINEERING

TEACHER

Kyaw Naing

G037 Tutorial

ESI- 8 Insulation (1)

(1) What is the purpose of using insulation?

Insulation is required to keep electrical conductors separated from each other and from other nearby objects.

(2) Describe

(a) Capacitance and dielectric hysteresis:

The presence of a dielectric between two conducting plates increases the measured capacitance between the plates. The behavior of the electrons and protons comprising the dielectric accounts for this capacitance increase. This phenomenon is worth investigating, for it explains some other characteristics of insulation of interest.

(b) Conduction current:

When voltage is applied between two plates separated by dielectric those few electrons that are present in the insulation drift from cathode to anode. This is termed conduction current and represents power loss in to the insulation. In insulation, the number of free electrons is low, and as a result the resistivity of the material is high. The number of free electrons may be increased by several processes.

(c) Surface leakage current:

Leakage currents flow along paths between electrodes over the surface of the insulating material. The magnitude of these currents is in no way related to the resistivity of the material itself. The value of the leakage current depends on the applied voltage, the insulation material, the surface contamination, and the moisture content of the air.

(d) Insulation breakdown:

Insulation may undergo a very sudden change in characteristics in a process known as breakdown.

(e) Volt-time characteristics of breakdown:

Both mechanism of insulation breakdown described above require energy to delivered from the voltage source to the insulation volume. This means that time is required for breakdown. The lower the applied voltage, the more slowly does the breakdown process proceed, and the longer the time to reach breakdown. At voltages below a critical value, the rate of energy dissipation by normal thermal conduction and convection processes is sufficient to prevent the growth of the breakdown process. At stress below this critical value, insulation may operate indefinitely without breakdown.

(f) Insulation deterioration:

Insulation is service may deteriorate, a fact which implies that periodic checks of insulation condition must be made to avoid equipment failure due to breakdown of insulation.

The conductivity of solid and liquid insulation increases rapidly with moisture content. Designs and maintenance procedures mist be such as to minimize the amount of moisture that may be absorbed.

(3) What are the sources of over voltage and explain?

Over voltages on power systems are traceable to three basic causes: lightning, switching and contact with circuits of higher voltage rating. The power system designer seeks to minimize the number of these occurrences to limit the magnitude of the voltages produced and to control their effects on operating equipment.

Lightning: Lighting results from the presence of clouds which have become charged by the action of falling rain and vertical air currents, a condition commonly found in cumulus clouds. Voltage many be set up on overhead lines due to direct strokes and indirect strokes.

Switching: Over voltages may result from switching operations on the closing of circuit breakers, or if restriking occurs within the breaker, on circuit-opening operations.

Contact with Circuits of Higher Voltage: Lines of different voltages class are sometimes carried on the same structure.

(4) How do you understand travelling waves?

The voltages set up on lines by lightning rise from zero to maximum value in a few microseconds. Transients due to switching produce voltages that rise very rapidly, although not as fast as those due to lighting. These voltages may be transmitted many miles over lines and may produce overvoltage's in stations far from their origin. The propagation of electrical disturbance down a line is very rapid but at a measurable rate. When very rapid voltage changes are involved, it is helpful to look at the circuit behavior in terms of travelling waves rather than by conventional methods of analysis.

(5) Describe the Application of the followings?

(a) Lightning arresters (b) Transmission line insulation

(a) Lightning arresters: Lightning arresters are devices put on electric power equipment to limit overvoltage to a value less than they would be if the arresters were not present. Ideally a lighting arrester should be off the line under normal operation, switch onto the line when the voltage is perhaps 20 percent above normal value, limit the voltage to this value regardless of the nature or source of the overvoltage, and switch off of the line when the disturbance is past and normal voltage had been restored.

(b) Transmission line insulation: The conductors of overhead transmission lines are supported by porcelain insulators and are insulated from each other by air between the points of attachment.

Flashover of line insulators is almost always traceable to the breakdown of the air around them due to overvoltage from lightning or other causes. Insulators whose surfaces are contaminated and then moistened by light rain or fog may flash over even under normal operating-voltage conditions. If an insulator is cracked or porous and permits lightning or power-frequency current to pass through the body of the insulator, it may be shattered, with the resultant dropping of the line.

The air between the conductors of a high-voltage transmission line is under electrical stress. This stress is relatively great immediately adjacent to the conductors and very low midway between them. When the stress in the air exceeds about 30 kilometers/cm, breakdown occurs within that area where the high stress exists. Hence on a transmission line it is possible to have dielectric breakdown of the air around the conductors without total breakdown between conductors. This condition is termed corona.

ESI- 8 Insulation (2)

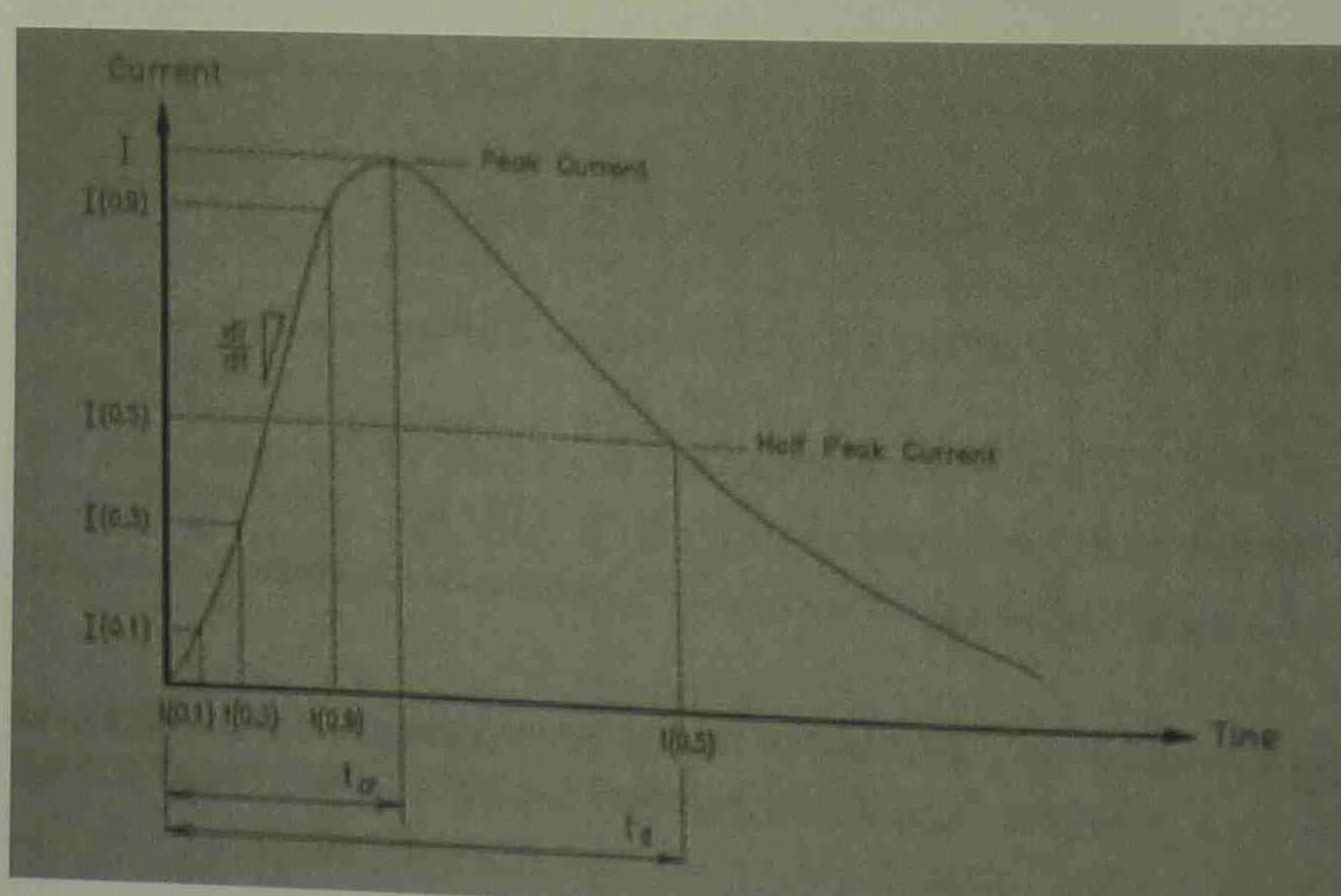
Source of electrical interference

(6) What are the sources of electrical interference?

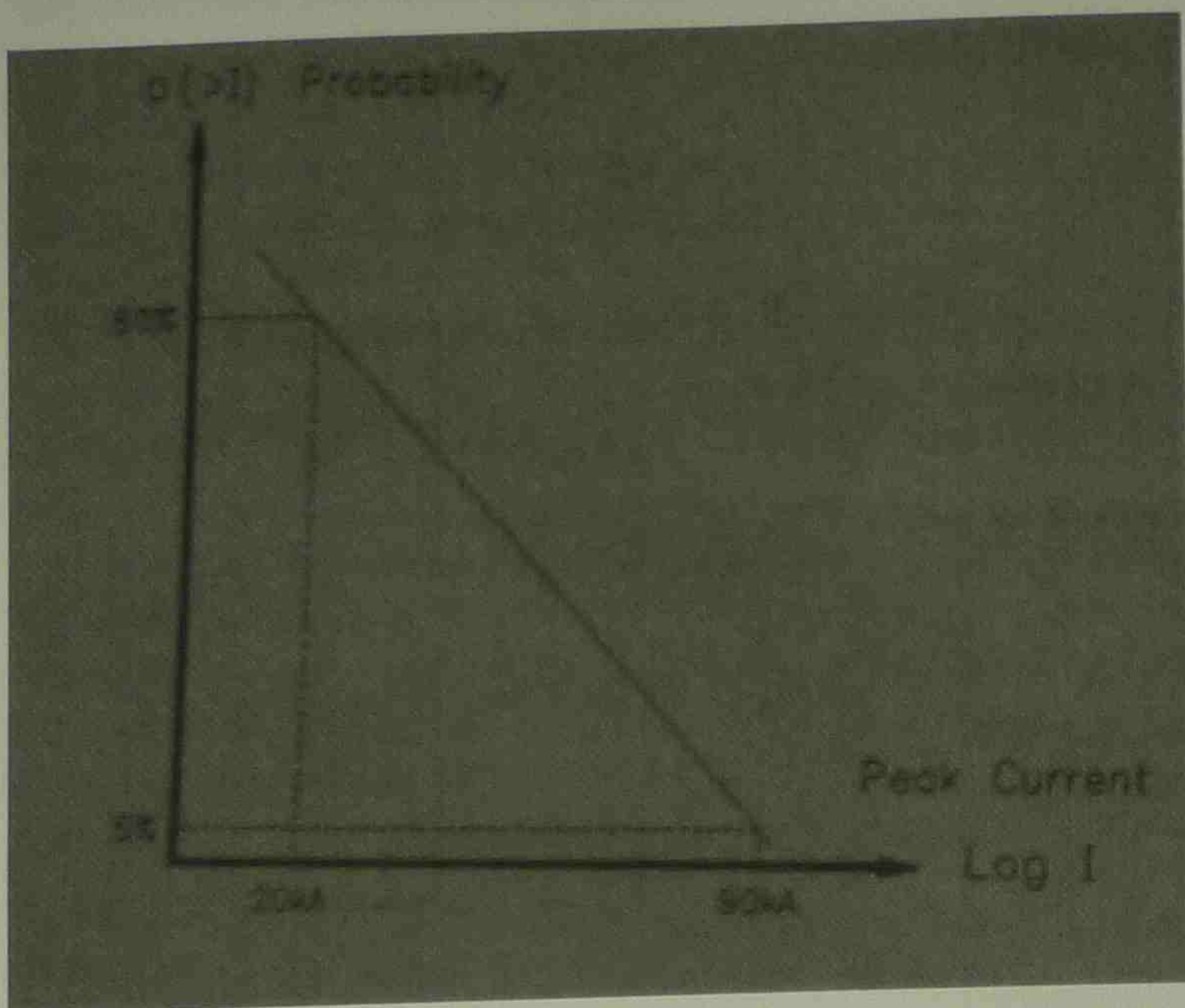
Electrical interference refers to the presence of unwanted voltages or currents, in cables or electronic equipment, which can damage the equipment or degrade its performance.

(7)Sketch (a) The lightning current waveform (b) Peak lightning current (c) Rate of rise of lightning current

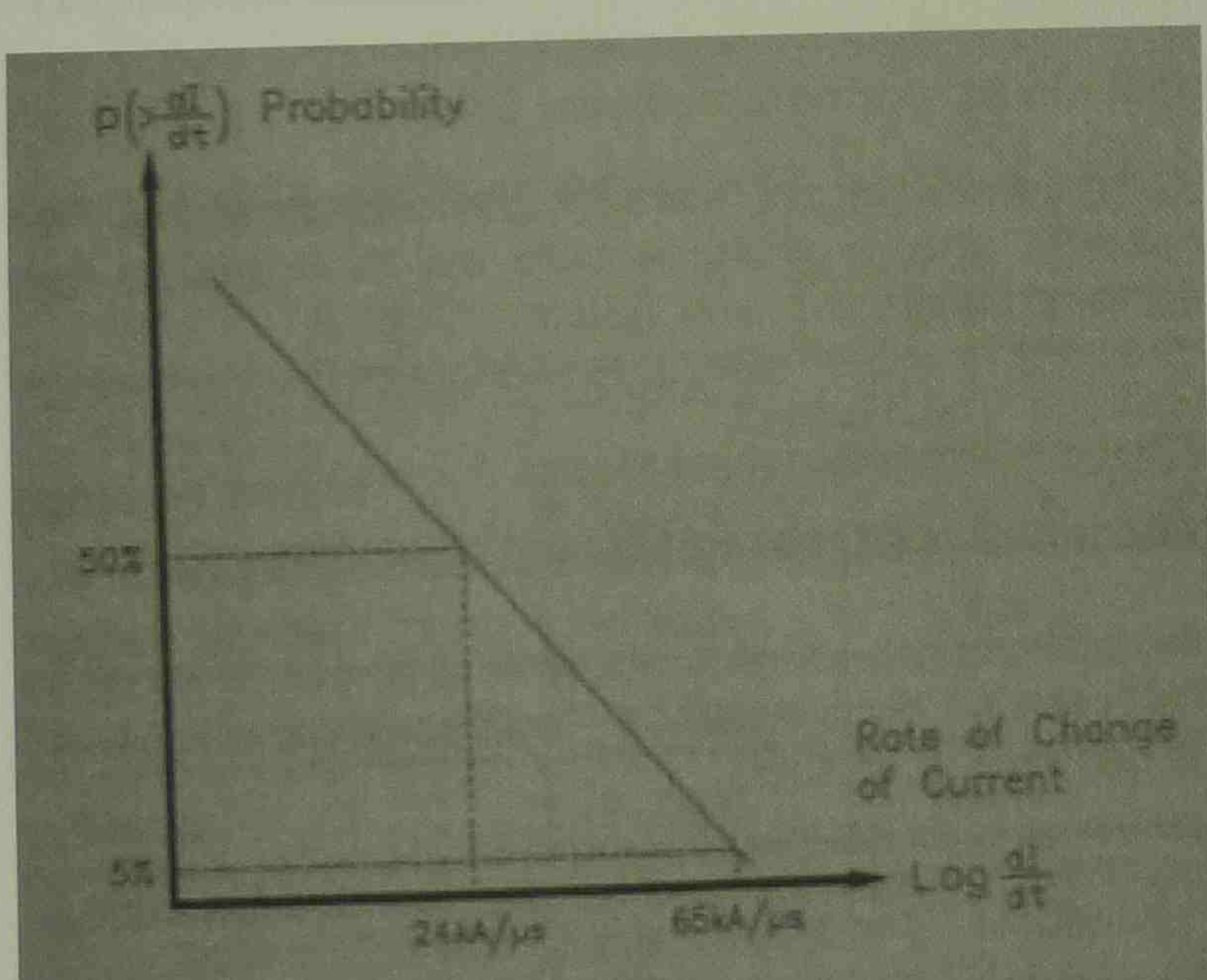
(a) **The lightning current waveform:**



(b) Peak lightning current:



(c) Rate of rise of lightning current:



(8) What is the duration of the lightning current waveform?

The duration of the lighting current waveform is described in terms of the time to crest t and the time to half-value t. For example, a 10µs/35µs waveform has a time to crest t of 10µs and a time to half value t of 35µs.

The typical duration of the current waveforms for negative downward strokes are:

- First negative stroke 5.5µs/75µs
- Subsequent negative strokes 1.1µs/32µs

(9) Describe the followings (a) Surge due to direct lightning strike (b) Induced surge due to adjacent lightning strike

(a) **Surge due to direct lightning strike:** Lighting behaves like a current source.. Consequently, the voltage at the point of strike is equal to the product of the lighting current I and the impedance Z presented by the structure and the earthing to the lighting current.

Simply, from Ohm's Law : $V = I \times Z$

(b) **Induced surge due to adjacent lightning strike:** High voltages and faults on transmission lines and other structures are not only caused by direct lighting strikes. High voltages can also be caused strikes in the vicinity of these facilities called adjacent lighting strikes. These cause induced voltages.

(10) Explain electrical interference due to switching event.

Switching events are a very common source of electrical interference and can cuase considerable problems for electronic equipment.

When an electric circuit is energized (switch on) and current begins to flow, a magnetic field is established around the conductor, which absorbs energy. The amount of energy absorbed by highly inductive loads, such as solenoids, electric motors, transformers, electric brakes, etc, is very high. However, switching inductive loads ON is seldom a major problem because the current grows relatively slowly to reach its full load value.

The problem usually arises when an inductive circuit is ***switched OFF***. When the current is interrupted, the magnetic field collapses. The energy, which is stored in the magnetic field, is then suddenly released. The energy is recovered in the form of current, which attempts to continue flowing in the circuit through the open contacts of the switch. The multiple strikes which then occur across the opening contacts of the switch generate a sequence of voltage transients or 'spikes', which are conducted along the cables to other connected equipment. The higher stored energy, the larger the resultant transient over-voltage.

(11)What are the disadvantages caused by lightning or switching?

The disadvantages caused by lighting or switching, can effect electronic equipment in the following ways:

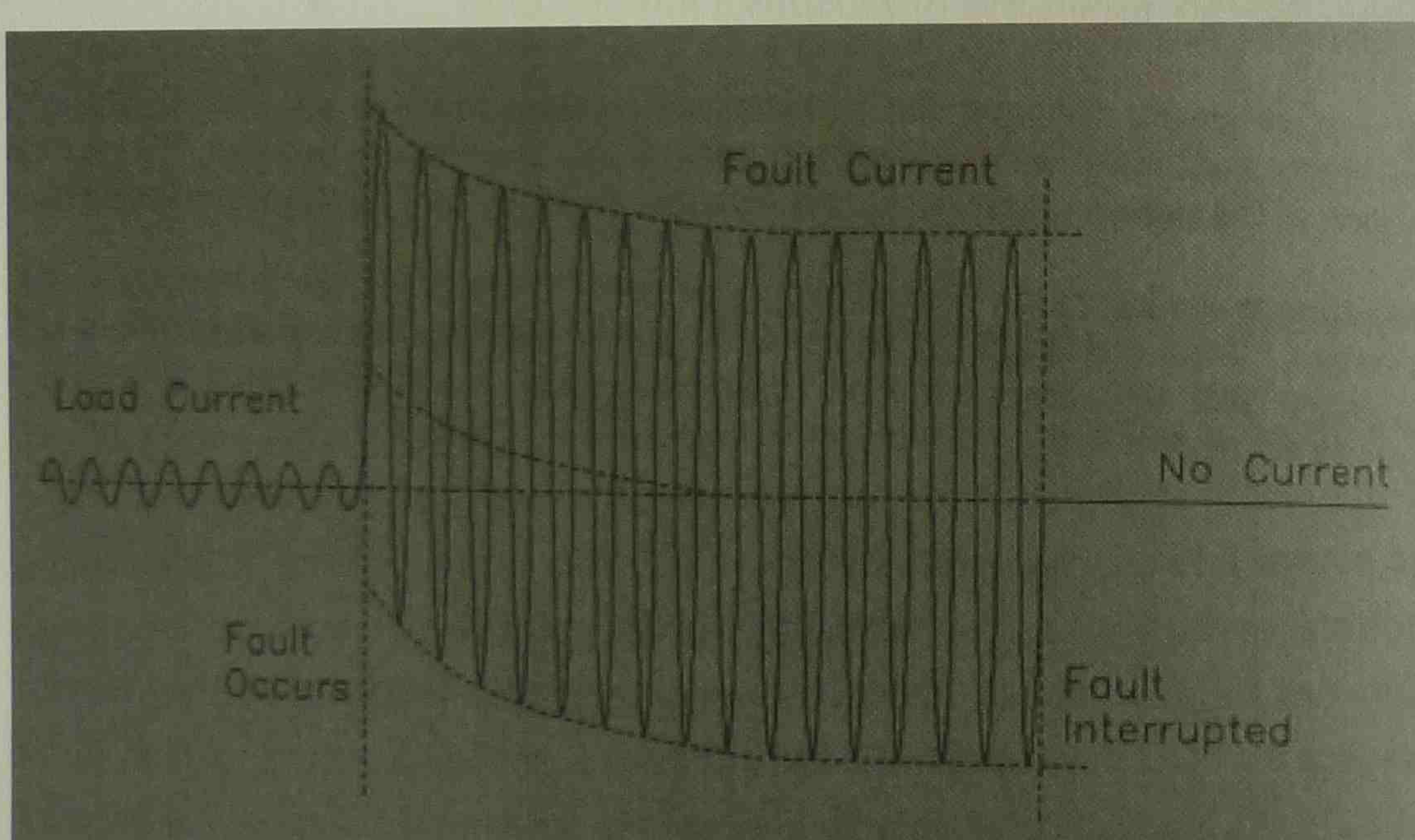
- **Disruption of Normal Operation:** Although no physical damage may appear to occur, the logic levels in digital systems and communications circuits can be disrupted, causing data loss, data corruption, unexplained communications 'hand-ups', processor lock-ups and spurious tripping of protection devices. These problems all result in frustrating down time and a lack of confidence in the integrity of the control system.

- **Degradation of components:** This problem is more serious because long term exposure to voltage and current stresses will degrade the electronic components, reduce their useful lifetime and eventually will result in equipment failure.
- **Damage to Equipment:** Severe transient over-voltages can sometimes result in immediate damage to the power supplies or I/O cards of the electronic equipment of the control system.

(12)Describe the followings with necessary sketches (a) Power system fault (b) Harmonic interference (c) Effect of harmonic on other equipments

Power system fault: An electrical power supply system comprises a network of transmission lines, transformers, and cables etc., which convey the electrical energy from the power generation station to the users. To isolate the voltages of the 3 phases from each other and from the ground, insulation mist be provided around the conductors. In the case of transmission lines, air is used as the insulation, while in the case of cables, transformers, motors etc., material such as Resins, XLPE, PVC and rubber are used for insulation.

When there is an insulation failure, high short circuit currents will flow in the power supply conductors. If the insulation failure results in a short circuit between phases, this is known as phase fault, and when the short circuit takes place between the phase and earth, it is known as an earth fault.



Harmonic interference: Converters comprise various combinations of diodes, thyristors, transistors, or other nonlinear devices which draw a non-sinusoidal current and distort the AC voltage in power supply system. Harmonics are not confined to the converter busbar but will affect equipment in other parts of a plant and the interconnected power system. They cause additional losses in other items of plant and are a major source of electrical interference. Harmonic distortion can be looked upon as a type of electrical pollution in a power system and are of concern because they can affect other connected equipment. As with other types of pollution, the source and magnitude of the harmonic distortion should be clearly understood in order to effectively deal with this problem.

Effect of harmonic on other equipments: Harmonic currents cause distortion of the mains voltage waveform which affects the performance of other equipment and creates additional losses and heating.

Capacitor banks are particularly vulnerable. They present a low impedance path to high frequency harmonic currents. These increase the dielectric losses in the capacitor bank which can lead to overloading and eventual failure. Transformers, motors, cables, busbars and switchgear supply current to converts should be derated to accommodate the additional harmonic currents and the extra losses associated with the high frequency 'skin-effect'.

The electronic equipment used for instrument, protection and control are also affected due to the interference coupled into the equipment or communications cables. This affects the reliability and performance of the control system.

The main supply current contains currents at the following harmonic frequencies:

$$f_n = (k.p \pm 1) \times f_1$$

where:	f_n	Frequency of the nth harmonic component of current
	f_1	fundamental frequency of the supply voltage
	k	integers 1,2,3,..........
	P	pulse number of the connected converter.

(13) What is the value of acceptable level of distortion in main supply system?

In the mains supply system, harmonic voltage distortion is the consequence of the flow of harmonic currents though the impedances in the power supply circuit connected to the converter. A typical power supply system at an industrial or mining plant consists of a source of AC power generation which can either be a local generating station in a small system or a power station at the other end of a transmission line or transformer in a large system. The impedance between the ideal generator and the main busbar is usually referred to as the source impedance Z_s of the supply system. Additional impedance, usually comprising cables, busbars, transformer, etc., exists between the main busbar and the converter busbar..

The flow of current to a variable speed motor is controlled by the conveter. The current is non-sinusoidal due to the non-linearity of the converter and the generation of harmonic currents. The flow of distorted current through the power distribution and supply system produces a distorted volt drop across the source and distribution impedances in series. Other equipment, such as electric motors or even other consumers can be connected to the main busbar. Consequently, this busbar is referred to as the ***Point of Common Coupling***

The voltage at the PCC will be distorted to an extent depending on the magnitude of the distorted current, the magnitude of the impedances and the ratio between them. The source impedance can easily be calculated from the system fault level and this is commonly used as the criteria for the permissible size of the converter load. If the magnitude and the frequency of each harmonic current is known, a simple application of Ohm's Law will give the magnitude of each harmonic voltage and the sum of them will give the total distorted voltage.

Briefly, limits are set for the level of Total Harmonic Voltage Distortion, which are acceptable at the Point of Common Coupling (PCC). The application of these standards requires the prior calculation of harmonic distortion at all points in the system before the converter equipment can be connected and under certain circumstance, actual measurements of harmonic voltage to confirm the level of distortion.

(14)What are the objectives of site earthing?

The main objectives of a good quality site earthing system are as follows:-

- To avoid physical damage to building and equipment due to direct or indirect lightning strikes and power system fault surges. The earthing system must provide a safe path for lighting and fault currents to flow into the body of the earth.
- To provide a safe working environment for personnel even during lightning strikes and power system faults. The 'touch potentials' at metallic enclosures should be below the voltage level at which personal injury can take place.
- To provide shielding and an alternative path for induced currents to reduce the effect of coupled noise and electronic equipment.
- To provide an equipotential platform on which electronic equipment can operate and be safely interconnected without fear of large differential voltages, even when the equipment may be located in several buildings, separated by some distance.

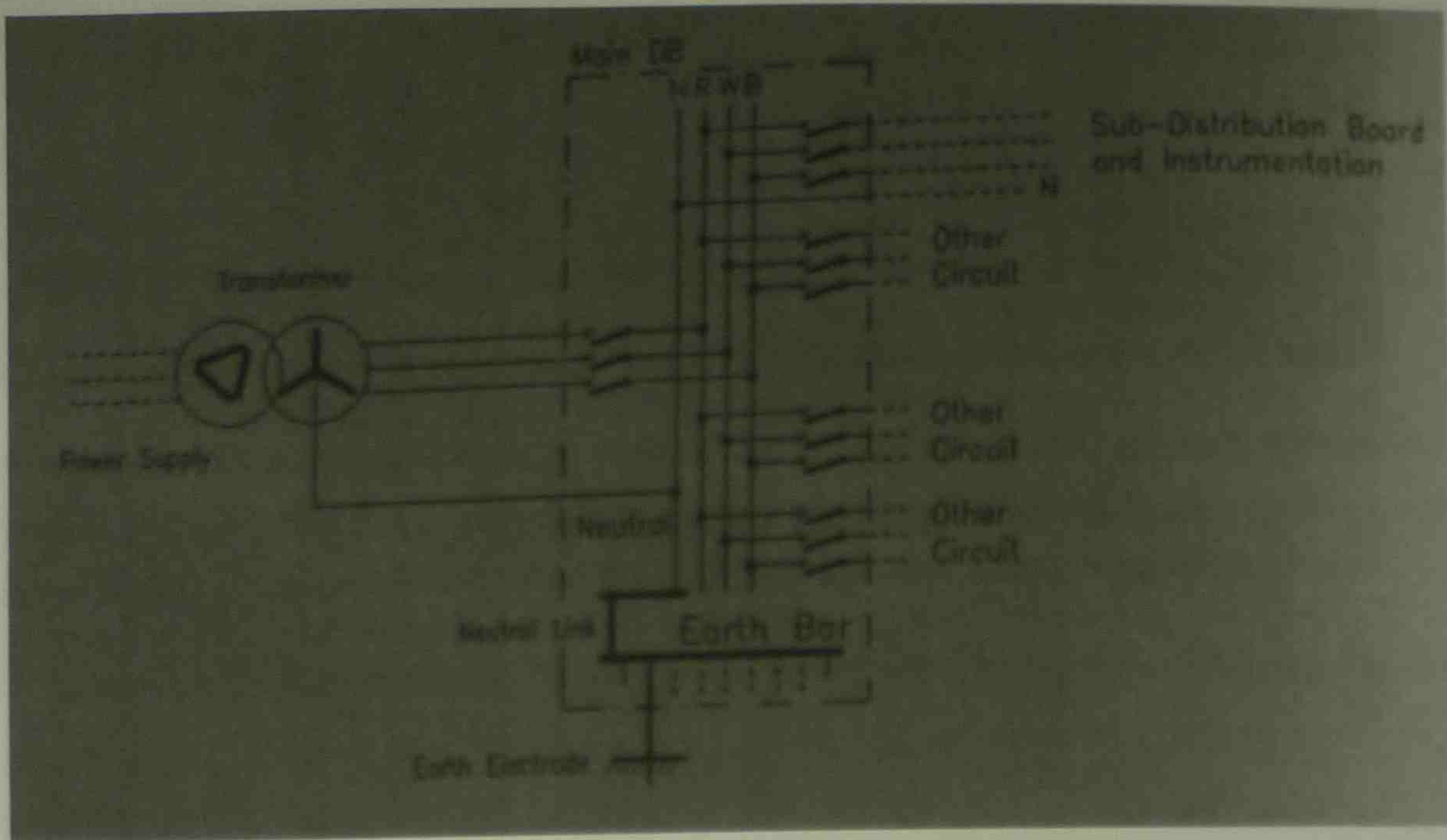
(15) Explain the categories of earthing systems with necessary sketches

The categories of earthing are

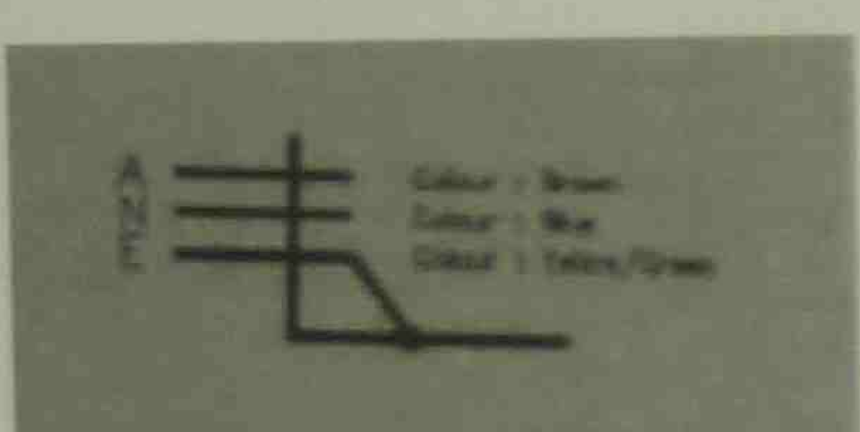
- Neutral Earthing
- Safety Earthing
- Signal Reference Conductor Earthing
- Screen Earthing

Neutral Earthing: Neutral earthing refers to the earthing of neutral point of the transformers for the power supply to buildings, industries sites etc. Distribution transformers are usally connected in the delta-star configuration, with the neutral point on the secondary side solidly earthed to the substation earth electrode.

Neutral earthing is particularly important to prevent over-voltages on the phase conductors of the 3-phase power supply system during fault.



Safety Earthing: The most electrical equipment, such as electric motors, switchgear, control panels, distribution boards, motor control centres, etc are located inside metal enclosures. If one of the phase conductors accidentally makes contact with the enclosure, it would become “alive” for the period until the fault were detected by the protection and isolated. This situation represents a considerable safety hazard to personnel standing next to or touching the “live” piece of equipment.



The Signal Reference Conductor: The purpose of the signal reference conductor is to provide a common reference plane for the small voltages associated with electric equipment. This is particularly important if the equipment is required to transfer signals to other remote electronic equipment or if electronic devices are connected together by data communications cables. Some common reference plane needs to be established between them.

Any decision to earth the signal reference conductor should be made purely from the point of view of noise immunity.

Serial Data Communications link between two PCs using a screened cable with the signal reference conductor earthed at both ends via Pin-7 on the serial port.

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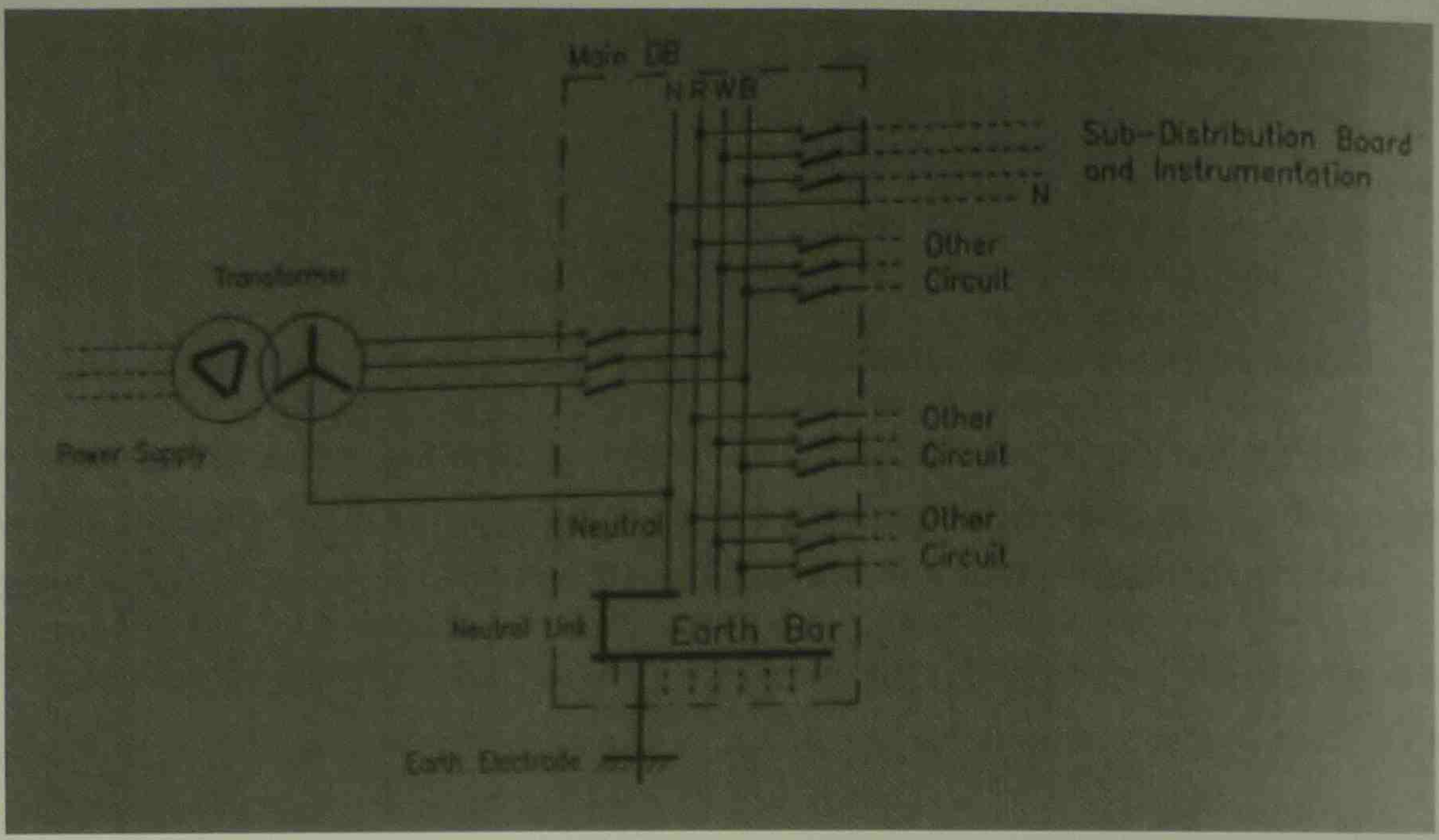

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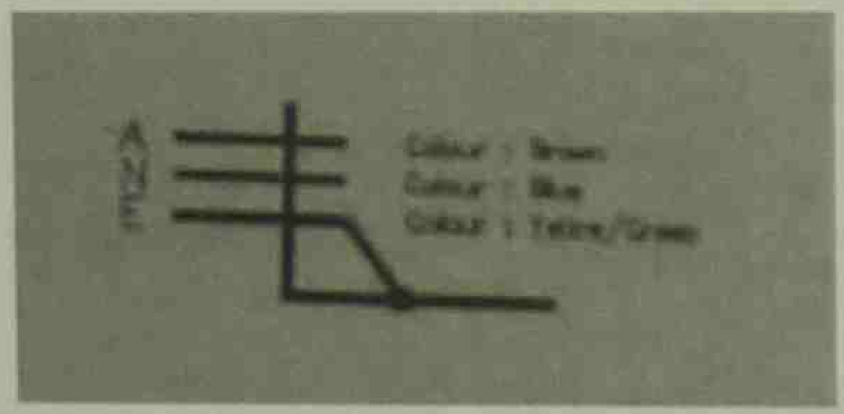

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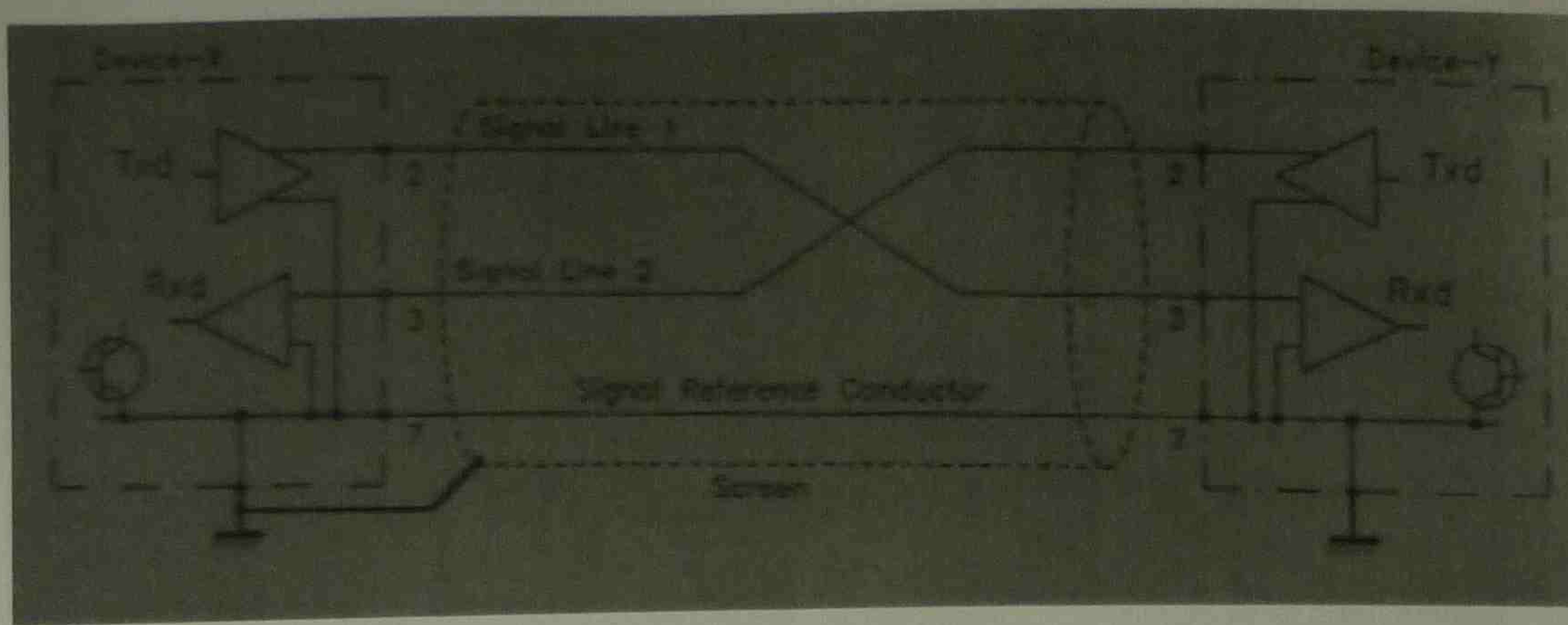


Screen Earthing: Signal cables and data communications cables usually include one or more screens, which are not electrically connected to the signal carrying conductors. The method of earthing these screens has a major influence on the noise immunity of the interconnection.

The most important thing about screen earthing is that something must be known about the other alternative bonded paths between the two electronic devices... screen earthing must be coordinated with the rest of the earthing system.

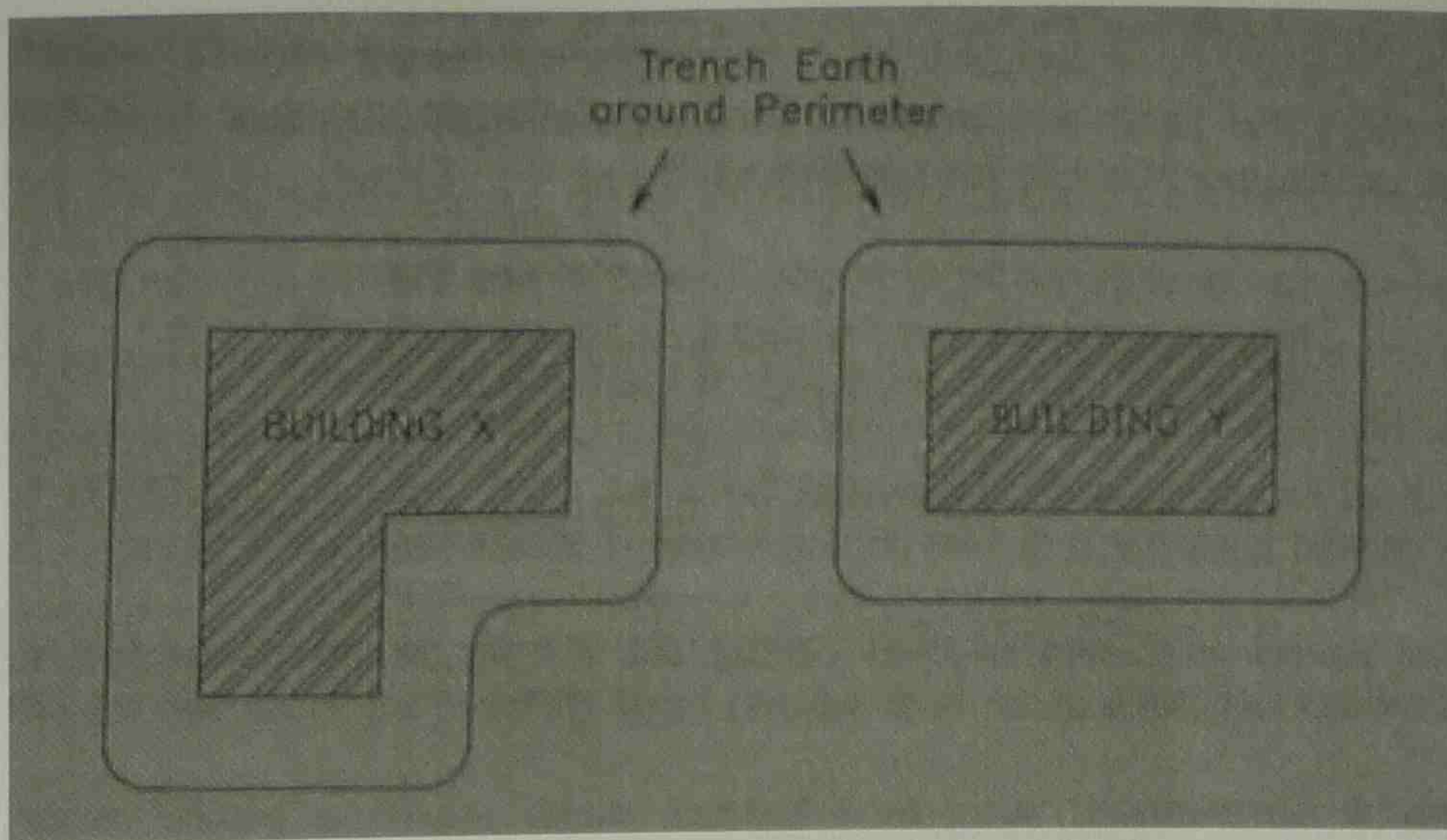
The symbol that is sued to indicate a Zero Signal Reference Grid is as follows:

(16) Describe the steps in designing an earthing system for a structure?

The following step-by-step approach to site earthing can be followed in most cases:

Step 1: Install the Trench Earth

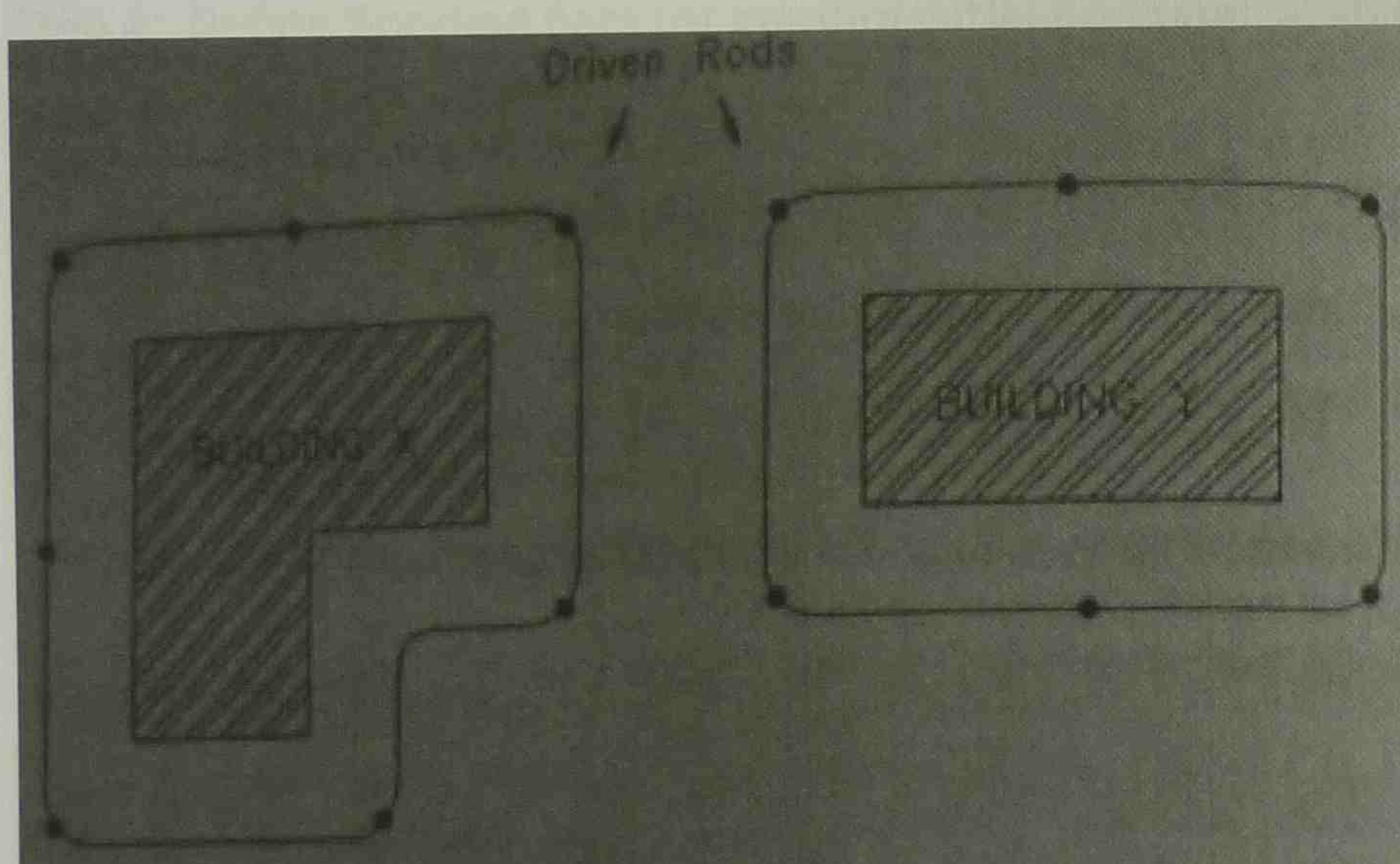
- Bury a trench earth around the perimeter of each building.
  Depth of trench earth : > 0.5m
  Distance from building : not closer than 1m from the walls
  Preferred earth conductor: Copper, ≥50mm^2 or dia ≥9.5mm, building reinforcing steel
- For a mast, a "crow's foot" trench earth arrangement is preferred with length of radials ≥30m and number of radials = 8.
- For a small structure, at least two down conductors, each connected to its own earth electrode should be used.



Install trench earth around perimeter of buildings.

Step 2: Install Driven Rods

- Place additional driven rods at regular intervals along the trench earth.
  Recommended distance between driven rods: 2 to 10 times rod depth (≤ 10m)
  Depth of driven rods: 2m to 3m
  Preferred rod material: Copper, galvanized steel or stainless steel.
- A trench earth electrode can be used without additional driven rods.

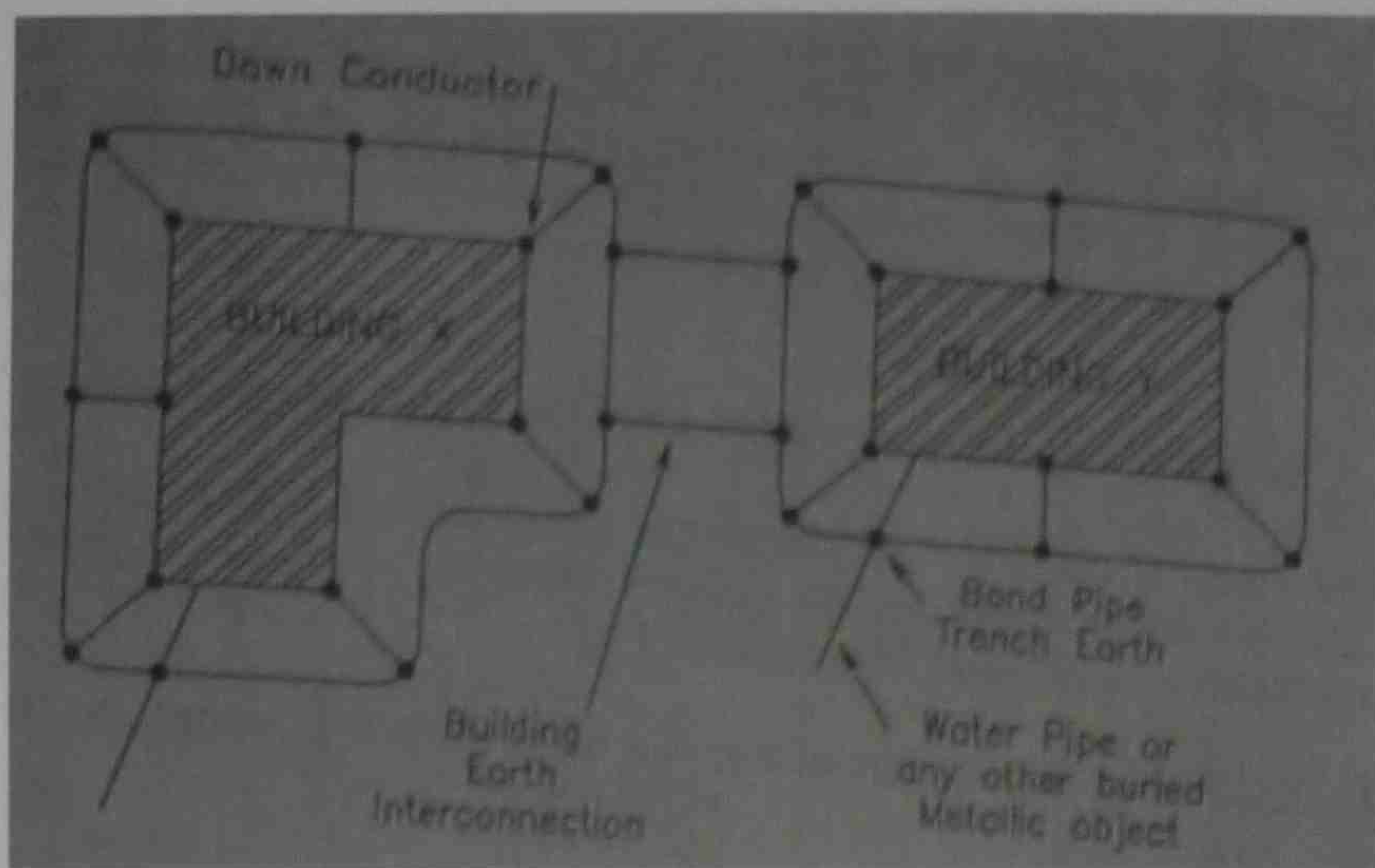


Step 3: Bonding of the earth Electrode to other Components:

- If there are power an signal cables passing between the buildings, and building earths should be interconnected. Any adjacent buried metallic objects such as metallic water pipes and structural steel in reinforced concrete foundations should also be incorporated in to the building earth.

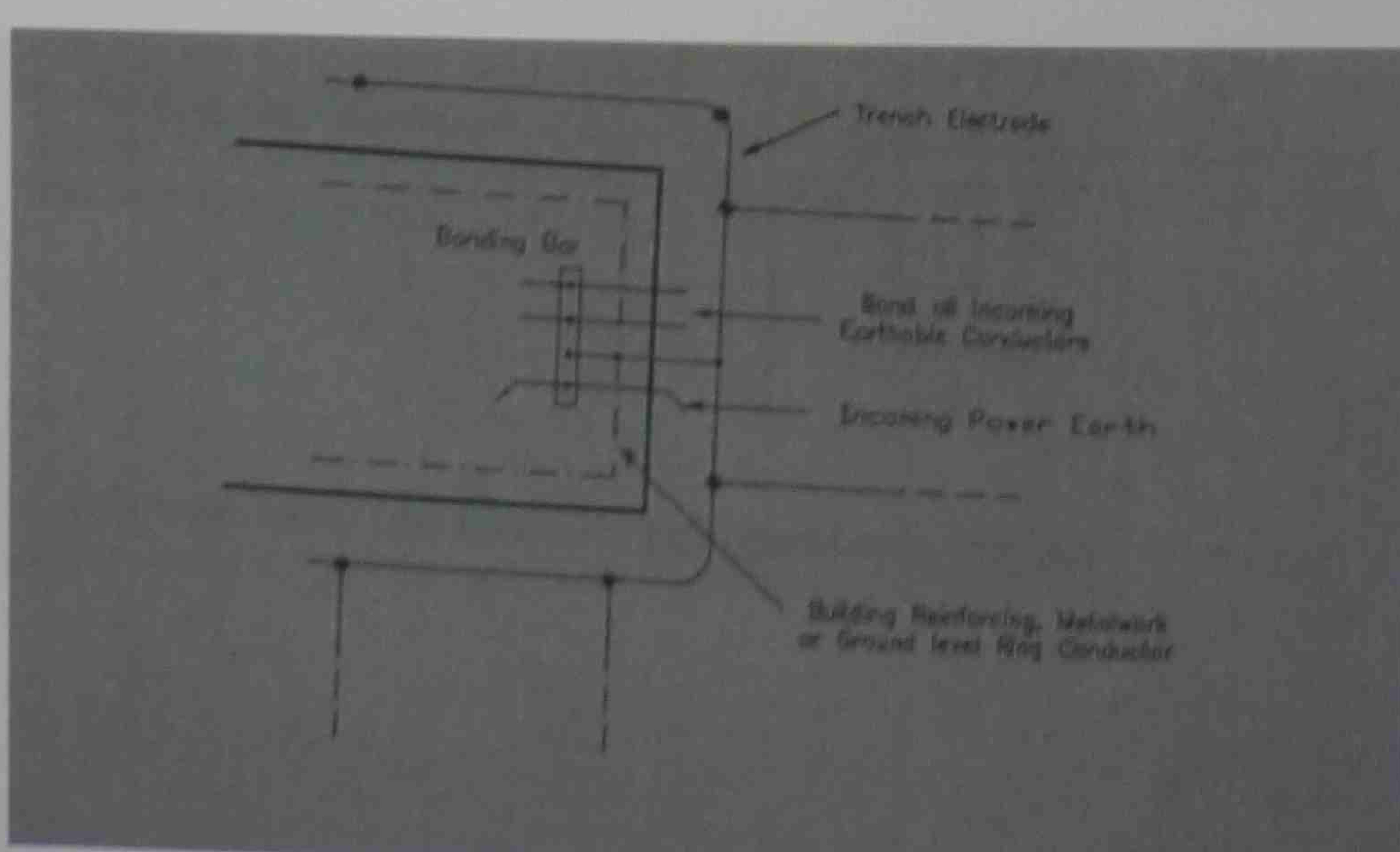
- Down conductors should be arranged in such a way that:
  - They offer several parallel paths for lightning current.
  - The length of the current path is kept to a minimum.

- At least two down conductors must be used. Their spacing should be exceed 25m for normal buildings and 10m for high hazard structures.
- If no trench earth exists, down conductors should be interconnected by means of horizontal ring conductors near ground level .
- Natural components, such as i-beams, metal sheeting, pipes, re-enforcing can form part of the down conductor, provided they are bonded to the air terminal. Horizontal ring conductors are not necessary in metal frame or reinforced buildings.



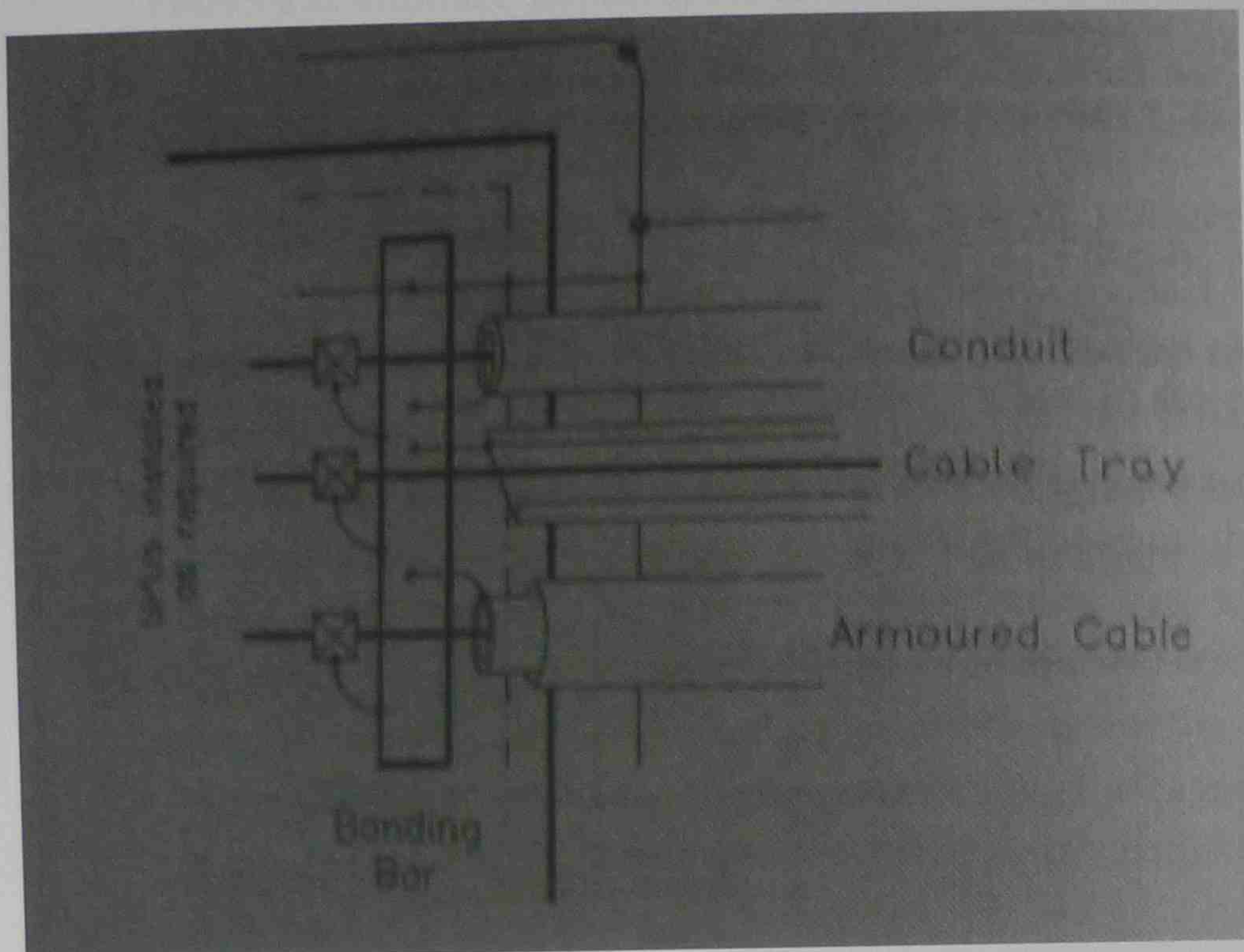
Step 4: Define Bonding Bars for equipotential Bonding:

- Define bonding bars for equipotential bonding at each building where more than one point of entry exists, ensure that bonding bars are themselves interconnected.
- Bond any external metalwork to the building earth.
- The bonding bar should be connected as closely as possible to th earth electrode as well as building metalwork, reinforcing, etc.
- Use bonding material dimensions in accordance with IEC 1024.1-1990.



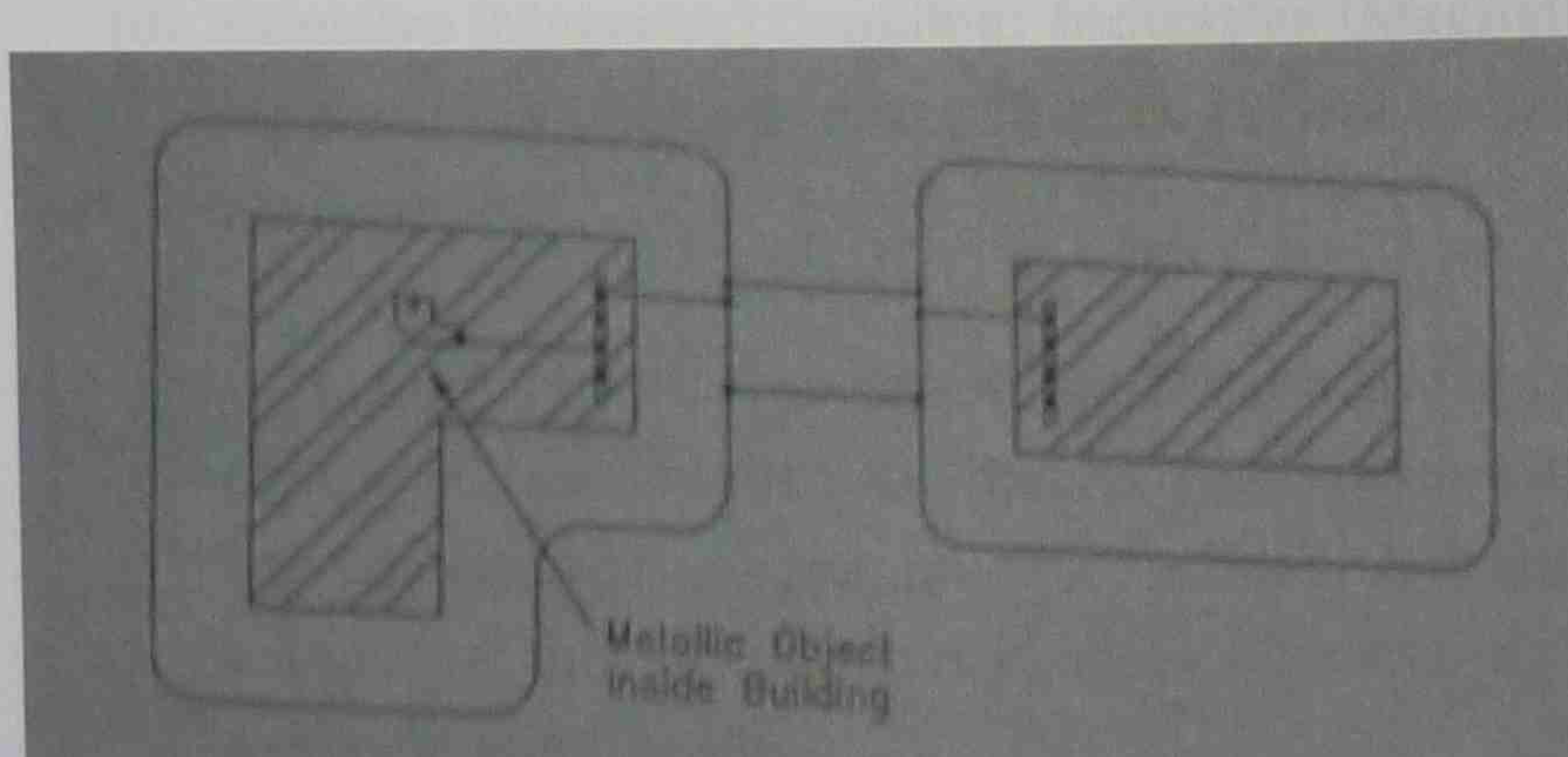
Step 5: Bonding the Conduit Cable Ladders and Cable Armouring

- Cables running between the buildings mist be run inside cable ducts such as conduit, armoured cable, cable support system, reinforced concrete ducts which are electrically continuous from end to end.
- Cable ducts mist be bonded to bonding bare at both buildings.
- It is recommended that power and signal lines enter the structure at the same location.
- Cables runs between buildings should be near to ground level and preferably buried.



Step 6 : Bond all Metallic Components inside the building to the Bonding Bar

- Metallic components inside the building must be bonded to the bonding bar.



Coupling interference into electrical system

(17) Explain (a) Unbalanced signal connection (b) Balanced signal connection (c) Capacitive (electro-static) Coupling (d) Inductive (magnetic) coupling

(a) **Unbalanced signal connection:** In simple data communications systems, such as those using the EIA/RS-232 interface standard, the connection is said to be "unbalanced" because only the conductor carries the signal voltage, with reference to a 'common' signal reference conductor. In American terminology this common wire is sometimes called the 'signal ground'.

(b) **Balanced signal connection:** Data communication interfaces, such as those using the EIA/RS-422 or EIA/RS-485 interface standards, require two conductors for each signal. The signal voltage for each channel is voltage difference between the two signal wires, hence its name is balanced differential system. Although a balanced connection still requires a reference conductor to provide a common reference for the two electronic devices at the ends of the signal cable, this reference conductor is not sued for signal transfer.

(c) **Capacitive (Electrostatic) Coupling:** Any two conductive metallic components separated in space will have an associated capacitance, which relates the charge on the conductors with the voltage difference e between the two conductors. The capacitance increases with area (A) of the conductors and decreases with separation distance (d) between the conductors.

These variables are related by the following were known equation $Q = CV$

Where: Q is the charge on each conductor

C Is the capacitance between the conductors

V Is the voltage between the conductors

(d) **Inductive (Magnetic) Coupling: Indicative** (Magnetic) coupling is the most frequent cause of problems with noise and interference in data communications circuits in the industrial environment.

Amongst the main problems are the power frequency voltages, which are coupled into the control and communication circuits from power cables, conduits, cable trays, etc running near to or parallel to the communication cables. Although this may not damage the circuits to the extent that they fail data bits in digital circuits may be corrupted, resulting in data errors and delaying data transfer.

The mechanism of inductive coupling is as follows:

- Any conductor carrying current will produce magnetic field around it. If there is an adjacent conductor, then a portion of this magnetic field will link with that conductor.
- Faraday's Law states that, it the magnetic field produced by conductor A changes due to the current in conductor A changing, then a voltage will be induced along the length of conductor B which is directly proportional to the rate of change of the flux linking conductor B.

(18) How will you reduce the effects of coupling in signal & control cables?

There is a combination of power, lighting, control, instrumentation and communication cables, the cable layouts should be designed as for as possible to avoid or reduce the effects of galvanic, capacitive and inductive coupling. This is of particular importance in modern automated plants, substations and buildings, where the measurements and control system depends on reliable data communications between several electronic devices.

To minimize the effects of noise and interference coupled into the electronic equipment.

(1) **Removal of the causes of coupled noise and interference:**
Where possible, the overall design should aim to achieve complete segregation of the power cables from cables from control, instrumentation and communication cables.

(2) **Shielding the electronic circuits form the sources of noise and interference.**
   (a) **Galvanic Isolation:** where possible, try to use a differential connection standard such as EIA/RS-422 or EIA/RS-485, in preference to an unbalanced connection standard, such as EIA/RS-232 or EIA/RS-565.
   (b) **Electrostatic Shielding:** In cases where there is possibility of high electric fields, capacitive shielding should be used, with the shield earthed at one end.
   (c) **Magnetic Shielding:** In cases where there is a possibility of high magnetic fields inductive shielding should be used, with the shield earthed at both ends and also at other convenient locations.

(3) **Reducing the effect of coupled noise and interference**.
Where possible, use twisted pairs to further reduce the effect of coupled noise and interference. Twisting results in less loop area for inductive coupling and also results in lower inductance per metre. Lower inductance allows higher frequencies to be transmitted over longer distances before signal distortion become significant.

Twisting also reduces inductive coupling with other signal conductors, The small spacing between the twisted signal conductors largely cancels the net magnetic fields associated with the conductor's currents.

(19) What is surge protection zone?

Surge Protection Zones are also sometimes called lightning Protection Zones. The two terms are interchangeable. Surge Protection Zones are characterized by significant changes of the electromagnetic conditions at their boundaries.

Electromagnetic conditions are defined in terms of:

- Capacitive coupling (Electric Fields)
- Inductive coupling (Magnetic Fields)

Surge Protection Zones imply the following requirements:

- At the boundary of the zones, all metal penetrations must be bonded to earth.
- Screening measures must be introduced for electrical path zones.
- Once a zone is defined, the electrical system must be designed, installed and maintained in such a manner that the zone definitions remain true.

(20) Explain (a) Shield design criteria (b) Maintaining shield integrity (c) Shielding electronic system

(d) Segregated instrument earthing system.

(a) Shield design criteria: A realistic objective is to achieve a nested shielding topology, where the zone exterior to the building is the most harsh and, as progress is made towards the more deeply nested zones, the electromagnetic environment becomes more benign. This nested approach is only achievable if the shields between the inside and the outside zone are not violated through incorrect terminations and earth connections.

(b) Maintaining shield integrity: Metal enclosures, metal cable ducts, metal conduits, etc perform very well as shields for electronic equipment. The reason is that induced current prefer to flow on the outside of the metal enclosures due to the well known 'skin effect'. This shields the interior some containing the electronic equipment, from interference.

(c) Shielding electronic system:

- Ensure that there is a solid bonding between all cabinets and panels containing electronic equipment with a single room or section of plant.

- Bond the cable screens to the PLC Cabinet as close to the point of entry as possible. Avoid using long 'tail'

- Bond discrete devices, such as a PLC Rack, to the metalwork of the enclosure, which is earthed at the base. This takes advantage of the low impedance of the metal structure.

- Preferably, also connect the discrete devices to the earth bar in the enclosure. Use straight runs by the shortest possible route. Do NOT coil the earth connection as this introduces extra inductance.

- The Signal Cable travels though a more harsh zone, so screens should be bonded at the entry to the enclosure.

(d) Segregated instrument earthing system: The power system and the instrument system are designed with separate earth bars, the latte usually being referred to as the 'clean' or 'instrument' earth. In fact, some manufactures of control equipment recommend this earthing solution. Although this approach may have some merit in excluding noise during normal operating conditions, there are considerable risks of severe equipment damage during abnormal situations, such as those which occur

Surge Protection Zones imply the following requirements:

- At the boundary of the zones, all metal penetrations must be bonded to earth.
- Screening measures must be introduced for electrical path zones.
- Once a zone is defined, the electrical system must be designed, installed and maintained in such a manner that the zone definitions remain true.

(20) Explain (a) Shield design criteria (b) Maintaining shield integrity (c) Shielding electronic system (d) Segregated instrument earthing system.

(a) Shield design criteria: A realistic objective is to achieve a nested shielding topology, where the zone exterior to the building is the most harsh and, as progress is made towards the more deeply nested zones, the electromagnetic environment becomes more benign. This nested approach is only achievable if the shields between the inside and the outside zone are not violated through incorrect terminations and earth connections.

(b) Maintaining shield integrity: Metal enclosures, metal cable ducts, metal conduits, etc perform very well as shields for electronic equipment. The reason is that induced current prefer to flow on the outside of the metal enclosures due to the well known 'skin effect'. This shields the interior some containing the electronic equipment, from interference.

(c) Shielding electronic system:

- Ensure that there is a solid bonding between all cabinets and panels containing electronic equipment with a single room or section of plant.

- Bond the cable screens to the PLC Cabinet as close to the point of entry as possible. Avoid using long 'tail'

- Bond discrete devices, such as a PLC Rack, to the metalwork of the enclosure, which is earthed at the base. This takes advantage of the low impedance of the metal structure.

- Preferably, also connect the discrete devices to the earth bar in the enclosure. Use straight runs by the shortest possible route. Do NOT coil the earth connection as this introduces extra inductance.

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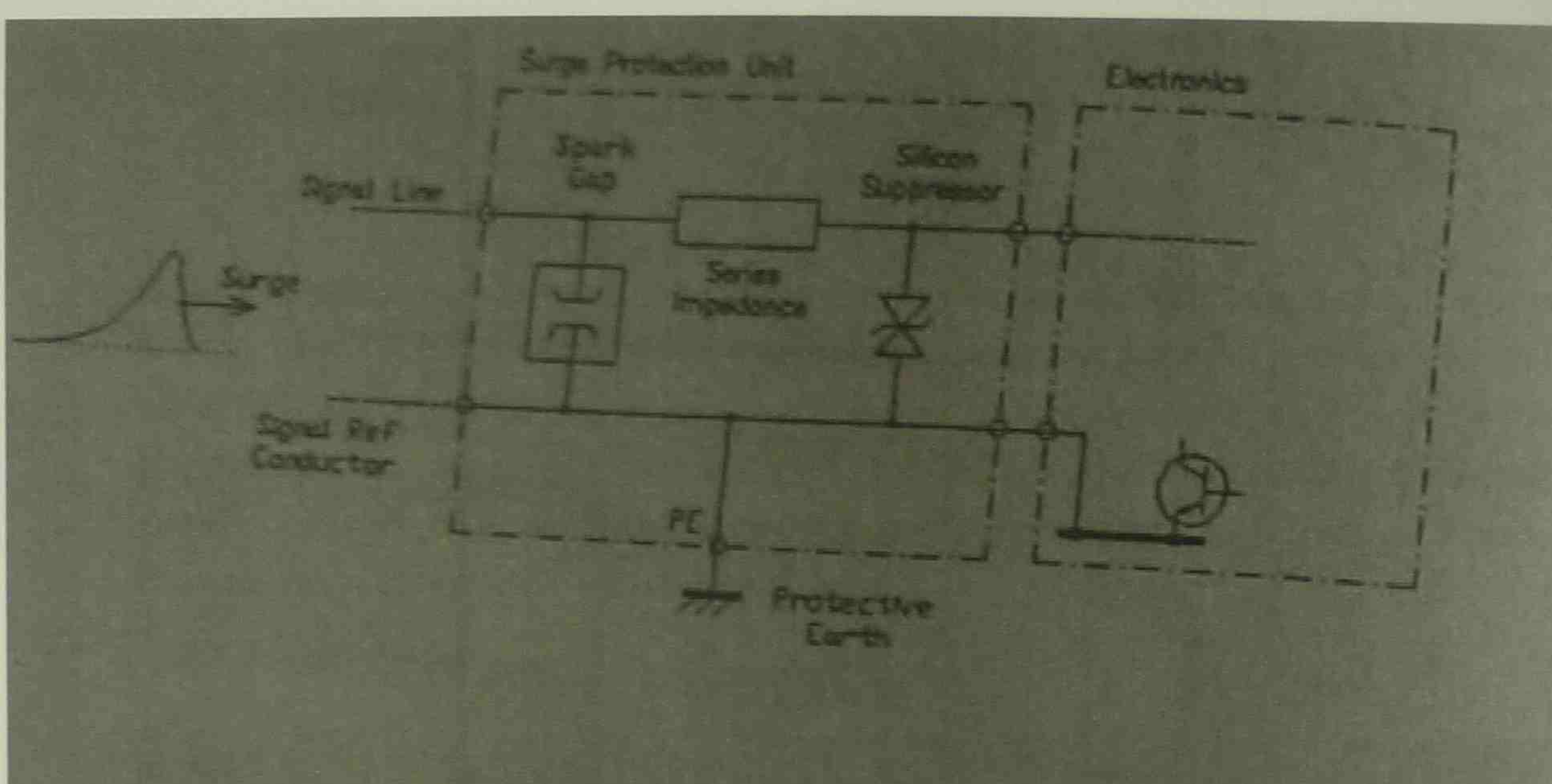
(d) Segregated instrument earthing system: The power system and the instrument system are designed with separate earth bars, the latte usually being referred to as the 'clean' or 'instrument' earth. In fact, some manufactures of control equipment recommend this earthing solution. Although this approach may have some merit in excluding noise during normal operating conditions, there are considerable risks of severe equipment damage during abnormal situations, such as those which occur during lightning. To avoid equipment damage particularly in high lightning areas, these two earths should be bonded together

(21) Explain the design of surge protection circuit.

The Surge Protection Units need to be specifically designed for the different I/O and be the electronic device they are required to protect.

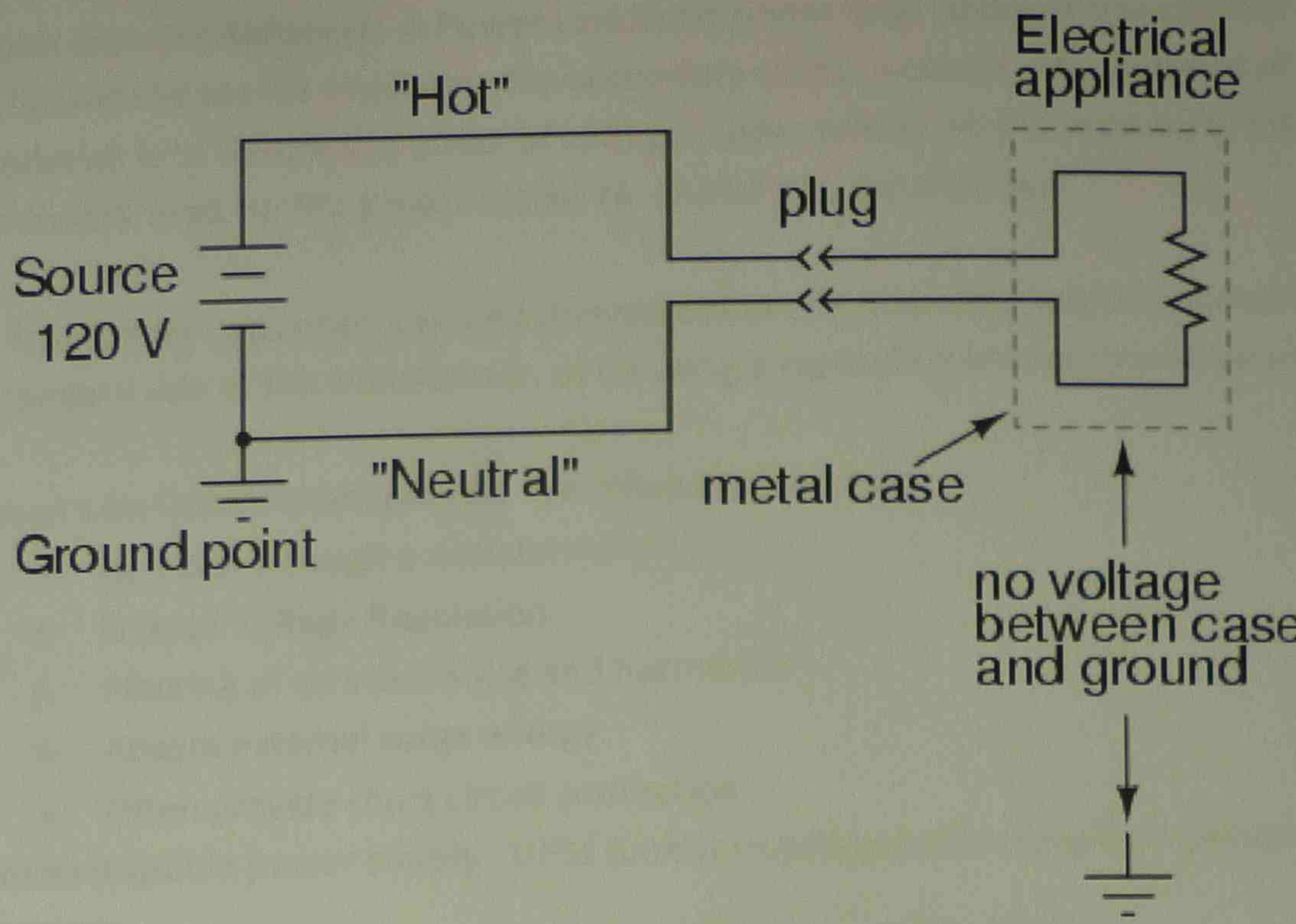
For the types of electronic circuits used in data communications, comprising ICs (Integrated circuits) such as UARTs (Universal Asynchronous Receiver/Transmitter), line drivers and line receivers, it is essential to use the 'fast' types of surge suppression components based on the silicon suppressor. With the limited surge energy absorption capability of the silicon suppressor, additional components such as Spark Gaps must be added to protect and silicon suppressor. The basic circuit used for this type of protection has the following form.



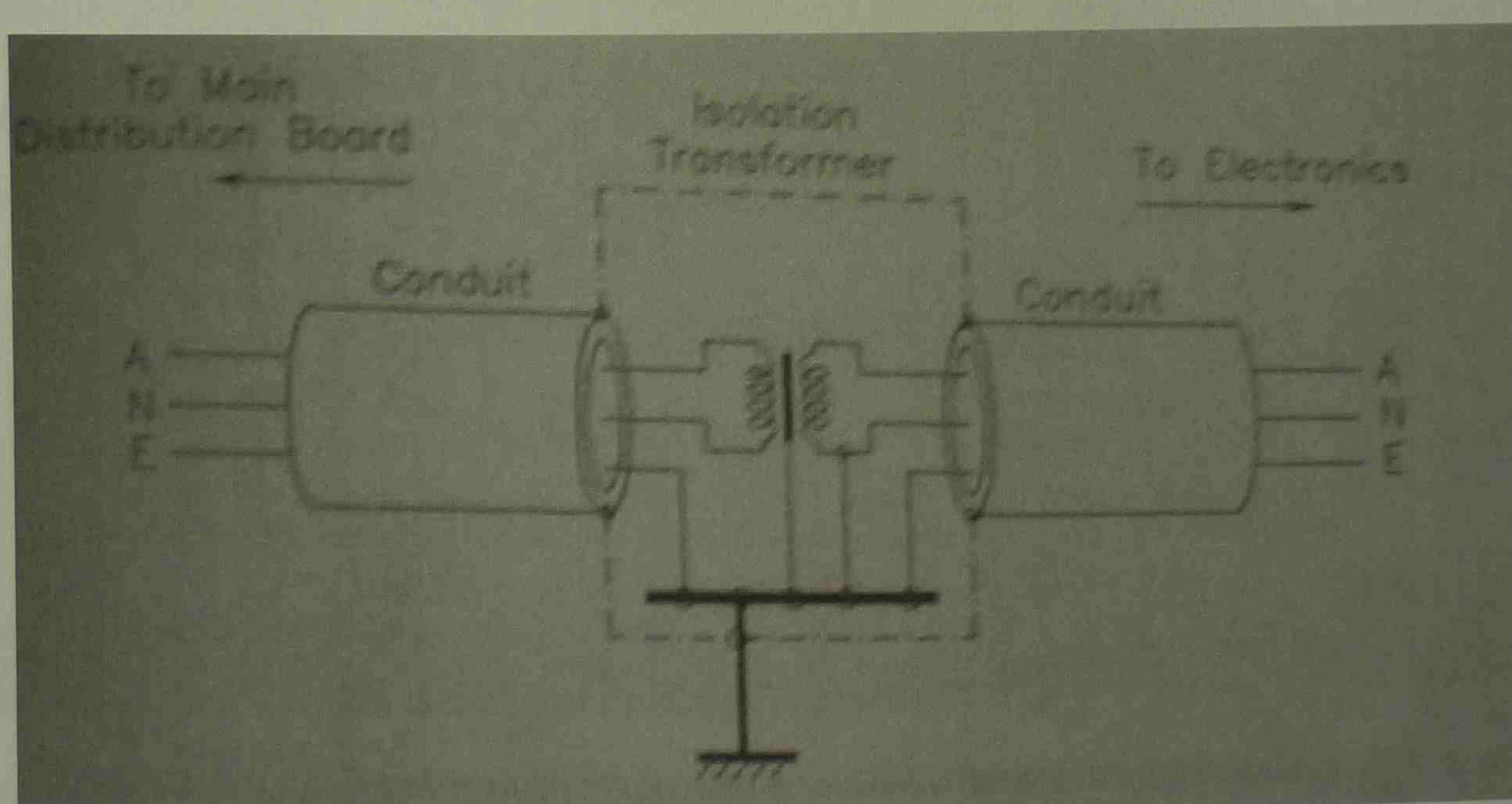
4 : *Basic Design of a SPU (Surge Suppression Unit)*

(22) Describe the followings with sketches. (a) Protecting the power supply side (b) Use of isolating transformer (c) Power line conditioner (d) Uninterruptible power supply (e) Testing surge protection device

(a) **Protecting the power supply side:** A power system with no secure connection to earth ground is unpredictable from a safety perspective: there's no way to guarantee how much or how little voltage will exist between any point in the circuit and earth ground. By grounding one side of the power system's voltage source, at least one point in the circuit can be assured to be electrically common with the earth and therefore present no shock hazard. In a simple two-wire electrical power system, the conductor connected to ground is called the *neutral*, and the other conductor is called the *hot*, also known as the *live* or the *active*.



(b) Use of isolating transformer: An Isolation Transformer is often provided in the power supply of the electronic equipment to provide complete galvanic separation between the 240V power supply and the 'internal' supply to the electronic components. One leg of the secondary side of the transformer is earthed to establish a new 'clean neutral'. In addition, the windings of these transformers are often screened to divert capacitively coupled high frequency noise or surges in the power supply conductors.



(c) **Power Line Conditioners:** A Power Line Conditioner is an isolation transformer with some additional feature for regulating the secondary output voltage. The purpose of the voltage regulation is to reduce the effect of voltage surges or dips on the secondary side. These devices are usually used for the power supply to smaller PLC installations.

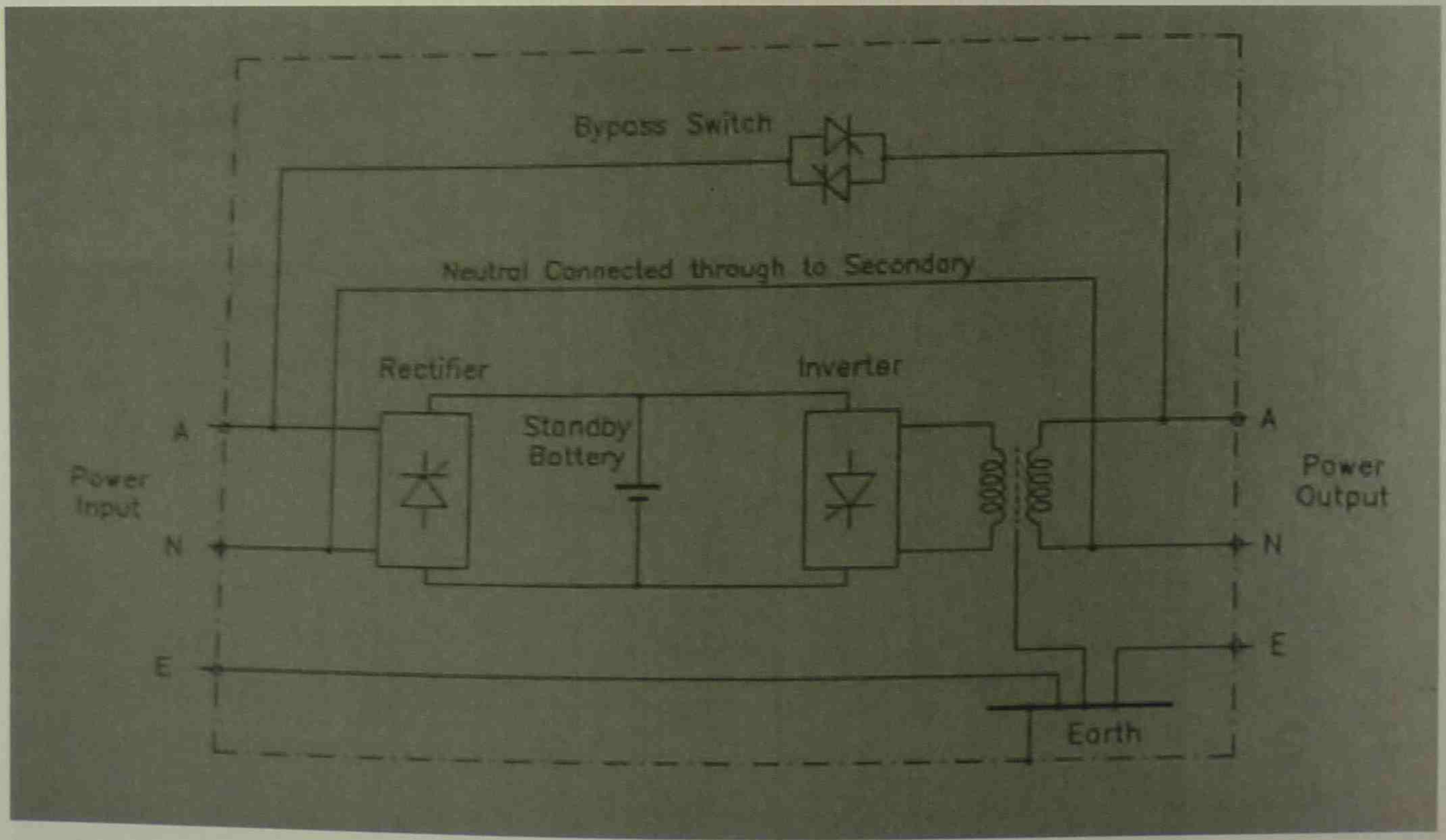
The voltage regulation can be achieved either electronically, with a regulating circuit on the secondary side of the transformer, or by using a regulating ferroresonant transformer.

Power Line Conditioners provide the following features:

- Isolation through a transformer
- Output Voltage Regulation
- Filtering of external noise and harmonics
- Absorb external surge energy
- Often provide short circuit protection

(d) **Uninterruptible power supply:** UPSs (uninterruptible power supplies) provide the following features:

- All the advantages of a Power Conditioner
- No-break standby supply for a certain period to cope with power interruptions and allow a controlled shutdown of the control system.



(e) **Testing surge protection device:** There is no alternative to actual laboratory testing of SPUs (surge Protection Units). The influence of stray effects can never be predicted. Testing is performed by applying 'standard' voltage and currents surges to the device.

(23) Define power quality

The quality of voltage and the quality of current and can be defined as: the measure, analysis, and improvement of the bus voltage to maintain a sinusoidal waveform at rated voltage and frequency. This definition includes all momentary and steady-state phenomena.

(24)What are the causes of disturbances in power system?

The power system impedance, any current harmonic will result in the generation and propagation of voltage harmonics and affects the entire power system. The impact of current harmonics generated by a nonlinear load on a typical power system with linear loads.

There are three types of disturbances in power systems.

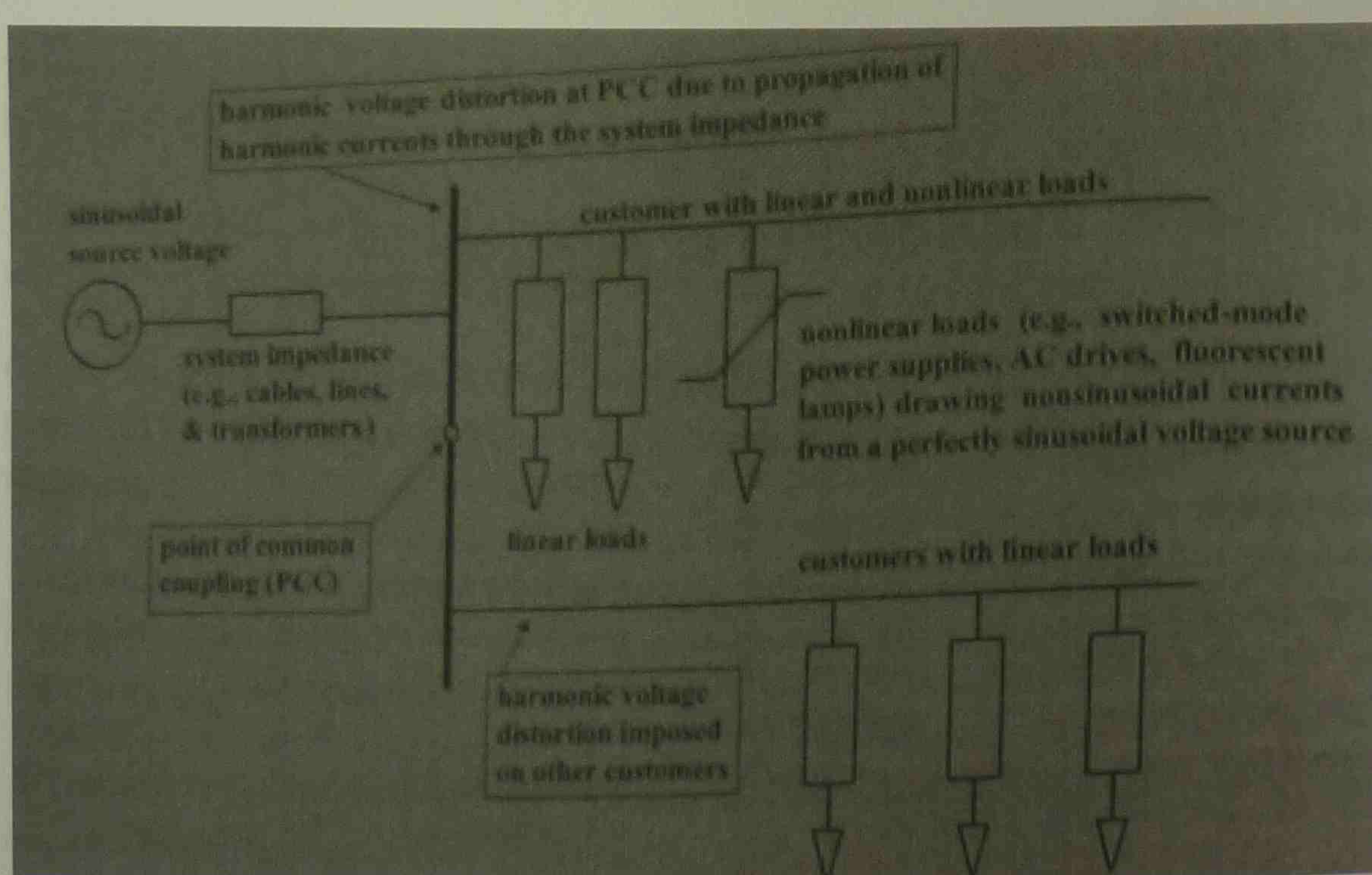
1) Small and predictable

2) Large and random and 3) Large and predictable.

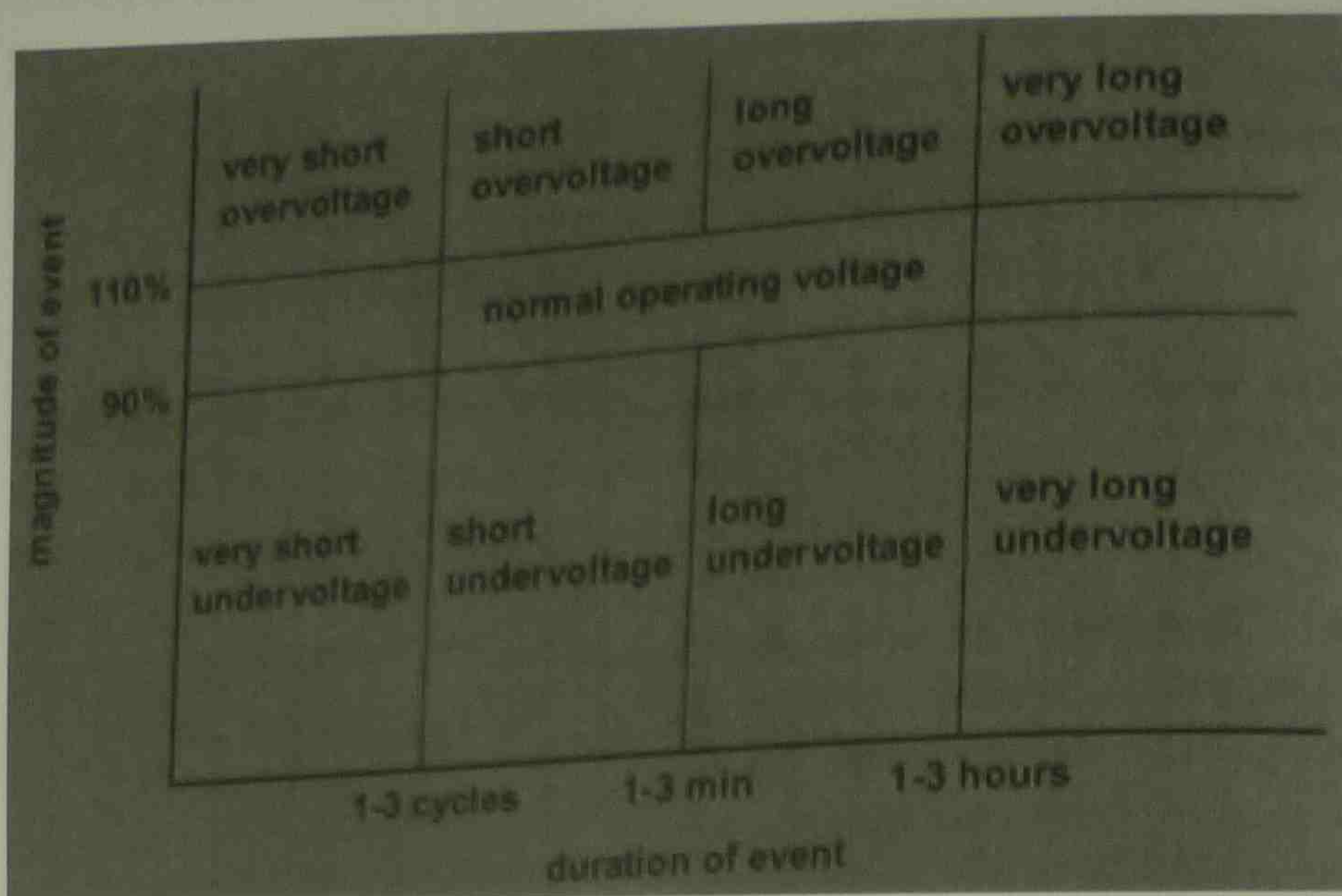
(25)How do harmonics propagate in power system? Explain with sketches.

Due to the power system impedance, any current harmonic will result in the generation and propagation voltage harmonics and affects the entire power system. The impact of current harmonics generated by a nonlinear load on a typical power system with linear loads.

The distortion sources into three categories: 1) Small and predictable 2) large and random 3) large and predictable.



(26) Sketch magnitude –duration plot for classification of power quality event.



The magnitude and duration of events can be used to classify power quality events. In the magnitude-duration plot, there are nine different parts. Various standards given different names to events in these parts. The voltage magnitude Is split into three regions:

- Interruption: voltage magnitude is zero
- Under voltage: voltage magnitude is below its nominal value, and
- Overvoltage: voltage magnitude is above its nominal

The duration of these events is split into four regions: very short, short, long, and very long. The borders in this plot are somewhat arbitrary and the user can set them according to the standard that is used.

IEEE standards use several additional terms to classify power quality events. Table provides information about categories and characteristics of electromagnetic phenomena defined by IEEE-1159.

(27) Explain the followings (a) Transient (b) Short duration voltage variations (c) Interruption (d) Sags (Dips) (e) Swells (f) Long duration voltage variation (g) Waveform distribution (h) Inter harmonic (i) Notching 3

(a) Transient: Power system transients are undesirable, fast and short duration events that produce distortions. Their characteristics and waveforms depend on the mechanism of generation and the network parameters at the point of interest.

Transients can be classified with their many characteristic components such as amplitude, duration, and rise time, frequency of ringing polarity, energy delivery capability, amplitude spectral density, and frequency of occurrence. Usually classified in to two categories: impulsive and oscillatory.

(b) Short duration voltage variations: There are three different types of short-duration events instantaneous, momentary, and temporary. Each category is divided into interruption, sag, and swell. Principal cases of short-duration voltage variations are fault conditions, large load Energization, and loose connections.

(c) Interruption: Interruption occurs when the supply voltage decreases to less than 0.1 pu for less than I minute. Some causes of interruption are equipment failure, control malfunction, and blown fuse or breaker opening. Interruption is usually measured by its duration.

(d) Sags: sags are short-duration reductions in the rms voltage between 0.1 and 0.9 pu. There is no clear definition for the duration of sag, but it is usually between 0.5 cycles and 1 minute. Voltage sages are usually caused by

- Energization of heavy loads,
- Starting of large induction motors,
- Single line-to-ground faults, and
- Load transferring from one power source to another.

(e) Swells: The increase of voltage magnitude between 1.1 and 1.8 pu is called swell. The most accepted duration of a swell is from 0.5 cycles to 1 minute. Swells are not as common as sags and their main causes are:

- Switching off of a large load,
- Energizing a capacitor bank.

(f) Long-duration voltage variation: The deviation of the rms value and voltage from the nominal value for longer than 1 minute is called long-duration voltage variation.

(g) Waveform Distortion: A steady-state deviation from a sine wave of power frequency is called waveform distortion. There are five primary types of wavefrom distortions: DC offset, harmonics, interharmonics, notching and electric noise.

(h) Inter harmonic: The frequency of interharmonics are not integer multiples of the fundamental frequency. Interharmonics appear as discrete frequencies or as a band spectrum. Main sources of interharmonics waveforms are static frequency converters, cycloconverters, induction motors, arcing devices, and computers. Interharmonics cause flicker, low-frequency torques, additional temperature rise in induction machines and malfunctioning of protective relays.

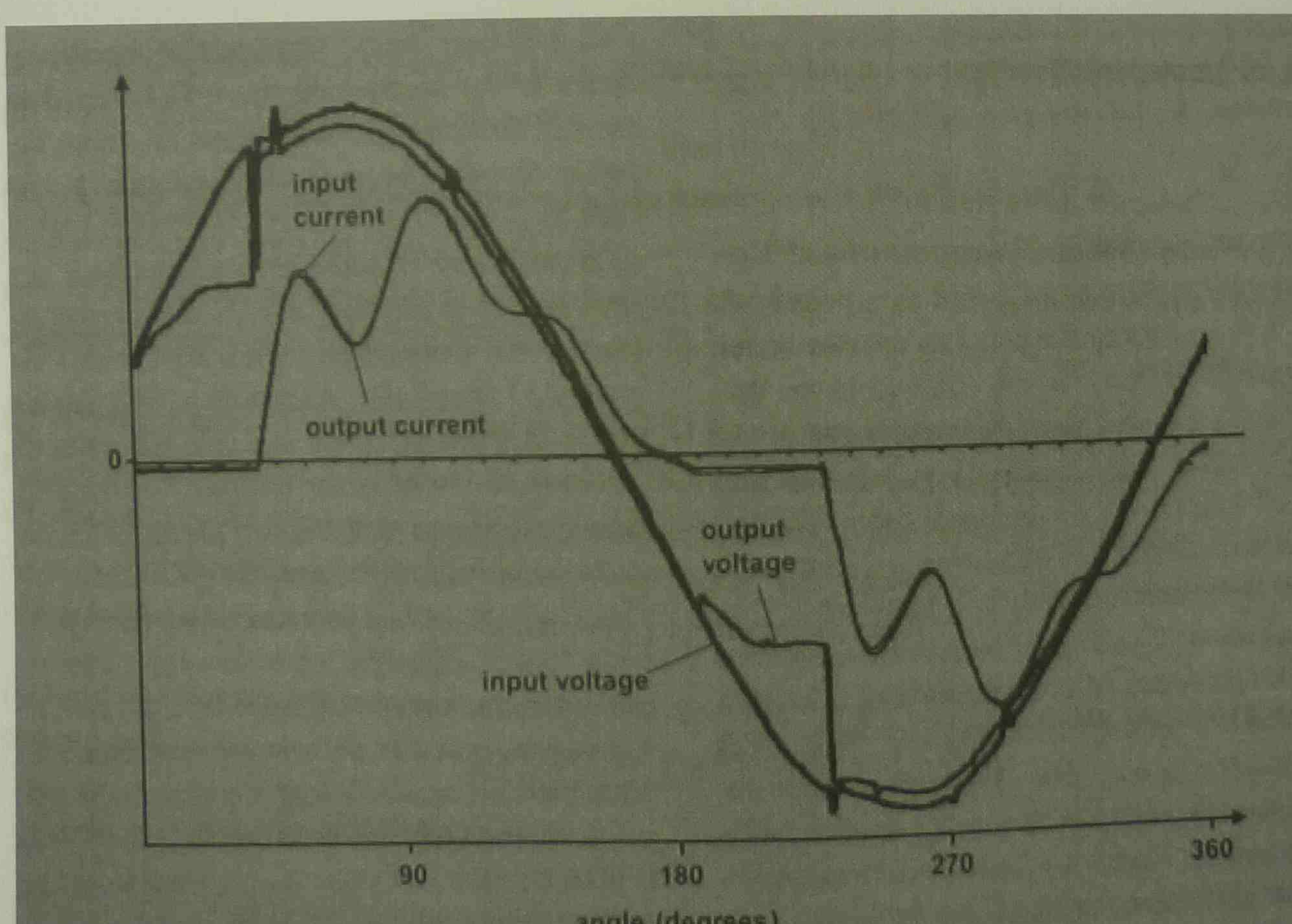
(i) Notching 3: A periodic voltage disturbance caused by line-commutated thyristor circuits is called notching. The notching appears in the line voltage waveform during normal operation of power electronic devices when the current commutates from one phase to another. During this nothing period, there exists a momentary short-circuit between the two commutating phases, reducing the line voltage; the voltage reduction is limited only by the system impedance.

Notching can be characterized by the following properties:

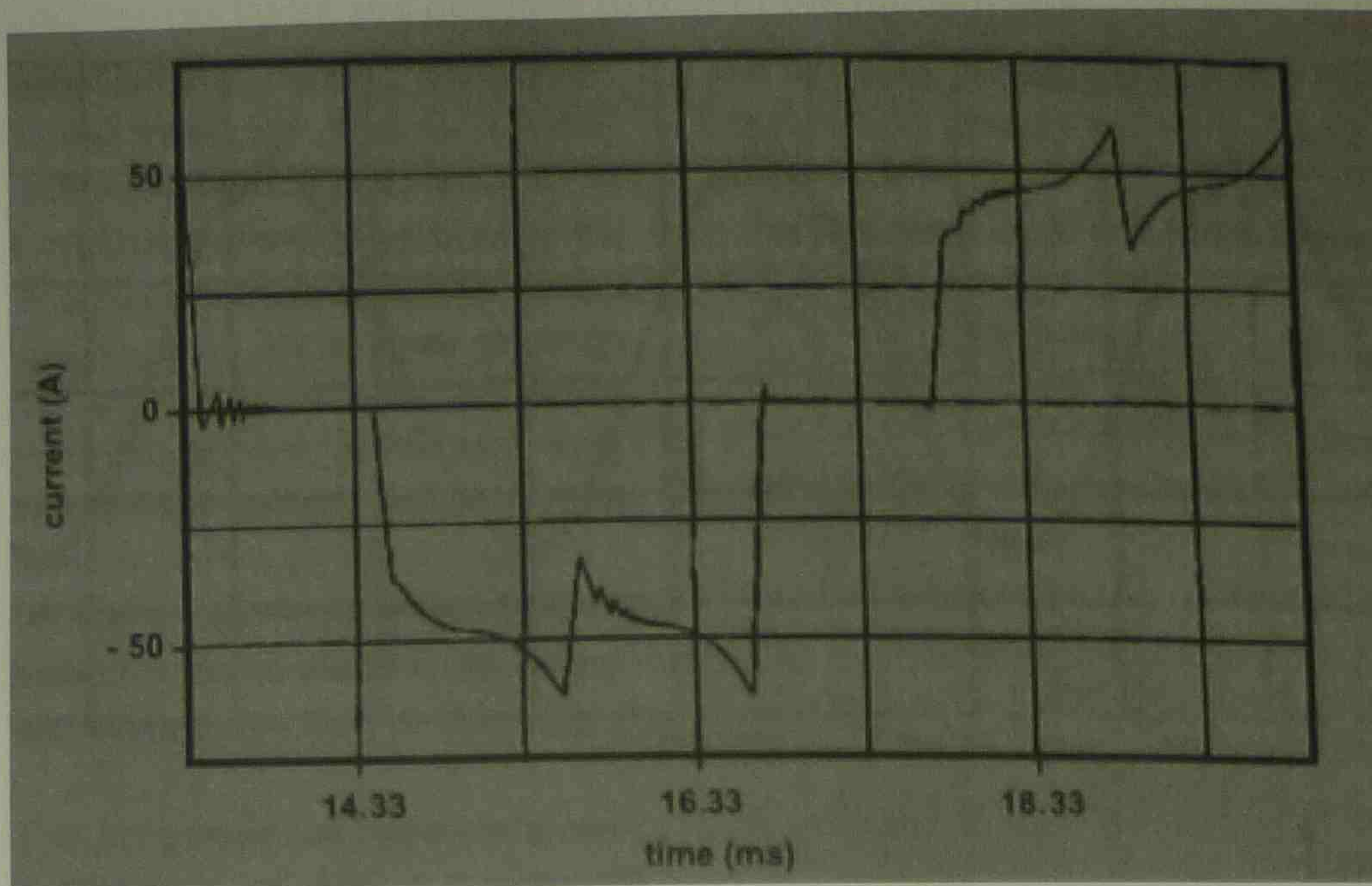
- *Notch depth:* average depth of the line voltage notch from the sinusoidal waveform at the fundamental frequency;
- *Notch width:* the duration of the commutation process;
- *Notch area:* the product of notch depth and width;
- *Notch position:* where the notch occurs on the sinusoidal waveform.

(28) Sketch (a) The measured wave shapes of 1 phase induction motor fed by thyristor/ triac controller at rated operation (b) Calculated current of brushless dc motor in full on mode at rated operation

(a)The measured wave shapes of 1 phase induction motor fed by thyristor/ triac controller at rated operation



(b) Calculated current of brushless dc motor in full on mode at rated operation.



(29) Explain (a) Sub harmonics (b) Inter harmonics (c) Positive –Negative & zero sequence harmonics (d) Time & spatial (space) harmonics.

(a) Sub Harmonics: Subharmonics have frequencies below the fundamental frequency. There are rarely subharmonics in power systems. Due to fast control of electronic power supplies of computers, inter and subharmonics are generated in the input current. Resonance between the harmonic currents or voltages with power system capacitance and inductance may cause subharmonics.

(b) Inter harmonic: The frequency of interharmonics are not integer multiples of the fundamental frequency. Interharmonics appear as discrete frequencies or as a band spectrum. Main sources of interharmonics waveforms are static frequency converters, cycloconverters, induction motors, arcing devices, and computers. Interharmonics cause flicker, low-frequency torques, additional temperature rise in induction machines and malfunctioning of protective relays.

(c) Positive –Negative & zero sequence harmonics: Assuming a positive-phase sequence balanced three-phase power system, the expressions for the fundamental current are

$$I_a(t) = I_a^{(1)} \cos(\omega_0 t)$$

$$I_b(t) = I_b^{(1)} \cos(\omega_0 t - 120^\circ)$$

$$I_c(t) = I_c^{(1)} \cos(\omega_0 t - 240^\circ)$$

The negative displacement angels indicate that the fundamental phasors rotate clockwise in the space time plane. The third harmonic phasors are in phase and have zero displacement angels between them. The third harmonic currents are known as zero-sequence harmonics.

Note that displacement angles are positive; there afore, the phase sequence of this harmonic is counter-clockwise and opposite to that of the fundamental. The fifth harmonic currents are known as negative sequence harmonics.

Similar relationships exist for other harmonic orders. Note that although the harmonic phase-shift angle has the effect of altering the shape of the composite waveform (eg., adding a third harmonic component with 0 degree phase shift to the fundamental results in a composite waveform with max peak-to-peak value whereas a 180 degree phase shift will result in a composite waveform with minimum peak-to-peak value), the phase-sequence order of the harmonics is not affected. Not all voltage and voltage and current systems can be decomposed into positive, negative and zero-sequence systems.

(d) Time & spatial (space) harmonics: Time harmonics are the harmonics in the voltage and current waveforms and electric machines and power system due to magnetic core saturation, presence of nonlinear loads, and irregular system conditions.

Spatial harmonics are referred to the harmonics in the flux linkage of rotating electromagnetic devices such as induction and syncranisces machines.

(30) Write the equations for the (a) Form factor (b) Total harmonic distortion (c) Ripple

(a) Form factor:

The form factor (FF) is a measure of the shape of the waveform and is defined as

$$FF = L_{peak} / L_{ave}$$

(b) Total harmonic distortion: The total common harmonic index used to indicate the harmonic content of a distorted waveform with a single number s the total harmonic distortion. It is measured of the effective value of the harmonic components of a distorted waveform, which is defined as the rms of the harmonics expressed in percentage of the fundamental component:

$$THD_i = \sqrt{\frac{\sum_{h=2}^{\infty} I_h^2}{I_1}}$$

(c) Ripple: The objective of this work is to investigate the ripple factor of half-wave rectifier circuits. The ripple factor is one of the important characteristics necessary when designing a power electronic converter. The ripple factor measures how much deviation the converter output parameter has, such as the output current, from its nominal designed value. In this paper the ripple factor of the output current of half-wave rectifiers is investigated. More specifically, the ripple factor of output current from more practical half-wave rectifiers that include inductive load with or without a freewheeling diode are analyzed and then compared to that of the basic half-wave rectifier consisting only of a resistive load. Derivation of the equations for the ripple factor for the three half-wave rectifier circuits is first presented. From these results, plots are generated using Pspice that will allow us to conveniently compare the ripple factor performance of each of the rectifiers

ESI 33.2 Harmonic in capacitor

(31)What are the applications of capacitors?

The application of capacitor banks in transmission and distribution systems has long been accepted as a necessary step in the design of utility power systems. Design considerations often include traditional factors such as voltage and reactive power control, power-factor correction and released capacity. More recent applications concern passive and active filtering as well as parallel and series power compensation. Capacitors are also incorporated in many PSS, FACTS, and custom power devices, as well as HVDC system.

An important application of capacitors in power systems is for power-factor correction. Poor power factor has many disadvantages:

- Degraded efficiency of distribution power systems,
- Decreased capacity of transmission, substations, and distribution systems,
- Poor voltage regulation, and
- Increased system losses.

(32) What is the first step to do harmonic analysis of capacitor?

Capacitor or frequency scanning is usually the first step in harmonic analysis for studying the impact of capacitors on system response at fundamental and harmonic frequencies. Problems with Harmonics often show up at capacitor banks first, resulting in fuse blowing and /or Capacitor failure. The main reason is that capacitors from either series or parallel resonant circuits, which magnify and distort their currents and voltages.

(33) What are the solution capacitors related problems?

There are a number of solutions to capacitor related problems.

a) Altering the system frequency response by changing capacitor sizes and/or locations

b) Altering source characteristics and

c) Designing Harmonic filters.

The last technique is probably the most effective one, because properly tuned filters can maintain the primary objective of capacitor application (e.g. power-factor correction, voltage control, and reactive power compensation) at the fundamental frequency, as well as low impedance paths at dominant harmonics.

(34) What are the disadvantages of poor power factor?

Poor Power factor has many disadvantages.

a) Degraded efficiency of distribution power system.

b) Decreased capacity of transmission, substation, and distribution systems.

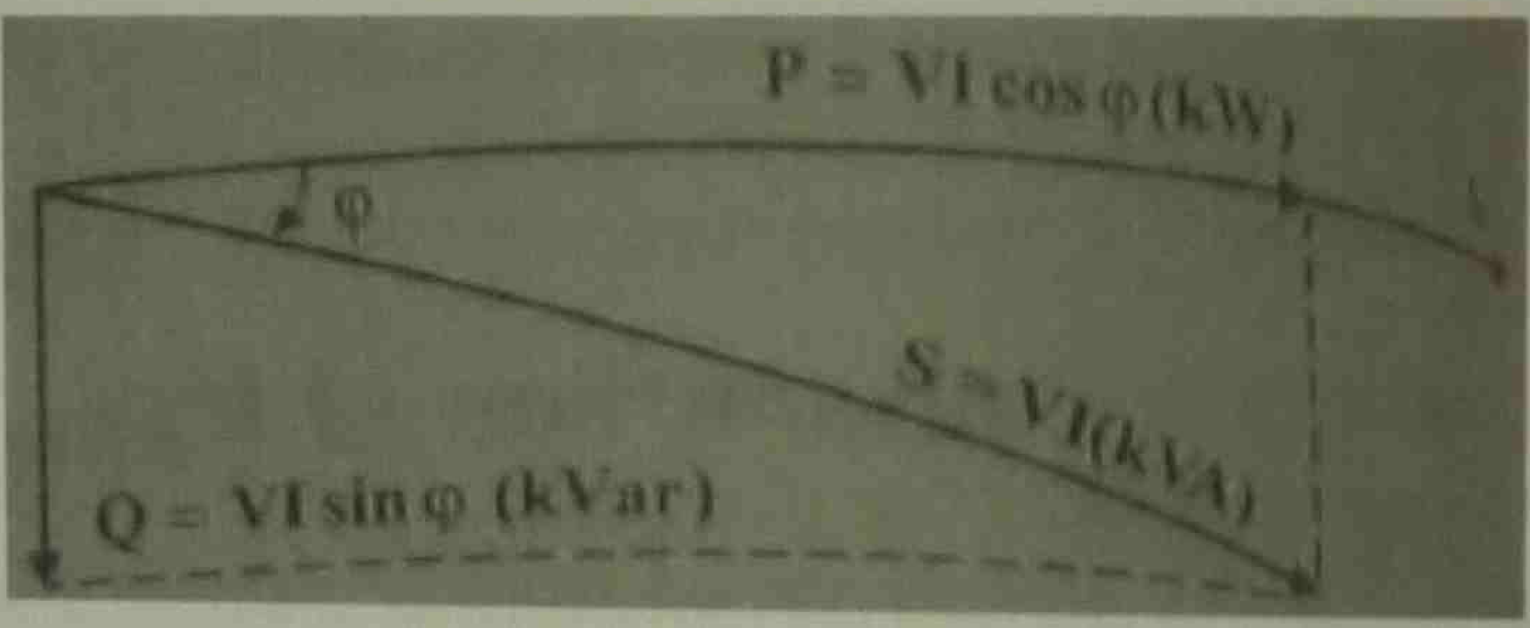
c) Poor voltage regulation and

d) Increased system losses.

(35) How will you calculate displacement power factor and total power factor?

Displacement power factor is the ratio of active or real fundamental power P (measured in W or KW) to the fundamental apparent power S (measured in VA or KVA). The reactive power Q (measured in VAr or KVAr) supplied to inductive devices is the vector difference between the real and apparent powers. The DPF is the cosine of the angle between these two quantities. It reflects how efficiently a facility uses electricity by comparing the amount of useful work that is extracted from the electrical apparent power supplied.

The relationship between S, P, Q is defined by the power triangle shown below.



S^2 = Sqrt $P^2 + Q^2$

The displacement power factor, determined from $\phi = \tan^{-1}(Q/P)$, measures the displacement angle between the fundamental components of the phase voltage and phase current.

Displacement power factor = DPF $\cos\phi = P/S$.

The DPF varies between Zero and One.

The DPF can be measured either by a direct reading Cos ϕ meter indicating an instantaneous value or by a recording VAr meter which allows recording of current voltage, and power factor over time.

<u>**Total Power Factor**</u>

The equations S^2 = Sqrt $P^2 + Q^2$ and DPF $\cos\phi = P/S$ assume that system loads have linear voltage-current characteristics and harmonic distortions are not significant. Harmonic voltage and current distortions will change the expression for the total apparent power and the total power factor (TPF).

Considering a voltage V(t) and a current i(t) expressed in terms of their rms harmonic components.

(36) Describe power quality associated with capacitors.

There are resonance effects and harmonic generation associates with capacitors installation. There are resonance effects and harmonic generation associates with capacitor installation and switching. Series and parallel resonance excitations lead to increase of voltages and currents, effects which can result in unacceptable stresses with respected to equipment installation or thermal degradation. Using joint capacitor banks for power-factor correction and reactive power compensations very well established approach. However, there is power quality problems associated with using capacitors for such as purpose, especially in the presence of harmonics.

Transients associated with capacitor switching are generally not a problem for utility equipment. However, they could cause a number of problems for the customers, including

- Voltage increases due to capacitor switching
- Transients can be magnified in a customer facility resulting in equipment damage or failure.
- Nuisance tripping or shutdown of adjustable-speed drives or other process equipment, even if the customer circuit does not employ any capacitors,
- Computer network problems, and
- Telephone and communication interference.

Improper placement and sizing of capacitor could cause parallel and series resonances and tune the system to a frequency that is excited by a harmonic source. In industrial power systems, capacitor banks are normally specified for PFE, filtering, or reactive-power compensation without regard to resonances and other harmonic concerns. High overvoltage's could result if the system is tuned to one harmonic only that is being supplied by a nonlinear load or saturated electromagnetic device such as a transformer. Moreover, the capacitive reactance is inversely proportional to frequency; therefore, harmonic currents may overload capacitors beyond their limits. Thus, capacitor banks themselves may be affected by resonance, and may fail prematurely. This may even lead to plant or feeder shutdowns.

(37) What is harmonic resonance?

Harmonics Resonance is a phenomenon which can occur in a power system. It can cause system instability or damage to electrical components such as capacitors and transformers. Harmonic resonance occurs when the inductive reactance and the capacitive reactance of the power system become equal.

(38) What is parallel resonance and series resonance?

Parallel Resonance: In a parallel-resonant circuit the inductive and the capacitive reactance impedance components are in parallel to a source of harmonic current and the resistive components of the impedances are small compared to the reactive components. The presence of a capacitor and harmonics may create such conditions and subject the system to failure. From the perspective of harmonic sources, shunt capacitor banks appear to be in parallel with the system short-circuit reactance.

Series Resonance: In a series-resonance circuit the inductive impedance of the system and the capacitive reactance of a capacitor bank are in series to a source of harmonic current. Series resonance usually occurs when capacitors are located towards the end of a feeder branch. From the harmonic sources perspective, the line impedance appears in series with the capacitor. At or close to, the resonant frequency of this series combination, its impedance will be very low. If any harmonic sources generates currents hear this resonant frequency, they will flow through the low-impedance path, causing interference in communication circuits along the resonant path, as well as excessive voltage distortion at the capacitor.

(39) Write the equations (a) Harmonic voltage constraint for capacitor (b) Harmonic current constant for capacitor (c) Harmonic reactive power constraint for capacitor

(a) Harmonic voltage constraint for capacitor: Assume harmonic voltages across the terminals of a capacitor, where V_{rms} is the terminal voltage. In the following relation h is the harmonic order of the voltage, current, and reactive power: h = 3^*, 5, 7, 9^*, 11, 13, 15^*, 17,........ We have

$$V_{rms} = \quad V_1^2 + \Sigma\, V_h^2$$

(b) Harmonic current constant for capacitor: Assume harmonic currents though the terminals of a capacitor, where I_{rms} is the total current:

$$I^2_{rms} = I^2_1 + I^2_2 + I^2_3 + \ldots\ldots$$

For sinusoidal current components I_1, I_2, I_3, ... one obtains with $\omega_1 = 2\pi f_1$

(c) Harmonic reactive power constraint for capacitor: In the presence of both voltage and current harmonics, the reactive power will also contains harmonics

$$Q = Q_1 + Q_2 + Q_3 + \ldots\ldots$$

$$= I_1V_1 + I_2V_2 + I_3V_3 + \ldots\ldots$$

$$= \omega_1 CV_1^2 + 2\omega_1 CV_2^2 + 3\omega_1 CV_3^2 + \ldots\ldots$$

$$= \omega_1 C[(V^2_{rms} - V_2^2 - V_3^2 - \ldots\ldots) + 2V_2^2 + 3V_3^2 + \ldots\ldots$$

$$= \omega_1 C[(V^2_{rms} + V_2^2 + 2V_3^2 + \ldots\ldots)]$$

$$= \omega_1 C[V^2 + \Sigma\,(h-1)V_h^2]$$

(44) How does temperature increase in transformer?

An isolation transformer's main purpose is to transfer electrical energy from the primary coil to the secondary coil (input to output). In doing this, the transformer converts some of the electrical energy into heat energy. Transformers develop heat in the same manner as light bulbs. Light bulbs have a certain amount of resistance and when a voltage is developed across the light bulb some of the energy is converted into heat. Transformers also have a resistance and when the power supplied from the transformer is increased, the amount of energy converted to heat also increases. This is where efficiency, maximum temperature rise, and insulation system temperatures are important in regards to isolation transformers

(45) How will you calculate harmonic losses and measured temperature increases of induction machines?

Measured additional temperature rises of the stator end winding and that of the squirrel-cage rotor winding at full load as a function of the harmonic voltage amplitude, phases hit and frequency for the same single-phase induction motor are depicted. Note that maximum additional temperature rises are obtained when the peak-to-peak value of the terminal voltage is a maximum as function of the superposed harmonic voltage with the fundamental voltage.

$P = 2hp$, $V_t = 115/208$ v, $I_t = 24/12$,

$f = 60H_z$, $\eta = 0.73$, $n_w = 1725$ rpm

The additional harmonic losses due to sub harmonic voltages and inter harmonics below the fundamental become very large even at low percentages and, therefore, the sub harmonic voltages must be limited to below 0.5% of the fundamental. Note that at the slip frequency which corresponds to a slip of s = 0 the total stator losses reach minimum because the total rotor losses are about zero.

(46) Explain the temperature rise of a single phase transformer due to single harmonic voltage.

Most electric appliances use eclectic motors and transformers. In all these cases the power systems sinusoidal voltage causes ohmic and iron-core losses resulting in a temperature rise, which approaches the rated temperature rise ($T_{riserat}$) continuous operation. $T_{rat} = T_{amb} + T_{riserat}$

Where $T_{amb} = 40^0C$ is the ambient temperature. His lifetime of magnetic devices is greatly dependent on this temperature rise and the lifetime will be reduced if this rated temperature rise is exceeding over may length of time.

The presence of voltage harmonics in the power systems voltage causes harmonic currents in induction motors and transformers of electrical appliances, resulting in an elevated temperature rise such that the device temperature is $T = T_{amb} + T_{riserat} + \Delta T_h$

The insulating material of electrical apertures, is used in electrical appliances, is of either organize if inorganic origin. The deterioration of the insulation caused by the elevated temperature rise is manifested by a reduction of the mechanical strength and or a change of the dielectric behavior of the insulation material. This thermal degradation is best represented by the reaction rate equation of Arrhenius. Plots which will be drawn based on this equation are called Arrhenius plots. The slopes of these plots are proportional to the activation energy and the insulation material under consideration. Knowing the rated life time of insulation materials at rated temperature and the elevated temperature rise(ΔT_h) due to given amplitudes and phase shifts $\emptyset_h$ of voltage harmonics, one will be able to estimate from the Arrhenius plot the reduction of the lifetime of electrical appliances due to ΔT_h.

(47) What is thermal aging?

The insulating material of an electric apparatus as sued in electrical appliances is of organic or inorganic origin. Due to the heating of these materials, caused by the loss within the machine, a deterioration of the insulating materials will occur. This deterioration is manifested either by

- Lowering of the mechanical strength and/or
- Changing of the dielectric behavior of the insulating material.

(48) Explain decrease of life time due to an additional temperature rise?

The slope of the Arrhenius plot based on

$$\text{Int} = \frac{\left(\frac{E}{K}\right)1}{T} + B$$

(49) What are possible limits for harmonic voltages?

The harmonic voltage spectra for a single-phase and for a three-phase feeder are proposed.

With average values of $K_{avg} = 0.85$ and $l_{avg} = 1.4$ for a single-phase induction motors, $K_{avg} = 0.95$ and $l_{avg} = 1.6$ for three-phase induction motors, $K_{avg} = 0.90$ and $l_{avg} = 1.75$ for single-phase and three-phase transformers, and $K_{avg} = 1.0$ and $l_{avg} = 1.0$ for universal machines, one obtains for the single-phase spectrum of the weighted harmonic-voltage factor.

For single Phase motors $\sum_{n=2}^{h_{max}} \frac{1}{h^k}\left[\frac{V_{PK}}{V_{P1}}\right] = 5.7$

three Phase Induction motor $\sum_{n=2}^{h_{max}} \frac{1}{h^k}\left[\frac{V_{Pn}}{V_{P1}}\right] = 5.7$

For single Phase transformer $\sum_{n=2}^{h_{max}} \frac{1}{h^k}\left[\frac{V_{Pn}}{V_{P1}}\right] = 7.37$

For three Phase transformer $\sum_{n=2}^{h_{max}} \frac{1}{h^k}\left[\frac{V_{Pn}}{V_{P1}}\right] = 7.4$

(50) Explain temperature increase of rotating machine with a step load.

An enclosed fan-cooled induction motor has a thermal time constant of $t_ø = 3h$ and a steady-state rated temperature of $ø = 120^0C$ at an ambient temperature of $ø_{amb} = 40^0C$. The motor has at time t = 0 a temperature of $ø = ø_{amb}$ and the motor is fully loaded at t = 0. Calculate the time $t_{95\%}$ when the fully loaded motor reaches 95% of its final temperature $ø_f = 120^0C$.

(51) What are the various operating modes of rotating machines & explain them in detail?

Depending on their application, rotating machines can be subjected to various operating modes such as steady-state, short-term, steady-state with short term, intermittent, and steady-state with intermittent operating modes.

Steady-State Operation: Steady-state temperature is reached when the operating time of the machine t_{oper} is large as compared with the time constant $t_ø$ of the machine. This is,

$$t_{oper} \geq (3\text{-}4)\ t_ø$$

According to experience the thermal time constant for openly ventilated machines is

$$t_ø = 1h$$

and for enclosed but ventilated machines

$$t_ø = (3\text{-}4)\ h$$

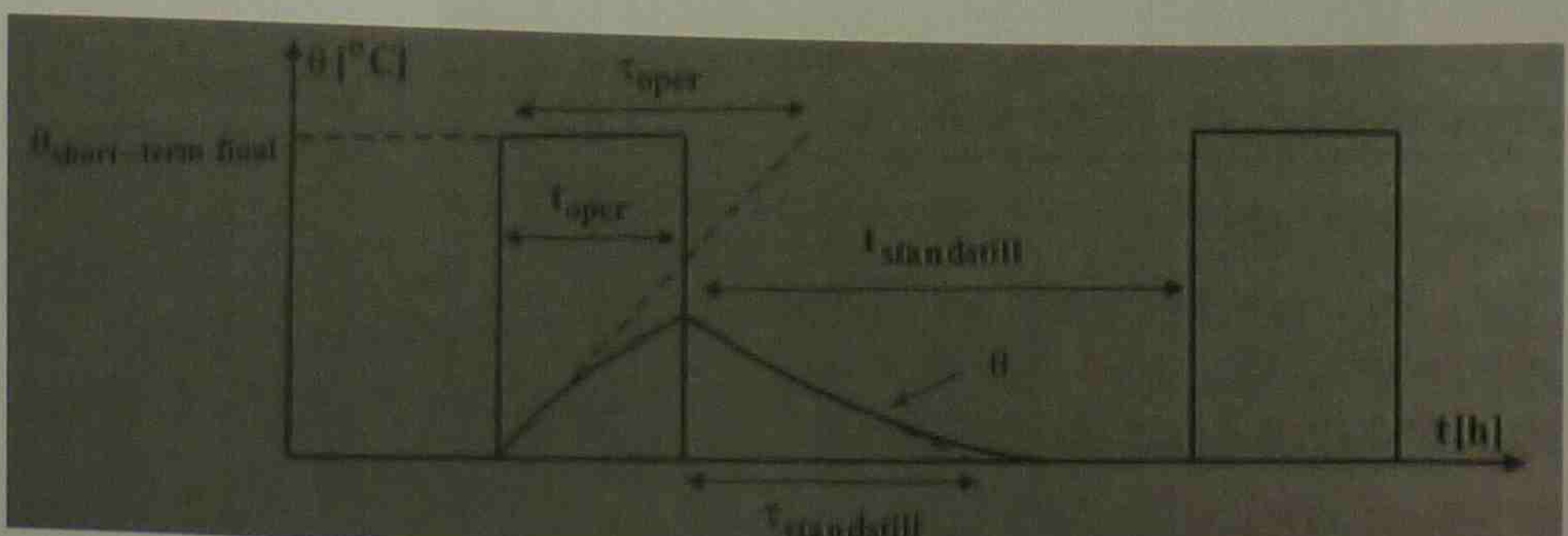
During steady-state operation the rated output power mist be delivered by the machine.

Short-Term Operation: For short-term operation one assumes that the machine cools down to the ambient temperature and its temperature rises is $ø_0 = 0$, illustrates the transient temperature of this operating mode.

The absence of any ventilation during standstill requires that the time constant during standstill be longer than that during operation, that is, $t_{standstill} > t_{oper}$. For short-term operation the times t_{oper} and $t_{standstill}$ must related to the time constants as follows:

$$t_{oper} < (3\text{-}4)\ t_{oper}$$

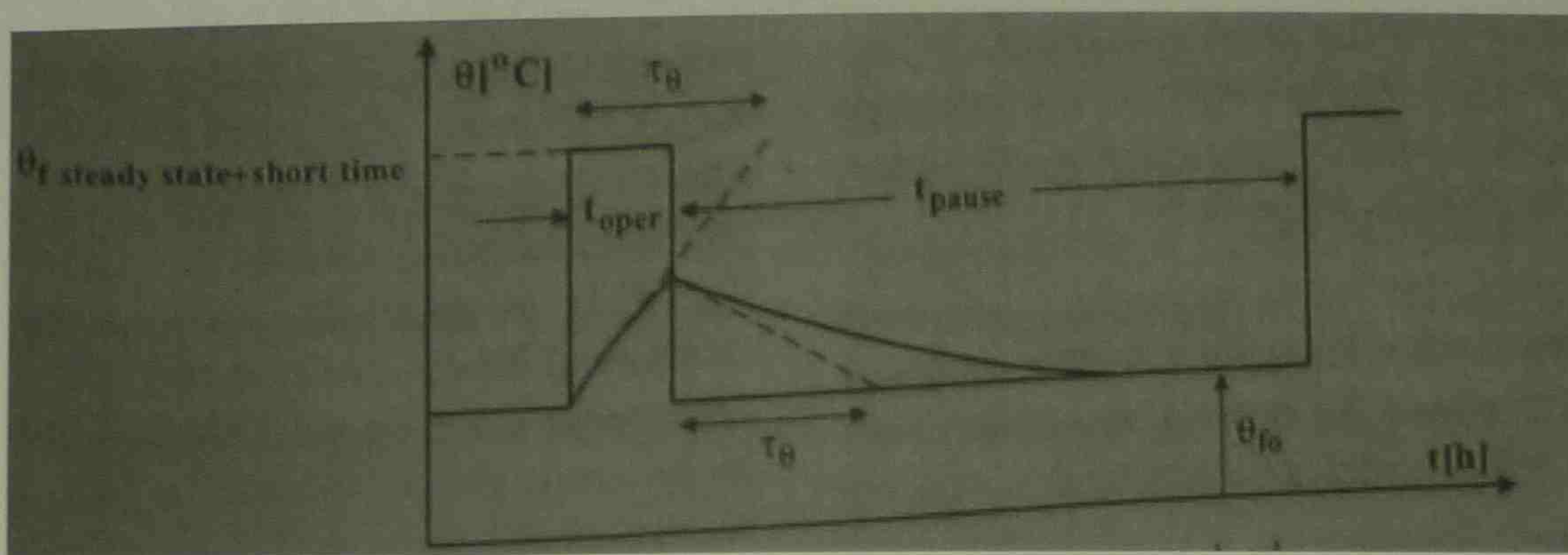
$$t_{standstill} < (3\text{-}4)\ t_{standstill}$$



Steady State with Short Term Operation: In this case the short term load is superposed with steady-state load. The operating time t_{oper} and the pause time t_{pause} relate to the time constant as follows:

$t_{oper} < (3\text{-}4)$

$t_{pause} > (3\text{-}4)$

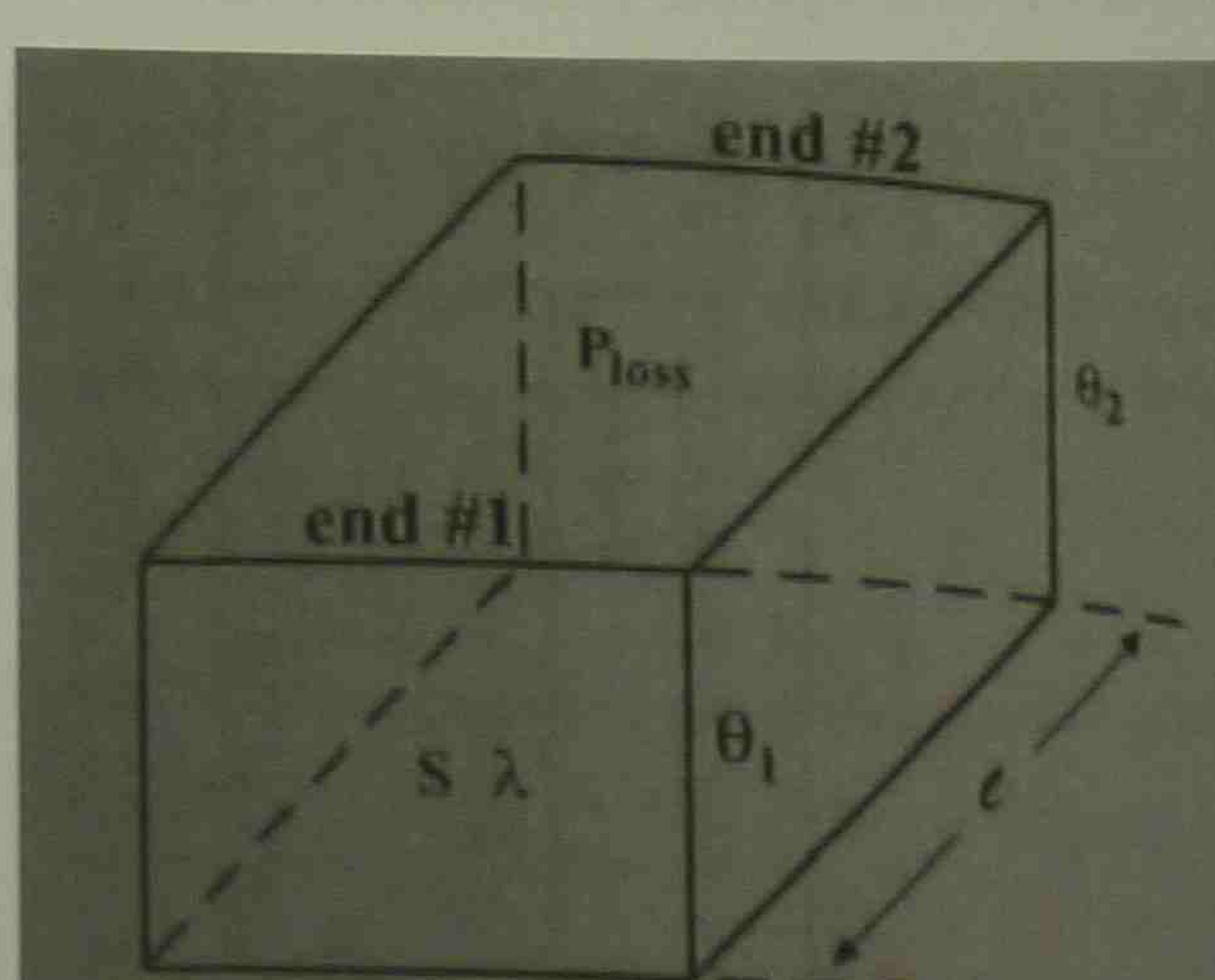


(52) How can you reduce vibration and torque pulsations in electric machines?

Vibrations and torque pulsations generate electromagnetic forces that mainly act on the end turns of stator windings. As it is well known the turns residing in the stator slots are not exposed to high magnetic fields and for this reason the magnetic forces acting on the turns within the slots are relatively small. Besides increased temperatures, vibrations and torque pulsations area major reason for the deterioration of the insulation materials. Vibrations and pulsating torques can have their origin in motor asymmetries and loads. For this reason it will be important to demonstrate how torque pulsations caused by loads can be reduced to an acceptable level.

(53)Calculate steady state temperature rise ΔT at electric apparatus based on thermal network.

The losses of an electric apparatus heat up various parts of the apparatus, and the losses are dissipated via heat conduction, convection, and radiation.



Where λ is the thermal conductivity of a homogeneous body measured in [W/m^{0}C], *S* is the surface of the homogeneous body perpendicular to the heat flow measured in m^2, and the length of the homogeneous body along the direction of the heat flow measured in *m*.

The temperature at end # 1 $ø_1$ is given by equation

$\Delta T = (ø_2 - ø_1) = \lambda.S\ P_{loss} = R_{conduct}\ P_{loss}$

The heat conduction resistance $R_{conduct} = \ / \lambda.S$

ESI 33.4 Harmonic in synchronous machines

(54) What are power quality problems of synchronous machines?

Power quality problems of synchronous machines can be of the following types due to abnormal operation:

- Unbalanced load,
- Torques during faults such as short-circuits, out-of-phase synchronization, unbalanced line voltages, reclosing,
- Winding forces during abnormal operation and faults,
- Excessive saturation of iron cores,
- Excessive saturation of iron cores,
- Excessive voltage and current harmonics,
- Harmonics torques,
- Mechanical vibrations and hunting,
- Static and dynamic rotor eccentricities,
- Bearing currents and shaft fluxes,
- Insulation stress due to nonlinear sources and loads,
- Dynamic instability when connected to weak systems and
- Premature aging of insulation material caused by cyclic operating modes as experienced by machines, for example, in pumped-storage and wind-power plants.

(55) Write electrical equation of a synchronous machine.

Based on the stator and rotor equivalent circuits, voltage equations can be obtained in terms of flux linkages and winding resistances. According to Faraday's and Kirchhoff's laws

$$V = Ri + d\psi / dt$$

Neglecting saturation the flux linkages are proportional to the current thus

$$\Psi = Li$$

The differential equation $d\psi / dt = v - RL^{-1}\Psi$

However, it is required to take into account the interaction between self and mutual inductances of the windings residing on the stator and rotor members. Thus, a set of different equations can be written in matrix form for the stator and rotor circuits as

$$V_{abc} = R_s i_{abc} + P\Psi_{abc}$$

$$V_{fdq} = R_R i_{fdq} + P\Psi_{fdq}$$

(56) Write mechanical equation of a synchronous machine.

The second-order mechanical equation of a synchronous machine can be decomposed into two first order differential equations: one for the mechanical

The mechanical equation is

$$T_e - T_L = \left(\frac{J}{p}\right)\frac{d\omega}{dt} + \left(\frac{f}{p}\right)\omega \qquad (3)$$

With

$$T_e = p(\phi_d i_q - \phi_q i_d) = p[\phi_f i_q + (L_d - L_q) i_d i_q] \qquad (4)$$

Where f is the damping torque coefficient, J is the moment of the rotor inertia, T_L is the load torque and p is the number of pole pairs.

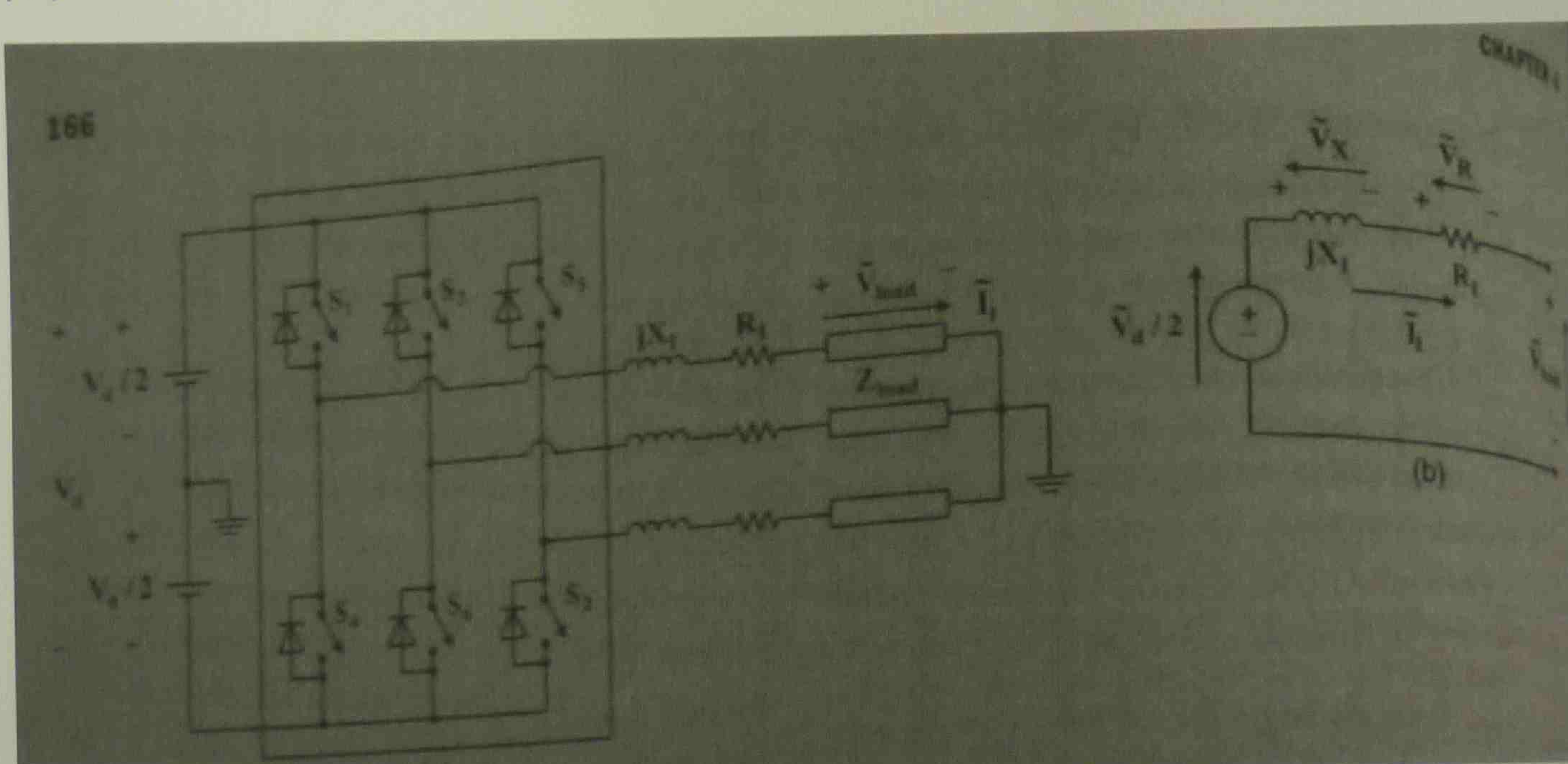
(57) Identify similarities between synchronous machine and PWM current controlled / voltage source inverter.

Inverters are electric devices transforming voltages and currents from a DC sources to an equivalent AC source. Illustrates the actual circuit of an inverter, where the input voltage is a DC voltage V_d and the output voltage is an AC voltage V_{load}. It is assumed that the PWM switching is lossless. The DC voltage $(V_d/2)$ is transformed to the AC side and represented by the phasor $(V_d/2)$, which makes the circuit similar to that of a round-rotor synchronous machine, as depicted. The relation between the output voltage $|V_{load}|$ of the inverter and the input voltage $V_d/2$.

$$\left|\tilde{V}_{\text{load}}\right| = m \cdot \frac{(V_d/2)}{\sqrt{2}},$$

Where $m \leq 1$ is the modulation index of the PWM. This relation appears to hold for operation around unity displacement factor only. In these references it is shown that at lagging displacement power factor a much higher input voltage V_d is sufficient. For example, although for unity displacement factor $V_{d\_unity\_pf}$ = 400 V is acceptable, a much higher input voltage, e.g., $V_{d\_unity\_pf}$ = 600 V is required for displacement factors larger than cos ø = 0.8 lagging at V_{load} = 139 V.

(58)Draw a phasor diagram of a salient pole synchronous machine.



(59) Explain the (a) Synchronous machine supplying non linear load (b) Switched reluctance machine suppling Iron core stacking factor and copper fill factor

(a) Synchronous machine supplying non linear load:

Synchronous machines or permanent magnet machines are used together with solid-state converters, that is, either rectifiers as a load or inverters feeding the machine. The question arises how much current distortion can be permitted in order to prevent noise and vibration as well as overheating? It is recommended to limit the total harmonic current distortion of the phase current to THD ≤ 5-20%. The 5% limit is for very large machines and the 20% limit is for small machines. The calculation of the synchronous, transient, and sub transient reactance's based on numerical field calculation.

Synchronous machines up t 5 MW are sued in variable-speed drives for wind-power plants. Enercon uses synchronous generators with a large pole number; this enables them to avoid any mechanical gear within the wind-power train. The AC output is rectified and an inverter supplies the wind power to the grid. Hydro generators are another example where a large number of poles are used.

b) Switched reluctance machine supplying Iron core stacking factor and copper fill factor:

Switched-reluctance machines have the advantage of simplicity: such machines consist of a salient pole rotor member without any winding and the stator member carries concentrated coils that are excited by a solid-state converter. The only disadvantages of such machines are the encoder required to sense the speed of the rotor and the acoustic noise emanating form the salient-pole rotor. The windage losses of such machines can be considerable.

The iron-core stacking factor depends on the lamination thicknesses. An approximate value for most commonly used designs is K_{fc} = 0.95. The copper-fill factor depends on the winding cross section and the wire diameter. An approximate value for most commonly used designs is K_{cu} = 0.70.

(60) Explain harmonic modeling of synchronous machine.

A machine model in phase coordinates can naturally reproduce these abnormal operation conditions because it is based on a realistic representation that an take into account the explicit time-varying nature of the stator and the mutual stator-rotor inductances, as well as the spatial harmonic effects. Harmonic modeling of synchronous machines is complicated by the following factors.

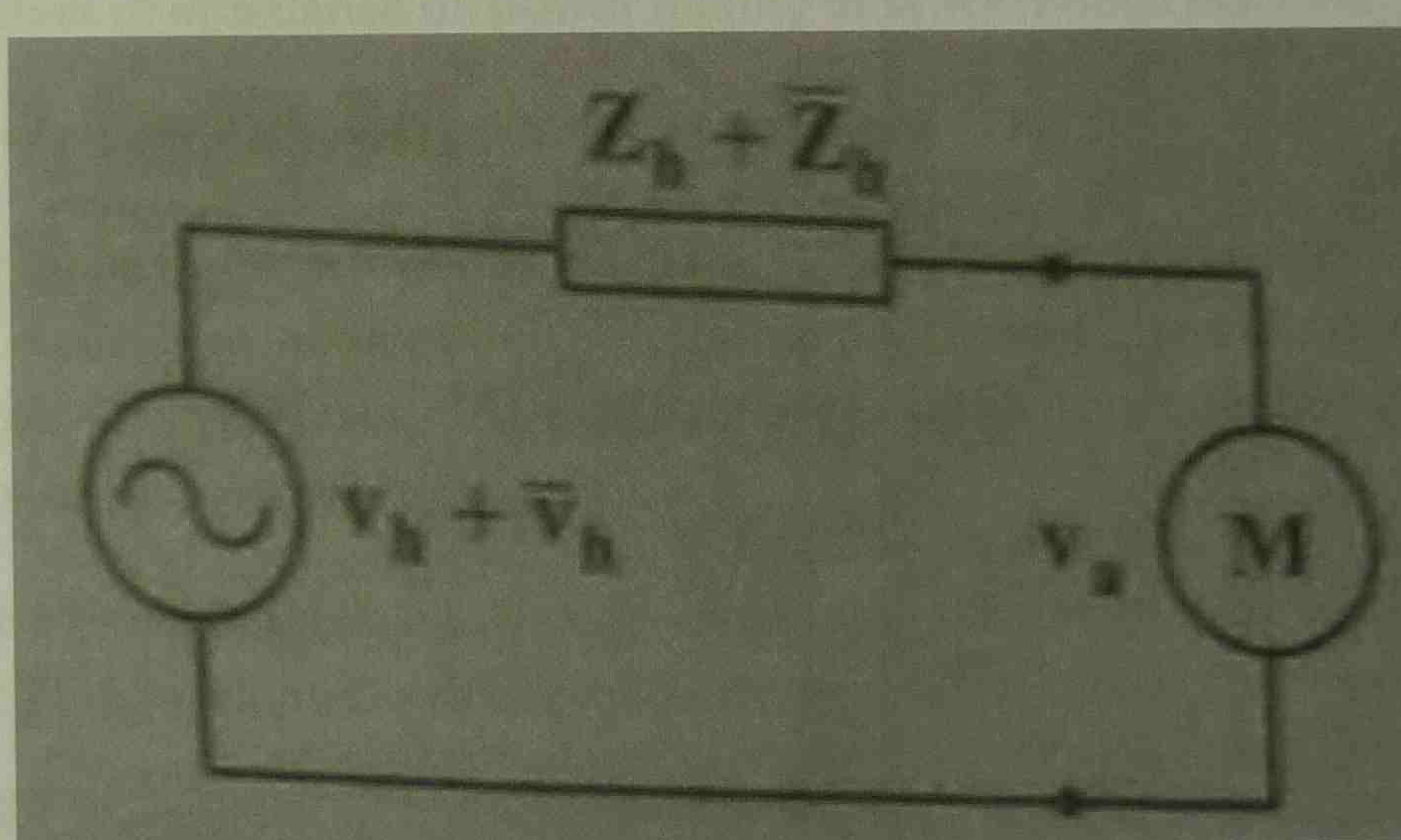
- ***Frequency-conversion process:*** Synchronous machines may experience a negative-sequence current in their armature, e.g., under unbalanced three=phase conditions. This current may induce a second-order harmonic of this negative-sequence armature current in the rotor. The rotor harmonic in turn may induce a third-order harmonic of this negative-sequence current in the armature, and so on. This frequency conversion causes the machine itself to internally generate harmonics, and therefore complicates the machine's reaction to external harmonics imposed by power sources.
- ***Saturation Effects:*** Saturation affects the machine's operating point. Saturation effects interact with the frequency-conversion process and cause a cross-coupling between the *d*- and *q*-axes.

- ***Machine Load Flow Constraints:*** Synchronous machine harmonic models are incorporated into harmonic load flow programs and must satisfy constraints imposed by the load flow program.
- ***Inverter-Fed or Rectifier-Loaded Machines:*** Hybrid automobile drives that predominantly are based on brushless DC machines, wind-power application, and rotating rectifiers for synchronous generators.

(61) Explain the behaviors of synchronous machine fed by a combination of harmonic voltage and the current source.

When a synchronous machine is subjected to a harmonic voltage disturbance at frequency $h\omega$, harmonic-current components are drawn at $h\omega$ and at the associated frequency $(h \pm 2)\ \omega$. The upper sign applies to the positive and the lower sign to the negative-phase sequence. Current flow at the associated frequency occurs because the machine is a time-varying electrical system. In a similar manner, a synchronous machine fed by harmonic currents at frequency $h\omega$ develops a voltage across its terminal at both the applied and the associated frequency $(h \pm 2)\ \omega$. Consequently the machine cannot be model by impedance defined by a single harmonic frequency.

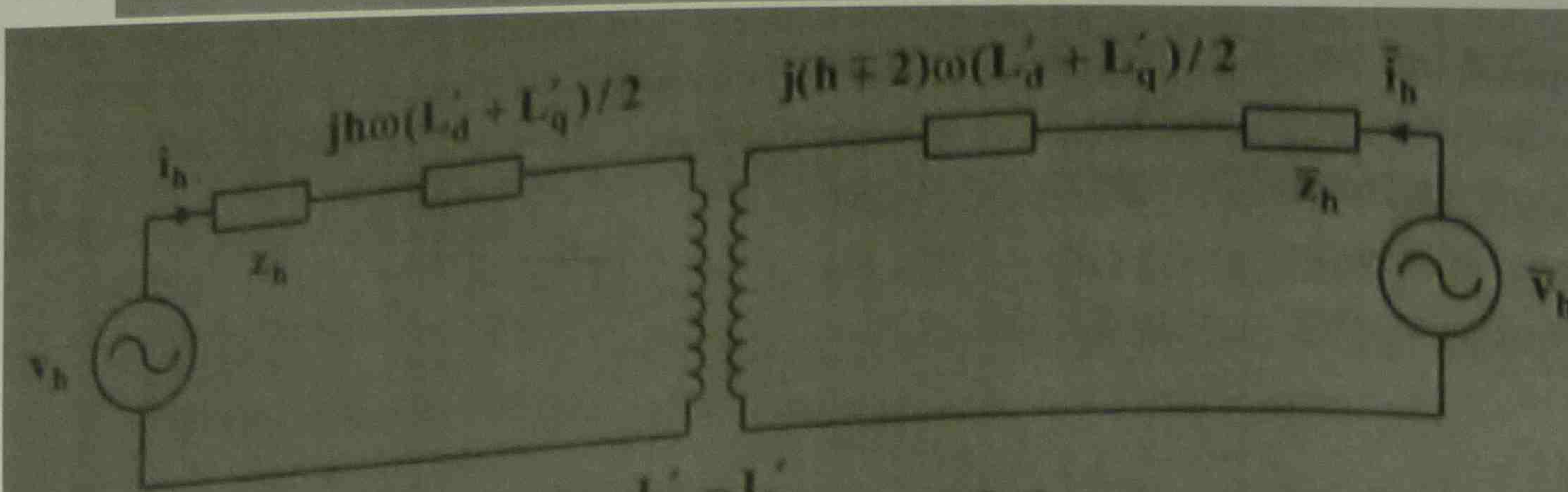
In general case, a machine will be subjected to applied voltages V_h and V_h via system impedances Z_h and Z_h as shown. The applied harmonic voltage V_h and V_h are assumed to have opposite phase sequences: one is of positive and the other of negative sequence. This is the condition that would apply if the distorting load responsible for the harmonic disturbance drew balanced currents.



Consequently, a single-phase model may be used. Voltage equations for the general case are obtained by applying a voltage mesh equation at both frequencies $h\omega$ and $(h \pm 2)\ \omega$. The voltage components applying across the machine are those given in response to the currents given. The interaction between the two sides of the circuit is represented by a mutual inductance, which is a simplification. This mutual inductance is nonreciprocal, and the frequency difference between the two sides is ignored.

The results presented here show that a synchronous machine cannot be modeled by one impedance if voltage sources have voltage components with several frequencies. IN the case where one harmonic voltage source is large and the other small then $V_h = 0$, and the apparent machine impedance to current flow is linear and time-varying.

$$Z_h = \frac{jh\omega(L_d' + L_q')}{2} + \frac{(h \mp 2)h\omega^2\left(\frac{L_d' - L_q'}{2}\right)^2}{\xi_h}.$$



$$M_{12} = jh\omega\left(\frac{L_d' - L_q'}{2}\right)\exp j(\pm 2\alpha)$$

$$M_{21} = j(h \mp 2)\omega\left(\frac{L_d' - L_q'}{2}\right)\exp j(\mp 2\alpha)$$

(62) Explain the followings (a) Effect of imbalance on power quality of synchronous machine

(b) Effect of delta connection on power quality of synchronous machine.

a) Effect of imbalance on power quality of synchronous machine: This section introduces a synchronous machine harmonic model that incorporated both frequency conversions and saturation effects under various machine load-flow constraints. The model resides in the frequency domain and can easily be incorporated into harmonic load-flow programs.

To model these effects and also to maintain an equivalent –circuit representation, a three-phase harmonic Norton equivalent circuit is developed with the following equations:

$$[I_{km}(h)] = [Y(h)]([V_k(h)] - [V_m(h)] - [E(h)]) + [I_{nl}(h)], \qquad (4\text{-}51a)$$

$$[E_{(h)}] = 0, \text{ if } h \neq 1$$

$$[I_{km}] = [I_{km-a} \quad I_{km-b} \quad I_{km-c}]^T$$

$$[V_k] = [V_{k-a} \quad V_{k-b} \quad V_{k-c}]^T$$

ESI 33.5 Harmonic in transformer

(66) Explain de-rating of transformer.

Rerating is defined as "the intentional reduction of stress/strength ratio in the application of an item, usually for the purpose of reducing the occurrence of stress-related failure (e.g., reduction of lifetime of transformer due to increased temperature beyond rated temperature)." Harmonic currents and voltages result in harmonic losses increasing the temperature rise. The rise beond its rated value results in a reduction of lifetime. For transformers two derating parameters can be defined:

- Reduction in apparent power rating (RAPR), and
- Real power capability (RPC).

Although the first one is independent of the power factor, the second one is strongly influenced by it.

(67) Describe sinusoidal (linear) modeling of transformer.

Transformer simulation under sinusoidal operating conditions is a well-researched subject and many steady-state and transient models are available. However, transformer cores are made of ferromagnetic materials with nonlinear B-H (λ-i) characteristics. They exhibit three types of nonlinearities that complicate their analysis: saturation effect, hysteresis loops, and eddy currents. These phenomena result in no sinusoidal flux, voltage and current waveforms on primary and secondary sides, and additional copper and core losses at fundamental and harmonic frequencies. Linear techniques for transformer modeling neglect these nonlinearities and sue constant values for the magnetizing inductance and the core-loss resistance. Some more complicated models assume nonlinear dependencies of hysteresis and eddy-current losses with fundamental voltage magnitude and frequency, and use a more accurate equivalent value for the core-loss resistance. Generally, transformer total core losses can be approximated as

$$P_{fc} = P_{hys} + P_{eddy} = K_{hys} (B_{max})^{\gamma} f + K_{eddy} (B_{max})^{2} f^{2}, \quad (2\text{-}1)$$

Where P_{hys}, P_{eddy}, B_{max} and f are hysteresis losses, eddy-current losses, maximum value of flux density, and fundamental frequency, respectively. K_{hys} is a constant for the grade of iron employed and K_{eddy} is the eddy-current constant for the conductive material. *S* is the Steinmetz exponent ranging from 1.5 to 2.5 depending on the operating point of transformer core.

ESI 33.6 Power quality improvement of capacitor bank

(68)What are the benefits of reactive power compensation?

Shunt capacitors applied at the receiving end of a power system feeder supplying a load at lagging power factor have several benefits, which may be the reason for their extensive applications. This section highlights some advantages of reactive power compensation.

- ***Improve Voltage Profile***: Highly utilized feeders with high reactive power demands have poor voltage profiles and experience large voltage variations when loading levels change significantly.

In a power system it is desirable to regulate bus voltages within a narrow range and to have a balanced load on all three phases. However, loads of the power system fluctuate and can result in voltage deviations beyond their acceptable limits. In view of the fact that the internal impedance of the AC system is mainly inductive, it is the reactive power change of the load that has the most adverse effect on voltage regulation.

- ***Released Power System Capacity***: When capacitors are placed in a power system, they deliver reactive power and furnish magnetizing current for motors, transformers, and other electromagnetic devices. This increases the power factor and it means that for a lower current level higher real power utilization occurs. Therefore, capacitor banks can be used to reduce overloading or permit additional load to be added to the existing system.
- ***Increased Plant Ratings***: Another undesirable effect of a network with poor power factor is a possible reduction in plant rating. This is often noticeable when transformer ratings are limited by overvoltage available from tapping. Correcting power factor to unity at the zone substation will maximize the real-power rating of transformers by providing access to thermal emergency ratings.
- ***Capital Deferment***: As ratings are based on apparent power rather than active power, reduced apparent power utilization reduces operating risks and can therefore defer expenditure related to the network expansion. This deferment can be applied from the distribution feeder, back to the zone substation, sub-transmission, terminal station, transmission network, and generation.

(69) What are the draw backs of reactive power compensation?

Although capacitor banks can undoubtedly provide many benefits to a power system, there are several situations where they can cause deterioration of power system. They may result in power quality problems, and in damage of connected equipment. In some situations, capacitors banks themselves may also become victims of unfortunate circumstances. Optimal placement and sizing of shunt capacitor banks will prevent most of these problems. This section highlights come draw backs of reactive power compensation.

- ***Resonance***: Resonance is the condition where the capacitive and inductive reactances of a system cancel each other, thus leaving the resistive elements in the system as the only form of impedance. The frequency at which this offsetting effect takes place is called the resonant frequency of the system. Resonance conditions will cause unacceptable high currents and overvoltage's to occur with the potential to damage not only the installed capacitor but also other equipment operating on the system. In case of resonance large power losses could be experienced by the system.
- ***Harmonic Resonance***: If the resonant frequency happens to coincide with one generated by a harmonic source then voltages and currents will increase disproportionately, causing damage to capacitors and other electrical equipment. Harmonic resonance may cause capacitor failure due to harmonic overvoltage's and over currents.
- ***Magnification of Capacitor-Switching Transients***: Capacitor-switching transients typically occur when a large capacitor on the high-voltage side of the power system is energized. This results in

magnification of transients at low-voltage capacitors. The magnified transient at a low-voltage remote end can reach up to 400% of its rated values.

- ***Overvoltages***: The voltages of a power system are often maintained within a specified upper and lower limit of the rated value. Capacitors, especially switched types, can cause overvoltage problems by increasing the voltage beyond its maximum desired value. This causes complications in the power system and can damage and deteriorate the system.

(70) Explain optimal placement and sizing of shunt capacitor bank in the presence of harmonics.

The problem of shunt capacitor allocation in distribution networks for reactive power compensation, voltage regulation, power factor correction, and power or energy loss reduction. Optimal capacitor bank placement is a well-researched subject. However, limited attention is given to this problem in the presence of voltage and current harmonics.

With the increasing application of nonlinear loads and devices casing voltage and current harmonics in distribution networks, special attention should be given to placement and sizing of capacitors in such systems with no sinusoidal voltages and currents. If capacitor banks are not properly sized and placed in such a power system, they may cause various operational and power quality problems:

- Amplification and propagation of current and voltage harmonics,
- Deterioration of power quality to unacceptable levels,
- Increased losses at fundamental and harmonic frequencies,
- Extensive reactive power demand and overvoltage's at fundamental and harmonic frequencies,
- Decreased capacities of distribution lines and transformers,
- Poor power-factor conditions, and
- Harmonic parallel resonances.

Proposed solution techniques for the capacitor allocation problem in the presence of harmonics can be classified into following categories:

- Exhaustive search
- Local variations
- Mixed integer-nonlinear programming
- Heuristic methods
- Maximum sensitivities selection
- Fuzzy set theory
- Genetic algorithms
- Genetic algorithm with fuzzy logic.

Most of these techniques are fast, but they suffer from the inability of escape local optimal solutions.

ESI 33.7 Power quality improvement of filter

(71) Why are the filters utilized in power system?

The implementation of harmonic filters has become an essential element of electric power networks. With the advancements in technology and significant improvements of power electronic devices, utilities are continually pressured to provide high-quality and reliable energy. Power electronic devices such as computers, printers, fax machines, fluorescent lighting, and most other office equipment generate harmonics. These types of devices are commonly classified as nonlinear loads. These loads create harmonics by drawing current in short pulses rather than in a sinusoidal manner.

Harmonic currents and the associated harmonic powers must be supplied from the utility system. The major issues associated with the supply of harmonics to nonlinear loads are severe overheating: increased operating temperatures of generators and transformers degrade the insulation material of their windings. If this heating were continued to the point at which the insulation fails, a flashover would occur. This would partially or permanently damage the device and result in loss of generation or transmission that could cause blackouts.

The installation of active filters proves indispensable for solving power quality problems in distribution networks such as the compensation of harmonic current and voltage, reactive power, voltage sags, voltage flicker, and negative-phase sequence currents. Ultimately, this would ensure a system with increased reliability and better power quality.

(72) Explain the classification of filters employed in power system.

Filters are capable of compensating harmonics of nonlinear loads through current-based compensation. They can also improve the quality of the AC supply, for example, compensating voltage harmonics sags, swell, notches, spikes, flickers, and imbalances through voltage-based techniques.

Classifications of filters may be performed based on various criteria, including the following:

- Number and type of elements
- Topology
- Supply system
- Type of nonlinear load such as current-source and voltage-source loads,
- Power rating
- Compensated variable
- Converter type
- Control technique
- Reference estimation technique

The choice of filter depends on the nature of the power quality problem, the required level and speed of compensation, as well as the economic cost associated with its implementation.

(73) Describe passive filters used in power system.

If a nonlinear load is locally causing significant harmonic distortion, passive filters may be installed to prevent the harmonic currents from being injected in to the system. Passive filters are inexpensive compared with most other mitigating devices. They are composed of only passive elements tuned to the harmonic frequencies of the currents or voltages that must be attenuated. Passive filters have better performances when they are placed close to the harmonic producing nonlinear loads.

They create a sharp parallel resonance at a frequency below the notch frequency. The resonant frequency of the power system must be carefully placed far from any significant harmonic distortion caused by the nonlinear load. Passive filters should be tuned slightly lower than harmonic to be attenuated. This will provide a margin of safety in case there is some change in the system parameters.

(74) Explain common types of passive filters for power quality improvement.

The configuration of a filter depends on the frequency spectrum and nature of the distortion.

The first-order damped and undamped high-pass filter is used to attenuate high-frequency current harmonics that cause telephone interference reduce voltage notching caused by commutation of SCRs, and provide partial displacement power factor correction of the fundamental load current. The single tuned low-pass is most commonly applied for mitigation of a single dominant low-order damped high-pass filter. Most nonlinear loads and devices generate more than one harmonic, however, and one filter is not usually adequate of effectively compensate, mitigate, or reduce all harmonics within the power system. There are different approaches to overcome this problem.

One approach is to use two single-tuned filters with identical characteristics to form a double band pass filter. In practice, there is more than one dominant low-order harmonic and combinations of three or more single-tuned filters are applied. Starting with the lowest harmonic order each filter is tuned to one harmonic frequency. This approach is not practical when the number of dominant low-order harmonics is large and higher order harmonics are present.

Another approach is to use a first-order high-pass filter or second-order high-pass filter and set the resonant frequency below the lowest order dominant harmonic frequency. The third and most implemented approach is to install a composite filter consisting of two or more branches of band-pass filter tuned at low-order harmonic frequencies and a parallel branch of high-pass filter tuned a higher frequencies. This configuration is suitable for most residential, domestic and industrial nonlinear loads such as are furnaces.

(75) Describe (a) First order damped high pass filter (b) Second order band pass filter (c) Composite filter

(a) First order damped high pass filter: A series connected resistance(R_1) is included to provide a damping characteristic.

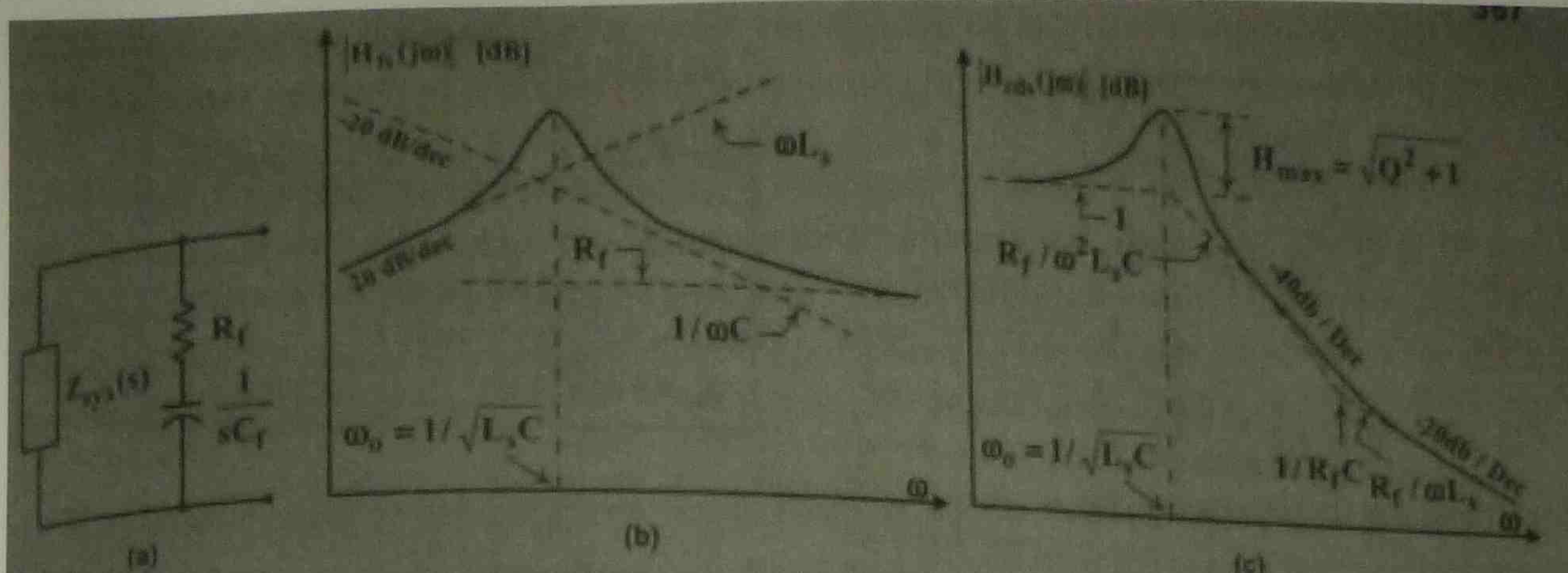
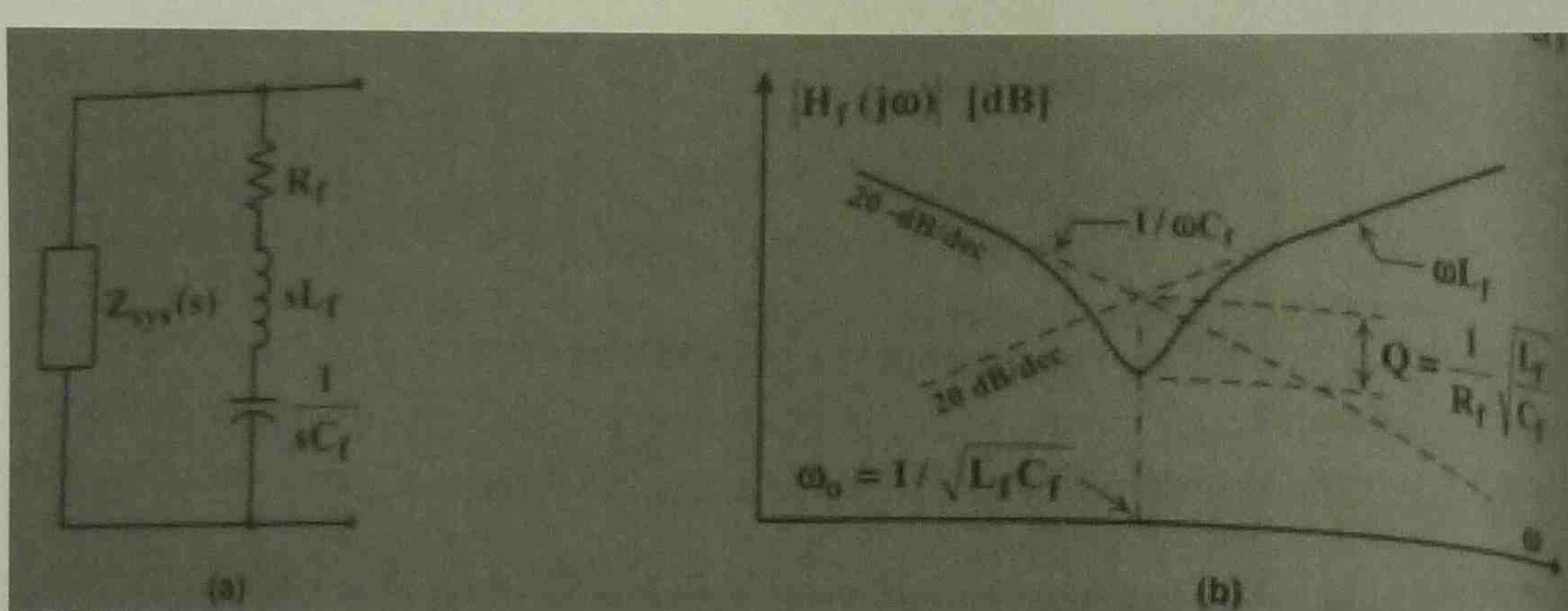


FIGURE 9.7 First-order damped high-pass filter: (a) equivalent circuit, (b) filter impedance transfer function, (c) current-divider transfer function.

The damping resistance significantly limits the high-frequency performance. Therefore, the damped filter is less desirable for telephone interference reduction applications.

For parallel resonant conditions, if the resonant frequency, a high-pass damping resistance (R_1) can be used to control and reduce the amplification. However, this will increase the fundamental frequency power loss and reduces the effectiveness of the high-pass attenuation above the frequency $1/(R_1C_1)$.

(b) Second order band pass filter: The second-order band-pass filter (also called single-tuned or series-resonant filter) is a series combination of capacitor (C_1), inductor (L_1), and a small damping resistor (R_1), as depicted. The damping resistance is usually due to the internal resistance of either the inductor or capacitor. This filter is tuned to attenuate one single low-order harmonic. Typically, combinations of band-pass filters are used because the power system contains a number of dominant low-order harmonics.



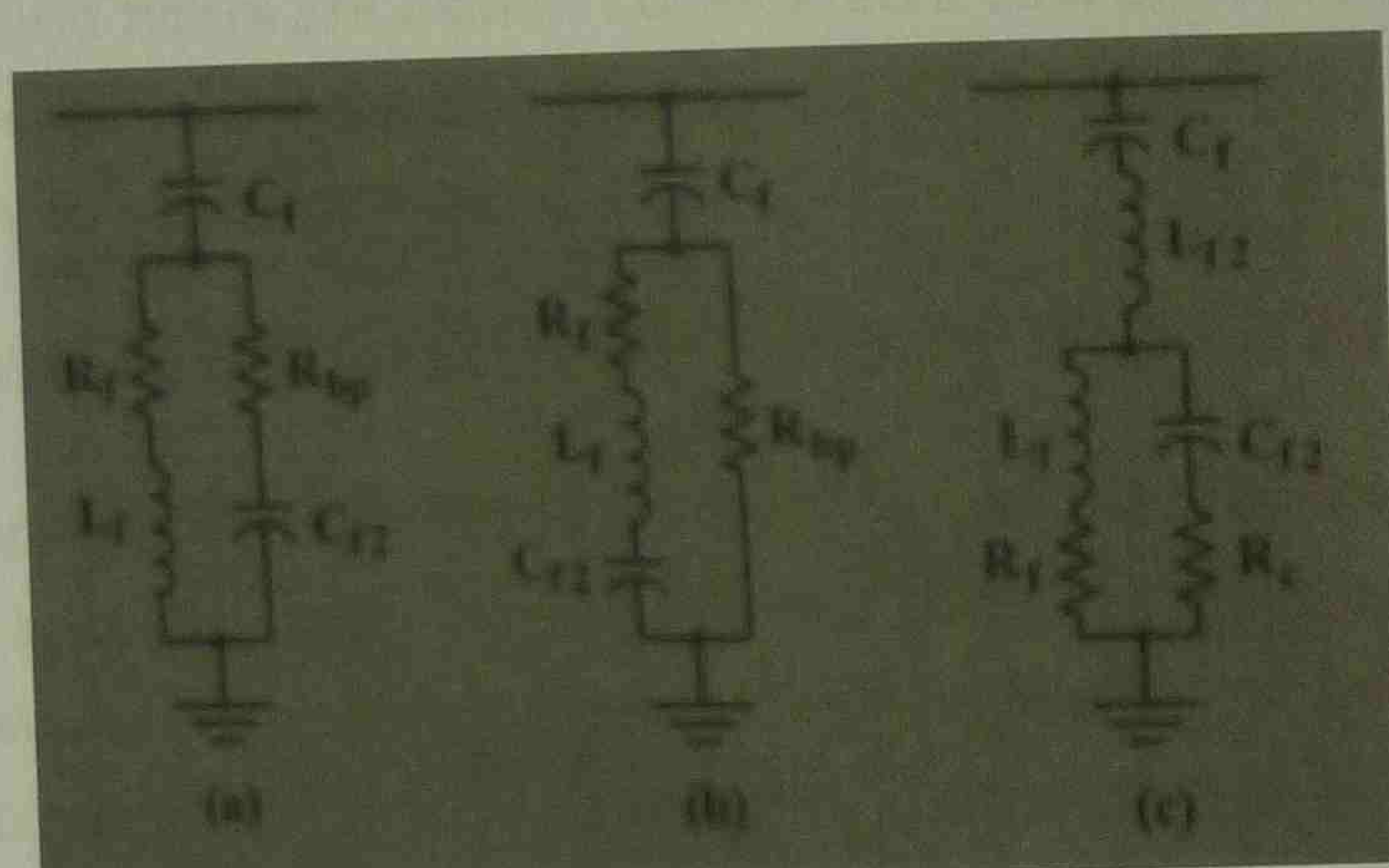
For high-voltage applications, the filter current has a low rms magnitude and does not require large current carrying conductors; therefore, air-core inductors are regularly used and the filter quality factor is relatively large. For low voltage applications, gapped iron-core inductors and conductors with a large cross section are employed.

The second-order band-pass filters are very popular and have many applications in power system design including transmission, distribution and utilization.

(c) Composite filter: Higher order filters are constructed by increasing the number of storage elements. However, their application in power systems is limited due to economic and reliability.

A third-order filter may be constructed by adding a series capacitance C_{12} to the inductor bypass resistance to limit I_{bp} and reduce the corresponding fundamental frequency losses or by including C_{12} in series L_f and sizing it to form a series resonant branch at the fundamental frequency to reduce I_{bp} and to increase filter efficiency. If a second inductor L_{f2} is added to the circuit, a fourth-order double band-pass filter will be obtained.

A common type of an nth-order composite filter for power quality improvement. Several band-pass filters are connected in parallel and individually tuned to selected harmonic frequency range. The last branch is a high-pass filter attenuating high-order harmonics, which usually are a result of fast switching actions. Composite filters are only applied when even-order harmonics are small since a parallel resonance will occur between any two adjacent band-pass filter branches and cause amplification of the distortion in that frequency range. For example, composite filter systems with shunt branches tuned at the 5th and 7th harmonics will have a resonant frequency about at the 6th harmonic. The impedance transfer function of the nth –order composite filter is



(76)Explain (a) Active filter (b) Hybrid filter.

(a) *Active filter*: Active filters are feasible alternatives to passive filters. For applications where the system configuration and the harmonic spectra of nonlinear loads change, active elements may be used instead of the passive components to provide dynamic compensation.

An active filter is implemented when the order numbers of harmonic currents are varying. This may be due to the nature of nonlinear loads injecting time-dependent harmonic spectra or may be caused by a change in the system configuration. The structure of an active filter may be that of series or parallel architectures. The proper structure for implementation depends on the types of harmonic sources in the power system and the effects that different filter solutions would cause to the overall system performance.

Active filters rely on active power conditioning to compensate undesirable harmonic currents replacing a portion of the distorted current wave stemming from the nonlinear load. This is achieved by producing harmonic components of equal amplitude but opposite phase angles, which cancel the injected harmonic components of the nonlinear loads. The main advantage of active filters over passive ones is their fine response to changing loads and harmonic variations. In addition, a single active filter can compensate more than one harmonic, and improve or mitigate other power quality problems such as flicker.

(b) *Hybrid filter*: Hybrid filters combine a number of passive and active filters and their structure may be of series or parallel topology or a combination of the two. They can be installed in single-phase, three-phase three-wire, and three-phase four-wire distorted systems. The passive circuit performs basic filtering action at the dominant harmonic frequencies whereas the active elements, through precise control, mitigate higher harmonics. This will effectively reduce the overall size and cost of active filtering.

There are different classifications of active and hybrid filters based on power rating supply system, topology, number of elements, speed of response, power circuit configuration, system parameters to be compensated, control approach and reference-signal estimation technique.

Hybrid filters are usually considered a cost effective option for power quality improvement, compensation of the poor power quality effects due to nonlinear loads, or to provide a sinusoidal AC supply to sensitive loads.

(77)What are SCADA tools for improving security and reliability?

Supervisory control and data acquisition plays an important role in distribution system components such as substations. There are many parts of a working SCADA system, which usually includes signal hardware, controllers, networks, human-machine interface communications equipment, and software. The term SCADA refers to the entire central system, which monitors data from various sensors what are either is close proximity or off site.

SCADA equipment such as RTUs and PLCs are applications of telecommunications principles. Interdisciplinary telecommunications programs (ITPs) combine state-of-the-art technology skills with the business, economic and regulatory insights necessary to thrive in a world of increasingly ubiquitous communications networks. ITPs are served by faculties in economics, electrical engineering, computer science, low, business, telecommunication industry, and government. They address research is wireless, cyber-security, network protocols, telecom economics and strategy, current national policy debates, multimedia, and so forth. Key topics by ITPs are

- Security and reliability of utility systems addressing a range of security-related issues on physical and information security as well as vulnerability assessment and management. The major areas discussed include physical security and access control asset protection, information systems analysis and protection, vulnerability, assessment, risk management, redundancy, review of existing security and reliability in power system, new security guidelines, threat response plan, and contingency operation.

- Risk analysis and public safety review various kinds of risks ranging from floods, power outages, and shock to biological hazards. Various approaches to setting safety standards and minimizing risk are explored.
- Current, future, and basic technical concepts of telecommunications systems are studied. They include an in-depth look at basic telecom terminology and concepts, introductions to voice and data networks, signaling, modulation frequency-band and propagation characteristics, spectral analysis of signals, modulation, digital coding, modulation multiplexing, detection, transmission systems, and switching systems with an introduction to different network configurations and traffic analysis.
- Data communications define data and computer communications terminology, standards, network models, routing and switching technologies and communication and network protocols that apply to wide-area networks WANs, metropolitan-area networks MANs, community wireless networks CWNs, and local-area networks LANs. Therefore focus on asynchronous and synchronous wide-area networks such as frame relay and synchronous optical networks' SONETs, the internet, routers, selected internet applications and Ethernets.
- Applied network security examines the critical aspects of network security. A technical discussion of threats, vulnerabilities, detection, and prevention is presented. Issues addressed are cryptography, firewalls, network protocols, intrusion detection, security architecture, security policy, forensic investigation, privacy, and the law.
- The emerging technology of internet accesses via the distribution system is addressed.

(78) Explain Intentional islanding Interconnected redundant and self heating power system.

The present interconnected power system evolved after 1940 and represents an efficient however complicated energy generation, distribution, and utilization network. It is reliable but also vulnerable to sabotage, economic issues, distributed generation, regulations as well as a lack of appropriately trained or educated engineers. Power systems can be configured in multiple ways: at one extreme we have one large power source that delivers all the required power to multiple loads over transmission lines of varying lengths. At other extreme there are individual sources that supply the needs for each and every load. In between we have multiple sources and loads of varying size that are connected by many transmission line s to supply the loads. The fundamental issue is how to balance efficiency, reliability, and security. For relatively small systems a single source serving multiple loads that are distributed over relatively small distances has the advantages of being able to share capacity as the demand varies from load to load as a function of time and to take advantage of the efficiencies of size. A single source for either one single load or several loads in the easiest to control and in many respects, the most secure, as possible failure mechanisms are associated with one source only. By connecting given loads to multiple sources with multiple transmission lines we increase the reliability, as the failure of any one source or transmission line can be compensated for by picking up the load from other sources or over other transmission lines. However, as the number of lines and sources becomes large the control problem becomes too large to be managed centrally. This problem of distributed control for complicated power networks is closely related to the same problem in communications, biological, economic, political and many other systems.

In the case of distributed generation with renewable energy sources additional constraints enter the control approach where the renewable sources are operated at near 100% capacity by imposing droop characteristics with steep slopes. The intermittent operation of renewable sources requires that peak-power plants are able to take over when the renewable sources are unable to generate power. In order to minimize peak-power generation capacity it will be advisable to also rely on energy storage plants.

The information that is required to operate a conventional stand-alone power plant with isochronous control is relatively well known. However, it is much less clear what information one needs to operate a network that is faced with new and changing requirements and constraints that are brought about by new security problems, environmental regulations, distributed generation, competition etc., Systems that can be considered as role models include the internet, multi stream multiprocessor computer systems for parallel computing and biological systems.

The systems with the most closely related set of constraints to the problem of the allocation of generation capacity and the distribution of power for varying loads with the loss of a generator or transmission line are communications networks. These networks have a large number of sources and sinks for information that may be connected by many transmission or communication lines. Strategies for the design of these networks that take into account the cutting of communication lines or the loss of nodes such as telephone switches have been developed. Typical designs for reliability include dual rings and meshes. If the proper information on the bandwidth and traffic are updated on a continuing basis then the nodes can be prepared to allocate the traffic around a given fault when it occurs. Thus a given can known at all times how it will reroute the traffic if a communication line is broken or an adjacent node is lost. This can be done without a central command system and is sense provides a self-organizing system to correct for communication line outrages or the loss of a node. Strategies used in communication theory can be effectively employed or modified to improve the reliability of power systems and their efficient operation.

Neural networks are useful ways to approach many complete pattern recognition and control problems that are at least philosophically modeled on biological systems, which use both feedback and feed-forward networks to generate adaptive responses to problems. One of the most common neural networks adjusts the connection weights, using a back propagation algorithm to adapt the network tp recognize the desired pattern. This property can be used to develop a control system that has best response to a wide variety of network problems. Feed-forward networks can be used to anticipate the power system behavior and to prevent problems such as a cascade of network overloads. Power system control and security problems can be formulated in such a way that neural networks can be used as portions of an effective control system. It is to be noted that we can now place computers in the feedback loop of a control system to perform much more complex functions than the classical control systems with a few passive elements.

(79) How do you understand the demand side management program?

Utilities continue to face fundamental changes:

- Distributed generation

- Greater access by utilities and others to the transmission systems of other utilities
- Competition for retail customers from other power sources, self-generation or cogeneration, and from other utility suppliers
- Reduction in the cost of renewable resources
- Growing use of demand-side management (DSM) programs as capacity and energy resources
- Increased concern with the environmental consequences of electricity production
- Growing public opposition to construction of new power plants
- Uncertainty about future load growth, fossil-fuel prices and availability, and possible additional regulations.

Load control programs are the most prevalent forms of demand-side management practiced by utilities interested in peak clipping. Three types of techniques are commonly used by utilities that would want to exercise control over customer loads:

- Direct control techniques by utilizing a communication system to remotely affect load operation. The communication technologies used include VHF radio, power linear carrier, ripple, FM-SCA radio, cable TV, and telephone.
- Local control techniques through the promotion and use of demand control equipment that operated according to local conditions. The technologies used in local control include temperature-activated cycling of air, timer tripping, and various mechanisms that employ timers, interlocks and multiple function demand limiters.
- Distributed control techniques that merge both direct and local control concepts by using a communications system to interface with or active a local control device.

(80) Define voltage regulation.

The steady-state voltage deviation is measured by the voltage regulation.

$$V_R = \left(1 - \frac{V_{rated} - |V|}{V_{rated}}\right) \cdot 100\%.$$

Where V_R is the percent voltage regulation, which is 100% for $|V| = V_{rated}$. The voltages $|V|$ and V_{rated} are the measured rms voltage and the rated voltage, respectively. The voltage regulation is a measure for the strength of a bus, that is, the ability of the bus to supply current without changing its voltage amplitude. The short-circuit ratio ($SCR = I_{xc}/I_{rated}$) indicative of the strength of a power system. Renewable sources have a limited short-circuit current capability, and for this reason they lead to weak systems. Typical values of SCR are in the range from 20 to 200 for residential and 1000 or more for industrial circuits. Whereas the voltage regulation characterizes steady-state voltage amplitudes, the voltage-tolerance curves measure the change in bus voltage during a few 60 H_z cycles.

(81) Explain load shedding and load management.

Load shedding is an important method to maintain the partial operation of the power system. Some utilities make agreements with customers who do not necessarily require power at all times. In case of shortage of electrical power due to failures or overloads due to air conditioning on a very hot day, customers will be removed from the load on a temporary basis. Utilities try to entice customers to this program by offering a lower electricity rate or other reimbursement mechanisms.

(82) Describe frequency variation within an interconnected power system as a result of two load changes.

The two areas are connected by a single transmission line. The power flow over the transmission line will appear as a positive load to one area and an equal but negative load to the other or vice versa, depending on the direction of power flow.

ESI 33.9 Power quality improvement –Power conditioner

(83)Explain (a) Shunt facts controller (b) Combined shunt series controller (c) Facts controller with storage (d) Active power line conditioner (e) Unified power quality conditioner

(a) *Shunt facts controller*: Three types for shunt Facts controllers are employed to inject compensation current into the system. An injected current in phase quadrature with the phase voltage results in Q control; other phase relations provide simultaneous control of P and Q.

- Variable impedance shunt FACTS controllers
- Switching converter SVG shunt FACTS controllers
- Hybrid SVG and switching converter shunt FACTS controllers.

(b) Combined shunt series controller: These controllers may consist of a number of shunt, a number of series, or a combination of shunt and series FACYS devices. Three popular combined shunt-series FACTS controllers are

- Unified power flow controller (UPFC) has one converter in series and the other in shunt with the transmission line.
- Interline power flow controller (IPFC) has both conyerters in series with usually a different line and
- Back-to-back STATCOM has both converters in shunt, each connected to a different power system.

(c) Facts controller with storage: Any of the converter-based FACTS devices can generally accommodate storage such as capacitors, batteries, and superconducting coils. These controllers are more effective for controlling system dynamics due to their ability to dynamically provide real power P from a system.

(d) Active power line conditioner: The APLC is a converter-based compensation device designed to improve the power quality of the entire distribution system by injecting corrective harmonics currents at selected buses. It is usually necessary to use more than one APLC unit to improve the power quality of the entire distribution system. Therefore, APLC units can be considered as a group of shunt active filters; their placement, sizing and compensations levels are normally designed and improve the power quality of the entire distribution system. The number of required APLC units depends on the severity of distortions the nature of the distribution system, and types of nonlinear loads, as well as the required quality of electric power. The design of APLCs does not consider transient distortions and stability issues.

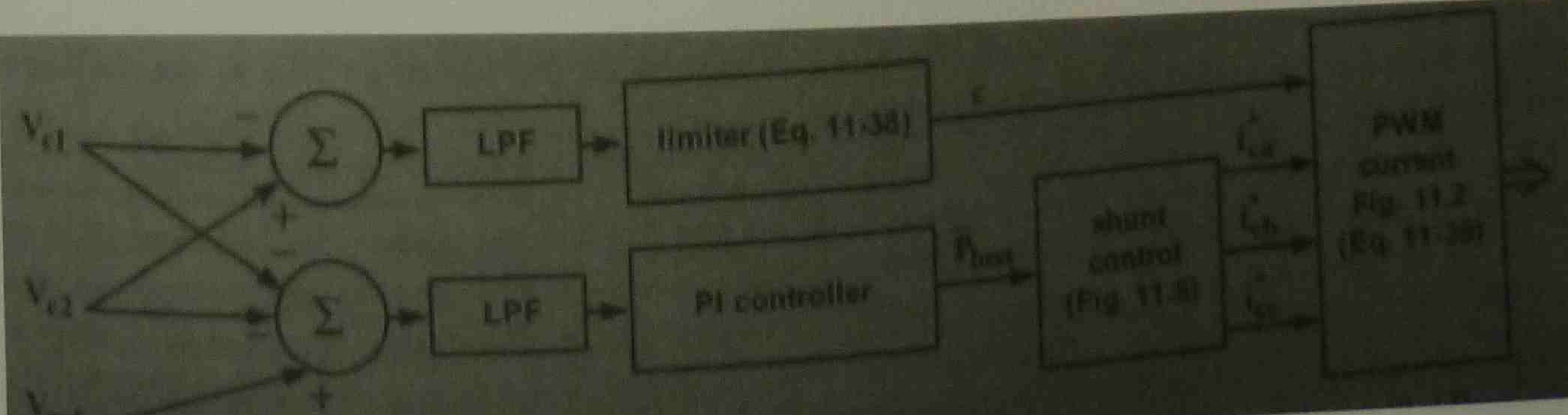
e) Unified power quality conditioner: Unified power quality conditioners are viable compensation devices that are used to ensure that delivered power meets all required standards and specifications at the point of installation. The ideal UPQC can be represented as the combination of a voltage-source converter and a common DC link. There are two possible ways of connecting the unit to the terminal voltages at PCC.

- Right-shunt UPQC, where the shunt compensator (i_c) is placed at the right side of the series compensator (v_c),
- Left-shunt UPQC, where the shunt compensator (i_c) is placed at the left side of V_c

These two structures have similar features; however, the overall characteristics of the right-shunt UPQC are superior.

(84) Explain control of series converter using instantaneous power theory.

Inputs of the series converter control system are the three phase supply voltages (V_{sa}, V_{sb}, V_{sc}), load voltages (V_a, V_b, V_c), and the line currents (i_a, i_b, i_c). Its outputs are reference compensating voltages V^*_{ca}, V^*_{cb}, V^*_{cc}. The compensating voltages consist of two components;



Adjustments to the generator commitment and loading are made by feedback rules or by a 'contingency-constrained optimal power flow which outputs a generator schedule.

Other constraints within which the operator must work are the requirements:

- To hold enough VAr reserves at strategic nodes in the system such that voltages can be maintained despite loss of a circuit, compensator, or generator;

- That across pre-defined boundaries, flows should not exceed certain values, otherwise a credible fault could plunge the system into instability. Both voltage-secure and stability-secure situations require considerable pre-event study and the use of sophisticated planning and operating software utilizing data from SCADA. Many programs to automatically derive secure dispatch and network configuration schedules are still under development and this provided a fruitful area for reach

(40) What are the causes that limit the life time of any device?

The lifetime of any device is limited by the aging of the insulation material energy due to temperature: the higher the activation energy of any material, the faster the aging proceeds.

(41) What are the mechanisms that reduce the life time?

There are few mechanisms by which the rated lifetime can be reduced:

- Temperature rises above the rated temperature an come about due to overload a voltage or currents harmonics.
- Lifetime can be also decreased by intermittent operation. It is well known that generators of pumped storage plants mist be rewound every 15 years as compared to 40 years for generators which operate at a constant temperature.
- Vibration within a machine due to load variations can destroy the mechanical properties of conductor insulation.
- Faults-such as short-circuits can impact the lifetime due to excessive mechanical forces asting on the winding and their insulation.

(42) What are the phases for estimation of the life time of magnetic devices?

There are different phases are involved in the estimation of the lifetime of magnetic devices:

- Modeling and computation of the additional losses sue to voltage or current harmonics,
- Determination of the ensuing temperature rises, and
- Estimation of the percentage decrease of life time as compared with rated lifetime

(43) How will you calculate the temperature rise of a drip proof 5 HP induction motor?

Calculate the temperature rise ΔT of a drip-proof induction motor provided the following data are given:

Input power P_{in} = 4355 W, output power P_{out} = 3730 W, line frequency f = 60Hz, thickness of stator slot insulation $\beta_1 = 6.10^{-4}$ m, thermal conductivity of stator slot insulation λ_1 = 0.148 W/m^{0}C, total area of the stator S_1 = 0.0701 m^2, thermal conductivity of the stator laminations λ_1 = 47.24 W/m^{0}C, radial height of the stator back iron h_{y1} = 0.0399mm cross-sectional area of the stator core at the middle of the stator back iron S_{y1} = 0.0325 m^2, length of the small air gap between the stator core and the frame of the motor $\beta_\delta = 5.10^{-6}$ m, thermal conductivity of the small air gap between stator core and frame λ_δ = 0.236 W/m^{0}C, outside surface area of the stator frame S_δ = 0.0403 m^2, surface thermal coefficient for dissipation of heat to stationary air α_0 = 18.70 W/m^{20}C, surface thermal coefficient for dissipation of heat to moving at v = 4.6 m/s α_v = 58.81W/m^{20}C, surface area in contact with stationary air S_0 = 0.181 m^2, and surface area in contact with moving air S_v = 0.696 m^2.

(63) Express non linear harmonic model of transformer.

Appropriate harmonic models of all power system components including transformers are the basis of harmonic analysis and loss calculations. Harmonic models of transformers are devised in two steps: the first is the construction of transformer harmonic model, which is mainly characterized by the analysis of the core nonlinearity, causing nonsinousoidal magnetizing and core-loss currents. The second step involves the relation between model parameters and harmonic frequencies. In the literature, many harmonic models for power transformers have been proposed and implemented. These models are based on one of the following approaches:

- Time-domain simulation
- Frequency-domain simulation
- Combined frequency-and time-domain simulation, and
- Numerical simulation

This section starts with the general harmonic model for a power transformer and the simulation techniques for modeling its nonlinear iron core. The remainder of the section briefly introduces the basic concepts and equations involving each of the above mentioned models techniques.

(64) Describe harmonic losses in transformer.

Losses due to harmonic currents and voltages occur in windings because of the skin effect and the proximity effect. It is well known that harmonic current $i_h(t)$ and harmonic voltage $V_h(t)$ must be present in order to produce harmonic losses.

$$P_h(t) = I_h(t) \cdot V_h(t)$$

If either $I_h(t)$ or $V_h(t)$ are zero then $P_h(t)$ will be zero as well. Harmonic losses occur also in iron cores due to hysteresis and eddy-current phenomena. For linear (B-H) characteristics of iron cores, the losses are dependent on fundamental and harmonic amplitudes only, whereas for nonlinear iron-core (B-H) characteristic the phase shift between harmonic voltage and fundamental voltage is important as well. For example, a magnetizing current with maximum peak-to-peak values results in larger maximum flux densities than a magnetizing current with minimum peak-to-peak values. Proximity losses in windings and conducting parts of a device occur due to the relative location between the various windings and conductive parts.

(65) Explain loss measurement.

For low efficiency ($\eta < 97\%$) devices the conventional indirect loss measurement approach, where the losses P_{loss} are the difference between measured input power P_{loss} is acceptable. However, for high efficiency ($\eta \geq 97\%$) devices the indirect loss measurement approach yields losses that have a large error.

KUBERUNATH BALANAGU

STUDENT NO: 372003863

ASSIGNMENT

SUBJECT: GO38

COURSE

ADVANCE DIPLOMA IN ELECTRICAL ENGINEERING

TEACHER

Kyaw Naing

G038 Tutorial

ESI 10.1 HV Equipments

(1)Explain (a) Main feeder (b) Conductor (c) Sectionalising (d)Re-closer (e) Operating voltage (f) Load balancing (g) Star/ Delta circuit (h) Higher voltage circuits (i) Voltage regulator (j) Booster (K) Capacitor

Main Feeder: The Main Feeders are usually three-phase three or four-wire circuits, and the branches are predominantly single-phase, although they may consist of two or three phases of the three-phase circuit if the loads carried on them are large or require polyphase supply.

Conductor: Conductor means a material allowing the flow of electric current. The sizes of wire for both main and branches, will depend on the voltage variation or regulation desired and on economy, wich includes evaluation of losses in the conductors.

Sectionalizing:

Recloser: Reclosers are designed to open when a fault occurs on that part of the main in which they are connected; a timing device, however, enables them to reclose a predetermined number of times for short durations. If the fault is of a temporary nature, such as wires swaying together or a tree limb falling on them, the recloser will remain closed and service will be resorted; should the fault persist, the recloser will remain open and disconnect the part of the main from the circuit.

Operating Voltage: The selection of the primary operating voltage is probably the factor having the greatest influence on the design of the primary system. It has a direct effect on the length of the feeder and its loading, the substation supplying the feeders and the number of feeders, the number of consumers affected by an outage, and on maintenance and operating practices. Several voltage levels have evolved in to "stand" nominal values of primary voltages: 2400, 4160, 7620, 13,200, 23,000, 34,500, 46,000 and 60,000 V.

Load Balancing: On polyphase portions of the feeder, on both main and braches, loads are balanced between phases as closely as practical by connecting transformers and single-phase branches to alternate phases of the circuit; this provides a more uniform balancing of loads along the line then would balancing in large blocks of loads. An approximate method multiplies each load by its distance from the substation; the sum of these, uniformly distributed, should be about the same for each phase.

Delta and Wye Circuits: Many of the older systems employed delta circuits with phase-to-phase voltages approximating 2400V; as loads increased, it was found economical to convert these into wye circuits with phase-to-phase voltages approximating 4160V, but with phase-to-neutral voltages remaining at the 2400-V level, permitting the use of the same transformers, insulators, and other single-phase equipment. The wye circuit necessitated a fourth, neutral conductor grounded in many places; later, a single conductor common to both the primary and secondary systems was employed safely, effecting greater economies.

Higher-Voltage Circuits: The higher-voltage circuit is generally designed for immediate wye-operation, omitting the intermediate delta operation. In addition to the grater construction costs, additional maintenance and operating cost must be considered in determining the economics of going to higher voltages. Beyond about 15 kv, handling such lines and equipment requires either "live lines" tools and methods or the deenergizing of lines and equipment. This latter condition may require additional sectionalizing facilities, including a greater number of extensions between feeders to enable loads to tbe transferred from the circuit to be deenergized.

The grater load-caring ability to the higher-voltage primary circuits tends to have them serve large areas and a greater number of customers, so that an interruption to an entire circuit will have greater effect on the area served. Rapid sectionalizing and reenergizing means are therefore more necessary and mist be considered in evaluating and service reliability factor in economic studies.

Voltage Regulators: A device or circuit that maintains a load voltage nearly constant over a range of variations of input voltage and load current. Voltage regulators are used wherever the unregulated voltage would vary more than can be tolerated by the electrical equipment using that voltage. Alternating-current distribution feeders use regulators to keep the voltage supplied to the user within a prescribed range. Electronic equipment often has voltage regulators in dc power supplies.

Booster: An increase or decrease in the primary voltage can also be obtained by the installation of transformer in the line to provide a fixed voltage drop. A distribution transformer, connected as an autotransformer, may be used to boost or buck the feeder voltage at the point of its installation. The percentage of boost or buck will depend on the ratio of the primary and secondary coils, including the tap used, of the transformer selected. The capacity for the unit is determined by the current-carrying capacity of the secondary coil, through which the entire line current will flow.

Capacitor: The current drawn by a capacitor has a leading power factor characteristic and will cause a voltage rise from the location of the capacitor back to the current source. The voltage rise will be equal to the reactance of the circuit.

Capacitors provide a constant increase in the level of voltage at the location of the capacitor that is the same under any load condition of the feeder, from light to heavy loading. If the capacitors are installed so that they may be switched on during heavy load periods and off at light load periods, voltage regulation can be improved.

(2) Sketch the following transformer connections (a) Single phase (b) Three phase

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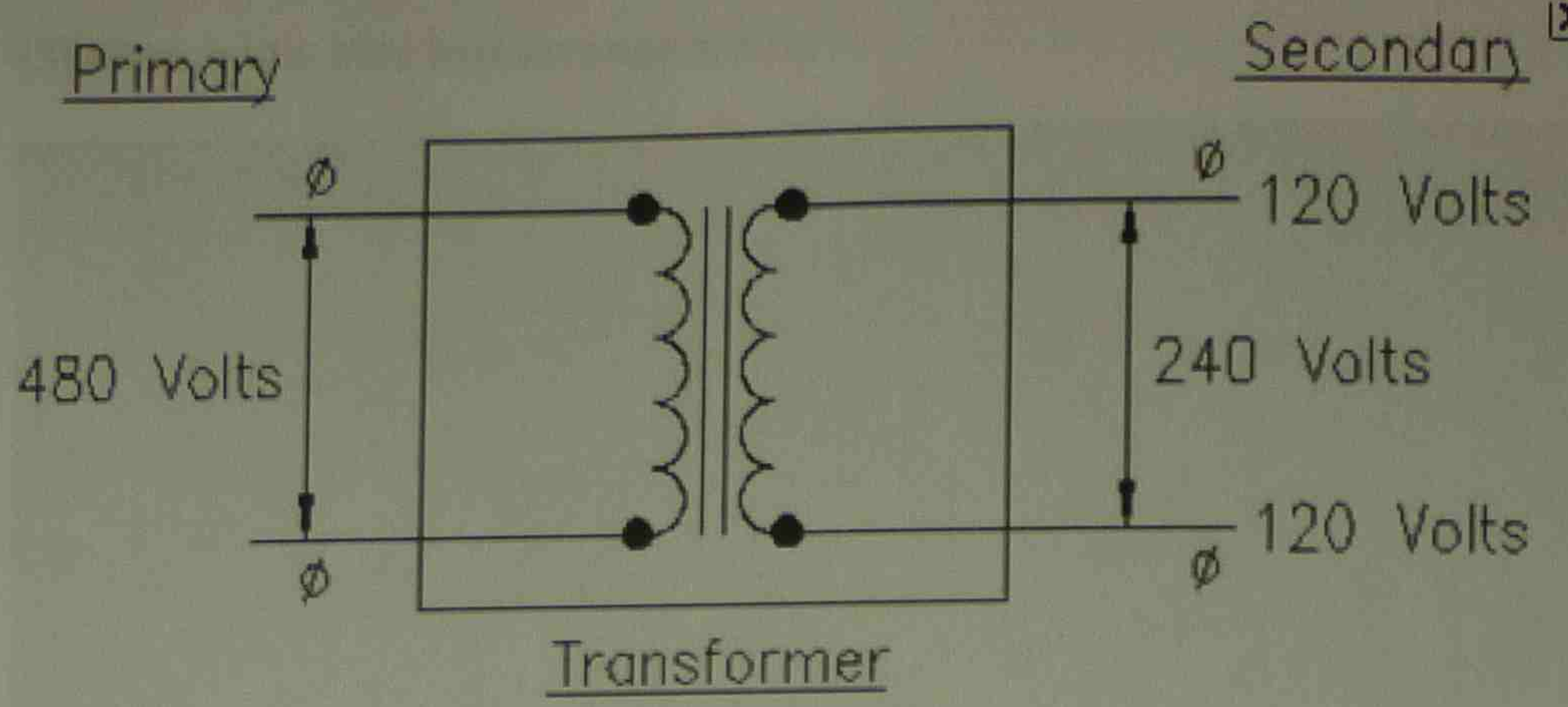
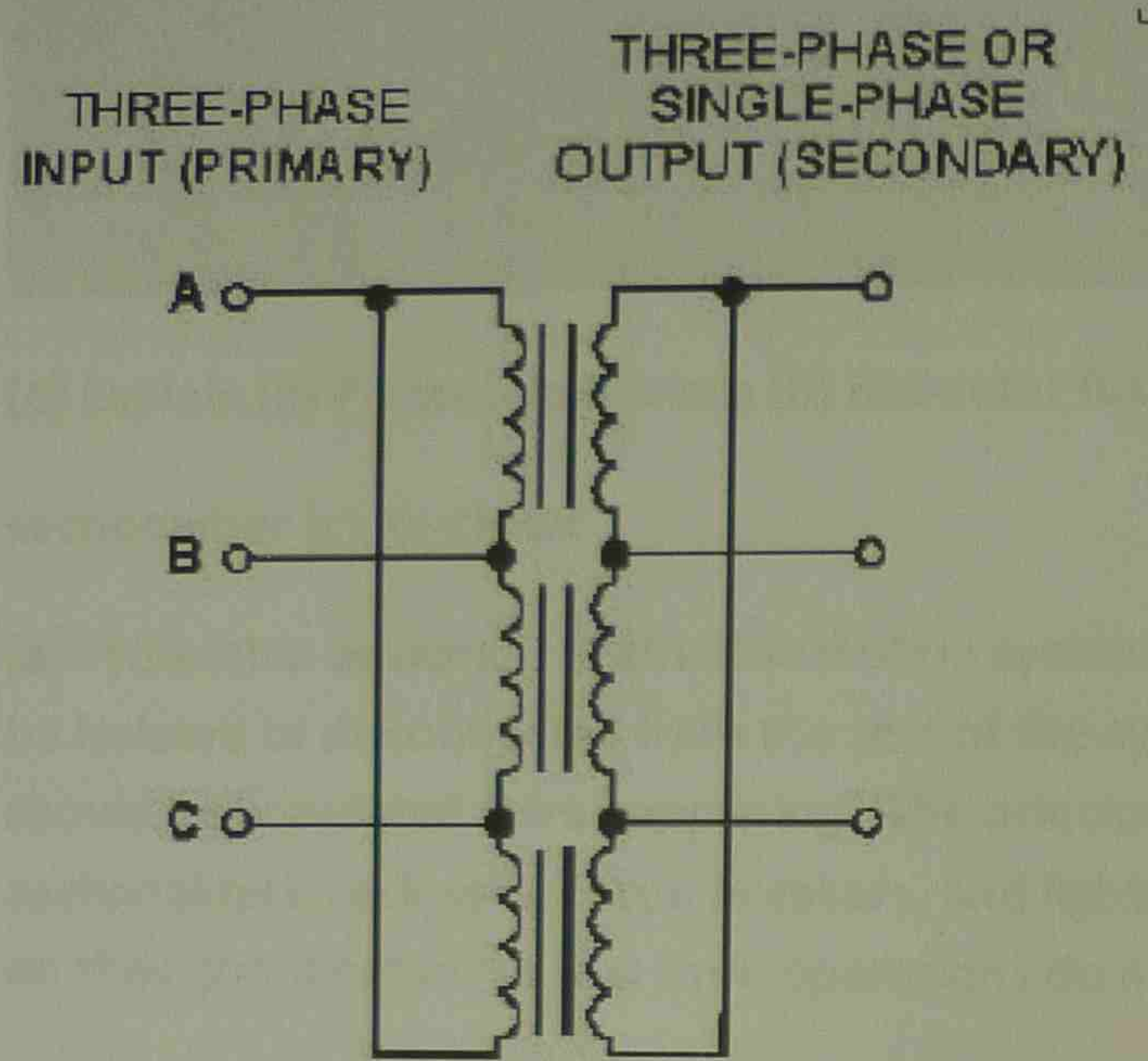




(3) Explain auto transformer.

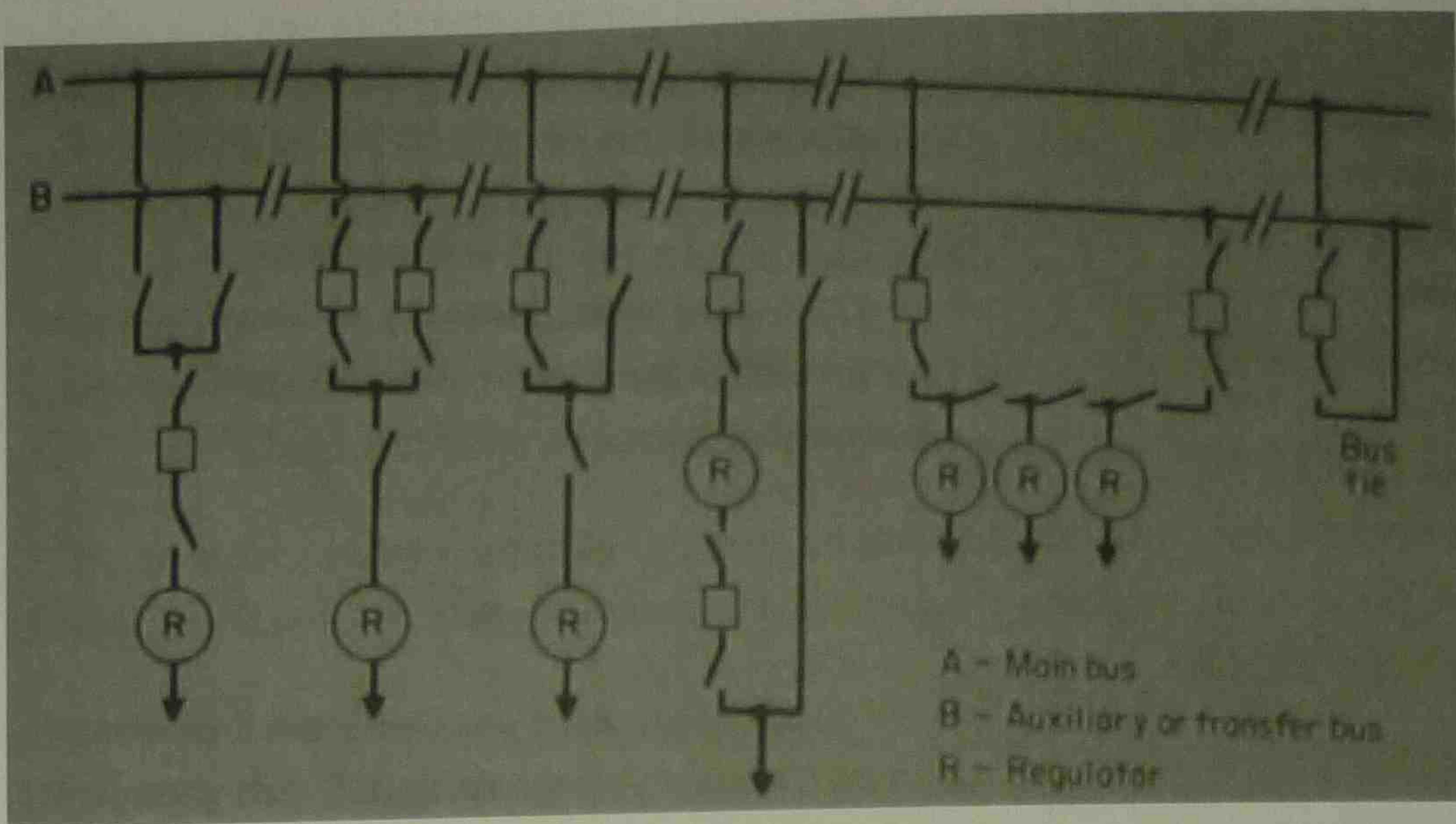
An autotransformer is an electrical transformer in which there is one winding, a portion of which is common to both the primary and the secondary circuits. In other words, the primary and secondary coils have some or all windings in common.

An autotransformer is commonly used for the voltage conversion of local power line voltage to some other Voltage value needed for a particular piece of electrical equipment. Most often, this conversion is from 125 Volts to 250 Volts, or 250 Volts to 125 Volts.

(4) Describe supply feeder and circuit breaker requirement of substation.

The number and sources of supply sub transmission feeders to the distribution substation will depend not only on the load to be served, but also on the degree of service reliability sought. Some rural substations may be supplied from only one sub transmission feeder, while substations serving urban and suburban areas have minimum of two supply feeders and may have several more. Each additional incoming feeder, however, adds to the bus and switching requirements, including auxiliary devices for their protection, all of which add to costs.

(5) Sketch low side bus arrangement.



(6) Explain (a) Protective devices (b) Repeater fuse (c) Transformer fuse (d) Automatic line sectionalizer (c) Re-closer

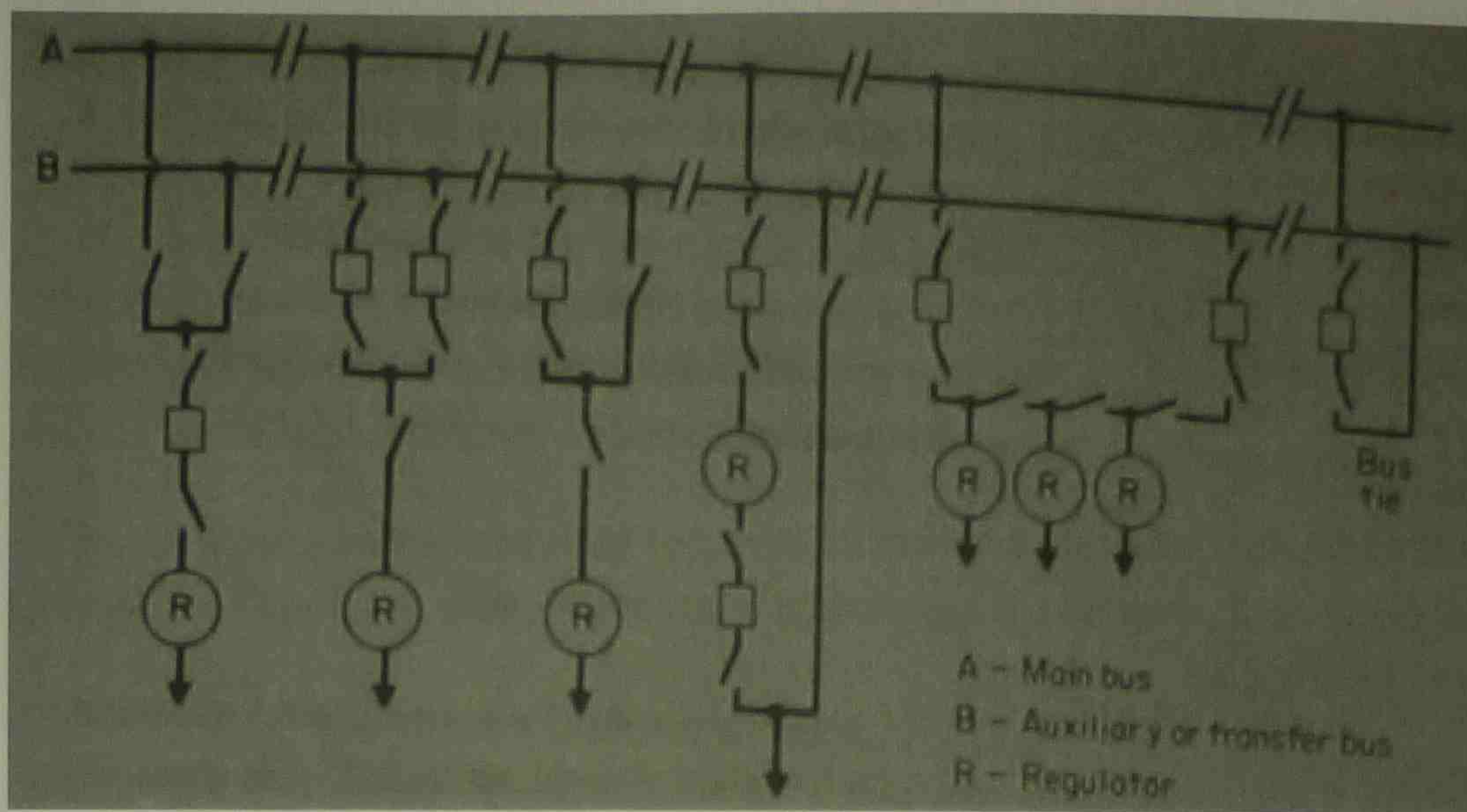
(a) Protective devices: For the distribution system of function satisfactorily, faults on any part of it must be isolated or disconnected from the rest of the system as quickly as possible; indeed, if possible, they should be prevented from happening. The principal devices to accomplish this include fuses, automatic sectionalizers, reclosers, circuit breakers, and lightning or surge arresters. Success, however, depends on their coordination so that their operations do not conflict with each other.

(b) Repeater fuse: Line fuses are sometimes installed in groups of two or three, known as repeater fuses, having a time delay between each two fuse units. When fault occurs, the first fuse will blow and the second fuse will be mechanically placed in the circuit by the opening of the first; if the fault persists, the second fuse will blow; if there is a third fuse, the process is repeated. If the fault is permanent, all of the fuses will blow and the faulted part of the circuit will be reenergized. New fuses must be installed to restore the line to normal.

(c) Transformer fuse: Fuses on the primary side of distribution transformers serve to disconnect the transformer from the circuit not only in the event of a fault in the transformer or on the secondary, but also when the normal load on the transformer becomes so high that failure is imminent. Fuses on the secondary side protect the transformer from faults or overloads on the secondary circuit it serves.

The characteristics of a primary fuse are a compromise between protection from a fault and protection from overload. Secondary fuses, known as limiters, are also provided at the juncture of secondary mains to isolate faulted sections of the secondary mains and to prevent the spread of burning in conductors where sufficient fault current does not exist to burn them clear in a small portion of the mains.

(5) Sketch low side bus arrangement.



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(b) Repeater fuse: Line fuses are sometimes installed in groups of two or three, known as repeater fuses, having a time delay between each two fuse units. When fault occurs, the first fuse will blow and the second fuse will be mechanically placed in the circuit by the opening of the first; if the fault persists, the second fuse will blow; if there is a third fuse, the process is repeated. If the fault is permanent, all of the fuses will blow and the faulted part of the circuit will be reenergized. New fuses must be installed to restore the line to normal.

(c) Transformer fuse: Fuses on the primary side of distribution transformers serve to disconnect the transformer from the circuit not only in the event of a fault in the transformer or on the secondary, but also when the normal load on the transformer becomes so high that failure is imminent. Fuses on the secondary side protect the transformer from faults or overloads on the secondary circuit it serves.

The characteristics of a primary fuse are a compromise between protection from a fault and protection from overload. Secondary fuses, known as limiters, are also provided at the juncture of secondary mains to isolate faulted sections of the secondary mains and to prevent the spread of burning in conductors where sufficient fault current does not exist to burn them clear in a small portion of the mains.

(d) Automatic line sectionalizer: Automatic line sectionalizers are connected on the distribution feeder in series with line and sectionalizing fuses; they are also in series with and electrically farther from the source than reclosers or circuit breakers with reclosing cycles. When fault occurs on the circuit beyond the sectionalizer, the fault current initiates a fault-counting relay that is coordinated with the characteristics of the fuses and other devices.

Sectionalizers are rated on continuous current-carrying capacity, minimum tripping and counting current, and maximum momentary fault current, as well as for maximum system voltage, load-break current, and impulse voltage or basic insulation level.

Sectionalizers are not required to interrupt fault current although fault current flows through them. They may be operated manually and are considered the same as load-break switches.

(e) Reclosers: Reclosers are essentially circuit breakers of lower capacity, both as to normal current and interrupting duty. They are usually installed on major branches of distribution feeders in series with other sectionalizing devices; perform the same function as repeater fuses connected in the circuit or circuit breakers at the substation.

Reclosers are designed to remain open, or "locked out," after a selected sequence of tripping operations. A fault will trip the recloser; if the fault is temporary in nature and no longer exists, the next tripping operation does not take place and the recloser returns to its normally closed position, ready for another insicent.

(7) What is Basic Insulation Level?

The coordination of insulation requires the establishment of a minimum level above which are components of a system and below which are the protected devices associated with those components. A joint committee of electrical engineers, utilities, and manufacturers adopted basic insulations levels which define the impulse voltages capable of being withstood by insulation of various insulation classes: Basic impulse insulation levels are reference levels expressed in wave not longer than 1.5 by 40 microseconds. Apparatus insulation as demonstrated by suitable tests shall be equal to or greater than the basic insulation level.

ESI 10.2 Substation Equipments

(8)What is co-ordination of protective devices, auxiliary circuits, substation electrical ground, bus design.

The circuit breakers that serve to reenergize equipment equipment require two sources of power for their proper operation: that which actuates the relays and that which causes the mechanical operation of equipment to take place.

Auxiliary Circuits: While the instrument transformers furnish the power that actuates the protective relays, a separate source of auxiliary power is provided to operate the trip coils, solenoids, and motors that may be involved. This separate source of power must be as reliable as practical.

In substations in which the power supply bus is sectionalized into two or more parts, transformers supplying station power may be connected to two sections separated from each other, with the transformer supplying the auxiliaries connected to one section and the equipment connected to the other. In other instances, the station transformer may be equipped with a throw over switch, operated manually or automatically, in order to improve the reliability of the supply of auxiliary power.

As a further precaution, control and auxiliary wiring systems are ungrounded and are provided with ground-detecting devices that actuate a light or alarm indicating the presence of a fault on the circuit involved. The auxiliary power supply may also supply some emergency station lighting.

Bus Design: The design of buses in a substation must take into account not only the current-carrying requirements under both normal and short-circuit conditions, but also voltage drips, power losses, and temperature rises. The current-carrying ability of buses, especially for the higher-capacity and higher-voltage circuits, must also take into account. Where buses are very closely situated, proximity effect must be considered which may further distort the distribution of the current flowing in the conductor and may affect the current carrying ability of the bus.

(9) Explain substation construction, combination indoor and outdoor, and unit substation.

Distribution substations may be constructed entirely indoors, entirely outdoors or in a combination of the two ways. One is Indoor and another is Outdoor.

In indoor construction, all the equipment is completely enclosed within a structure, protected from the weather. Measures are taken to ensure that the failure of a piece of equipment does not spread and the involve other units. Reinforced concrete fire and explosion resistant walls or barriers are installed between major pieces of equipment-resistant walls or barriers are installed between major pieces of equipment, such as a transformers, circuit breakers, and regulators.

Outdoor substations have all of the equipment located outdoors within a securely fenced off area. Here too, provisions are made for the maintenance, repair, and replacement of the pieces of equipment. Sumps may be constructed beneath a unit, in the form of dikes or pits containing coarse gravel or crushed stone, of a sufficient volume to hold possible oil spillage from the unit. Depending on the availability of a load and the spacing between units, fire walls between major units may be desirable.

In the combined indoor and outdoor arrangement, the major units, usually the transformers only, but sometimes circuit breaker also are located outdoors, and the remaining equipment is housed in a building of some king. The requirements already outlined should be followed In connection with each portion of the substation. Such substations are located in areas where appearances may be a major consideration and some equipment, sometimes concealed by landscaping, may found acceptable.

(10) Explain revenue metering, PF correction, Demand control, Electronic metering, Service conductor.

Revenue Metering: Metering for revenue [purposes, in itself, is not the responsibility of distribution engineer, but the data accumulated by meters so used can serve in optimizing the planning and design as well as the operation of distribution systems. The sane computer that translates meter readings in to consumer's bills can also be programmed to make selective summaries of such data simultaneously converting such consumption data in to loads and demands on the several elements of the distribution system.

Meters for revenue purpose measure energy in kilowatt-hours and power demand in kilowatts. They are connected in circuits in the same manner as wattmeter's and have both current and potential coils.

Power Factor Correction: For some larger consumers, the reactive KVA load is also measured in KVA-hours along with kilowatt-hour consumption. By properly interrelating these quantities for the period of time covered, a value of average power factor of the consumers load is obtained. With rate schedules tailored to reflect rewards for power factor, the installation of power corrective measures at the consumer's expense is encouraged; these may be banks of capacitors, synchronous motors, or both.

Demand Control: Rate schedules are designed to encourage the consumer to arrange the operation of loads so as to hold down maximum demand.

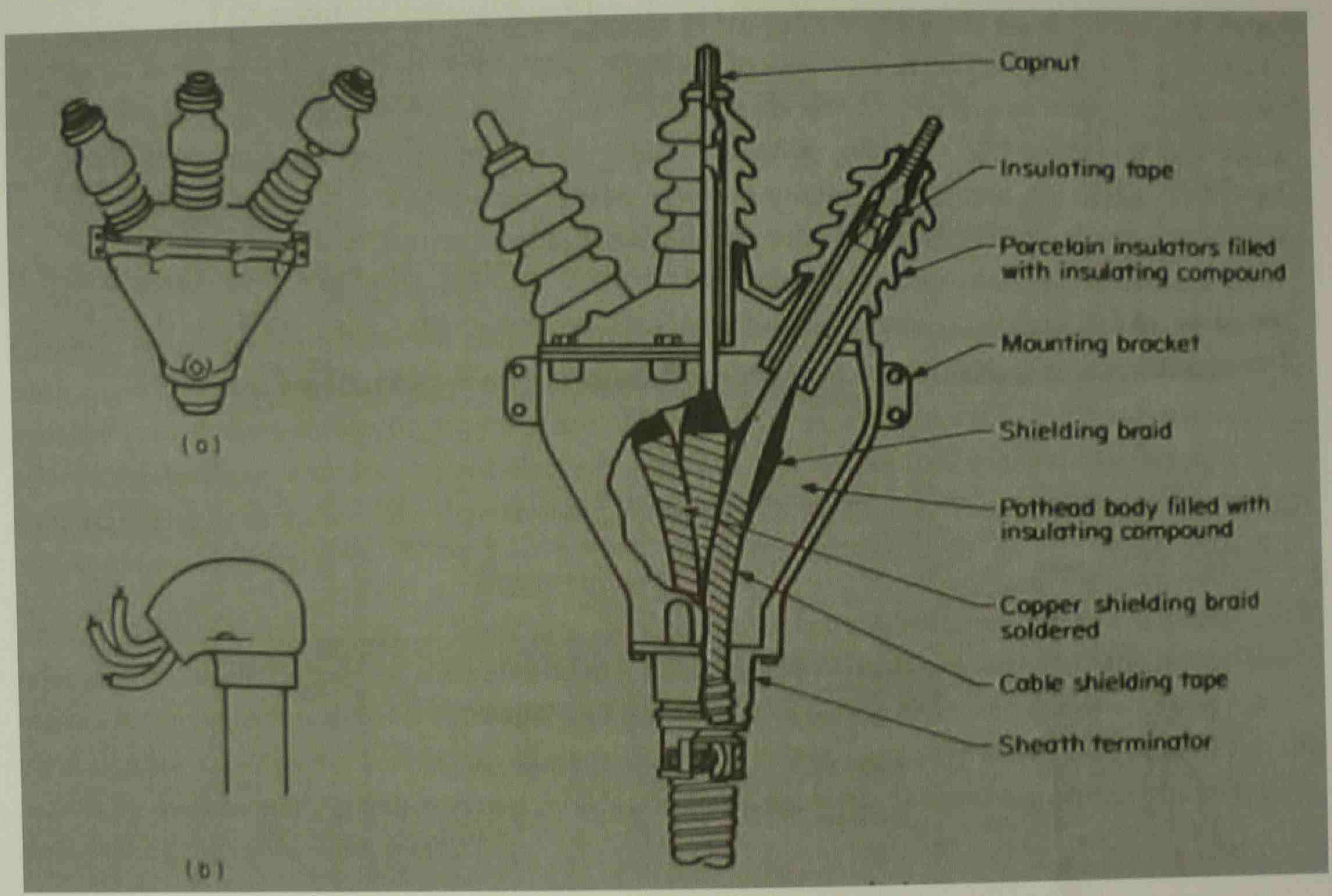
Many of the relatively smaller consumers arrange the operation of major pieces of equipment on a predetermined schedule in an effect to hold down their overall maximum demand, usually concentrating on reducing or eliminating short-term peaks. In large industrial and commercial installations, the demand is continuously monitored by the consumer using impulses generated by the utility's demand meter.

Electronic metering: The development of so-called microelectronic processing techniques is making the kilowatt-hour meter more than just a device for billing purposes; it also provides another tool for use by the distribution engineer and operator. By adding memory and other circuitry to the register of the meter, its functions can be expanded to provide additional data valuable to the distribution engineers. Microprocessors can be programmed to process the data and execute predetermined commands. This feature can be extended to control individual consumer loads in order to restrict consumers demand and collectively, reduce the peak demands on the several elements of electrical system all the way back to the generators.

Service Conductor: Overhead services for many years were of the open wire or multiple-conductor types. Open-wire construction, with separate weatherproof covered wire and bare neutral, held a part on separate insulators, not only cheaper, but allowed a third or fourth conductor to be added very readily. In multiple-conductor construction, sometimes known as "duplex" or "triplex" cables, the service cable consisted of one or two insulated conductors about which the neutral conductor strands were wound, the whole enclosed by weatherproof braiding. This type of construction made for better appearance, and slightly better reactance. Many of both open-wire and multi-conductor services still exist and will continue to do so far an indefinite time.

In some instances, consumers are served form midspan taps in others, from poles. In many instances, services are placed underground. Lead-sheath rubber-insulated cables installed in ducts or conduits, or supplied with armor and buried directly in the ground. Plastic –insulated conductors requiring no sheathing have largely taken the pace of such underground cables.

(11)Sketch the followings (a) Connection between OH and UG line



(12) What are dielectric values of wood?

Wood offers a marked resistance to the passage of an electric current and at least for lower voltages, may be classed as a nonconductor. Its dielectric strength varies with different species and is greater across the grain than along grain; changes in temperature affected the dielectric strength substantially, approximately doubling with each decrease of 22.50F or 12.50C. The most significant variation, however, takes place with changes in moisture content as wood dries from fiber saturation to the vacuumed oven-dry condition, its dielectric value approaches infinity.

Preservatives, however, have great influence on the dielectric strength of the wood, especially those consisting of chlorides; older poles treated with creosote and its derivatives have been found to experience.

Wood	Weight	Ultimate Strength
Northern White Cedar	23	3,600
Redwood	24	4,400
Cypress	29	4,800
Western Red Cedar	23	5,600
Chestnut	41	6,000
Southern Yellow Pine	35	7,400
Douglas Fir	32	8,000
Wallaba	-	11,000
Locust	-	12,800

(13) Describe concrete poles, Racks, Insulator.

Concrete Poles: Concrete poles are manufactured with hollow cores to reduce their weight, which has been a disadvantage, especially when they are handled in the field. Reinforcing steel strands are installed longitudinally for the full length of the pole and prestressed before the concrete is placed; reinforcing steel standards are also installed, essentially at right angles to the longitudinal reinforcing strands, usually as special coils wrapped around and welded to them in a manner to prevent movement during concrete casting.

RACKS: Secondary conductors, for many years supported horizontally on wood cross arms, were relocated to a lower position on the pole and mounted vertically on a rack attached to the pole. They make a better appearance and are stronger and less costly than cross arms; and the wires being in a vertical plane, service wires running in different directions do not cross each other. With this design the worker on the secondary conductors and services need not approach the primary conductors on the pole, making for a safer work method.

Many secondary-service installations on cross arms and on racks still exist and will continue to do so for a long time.

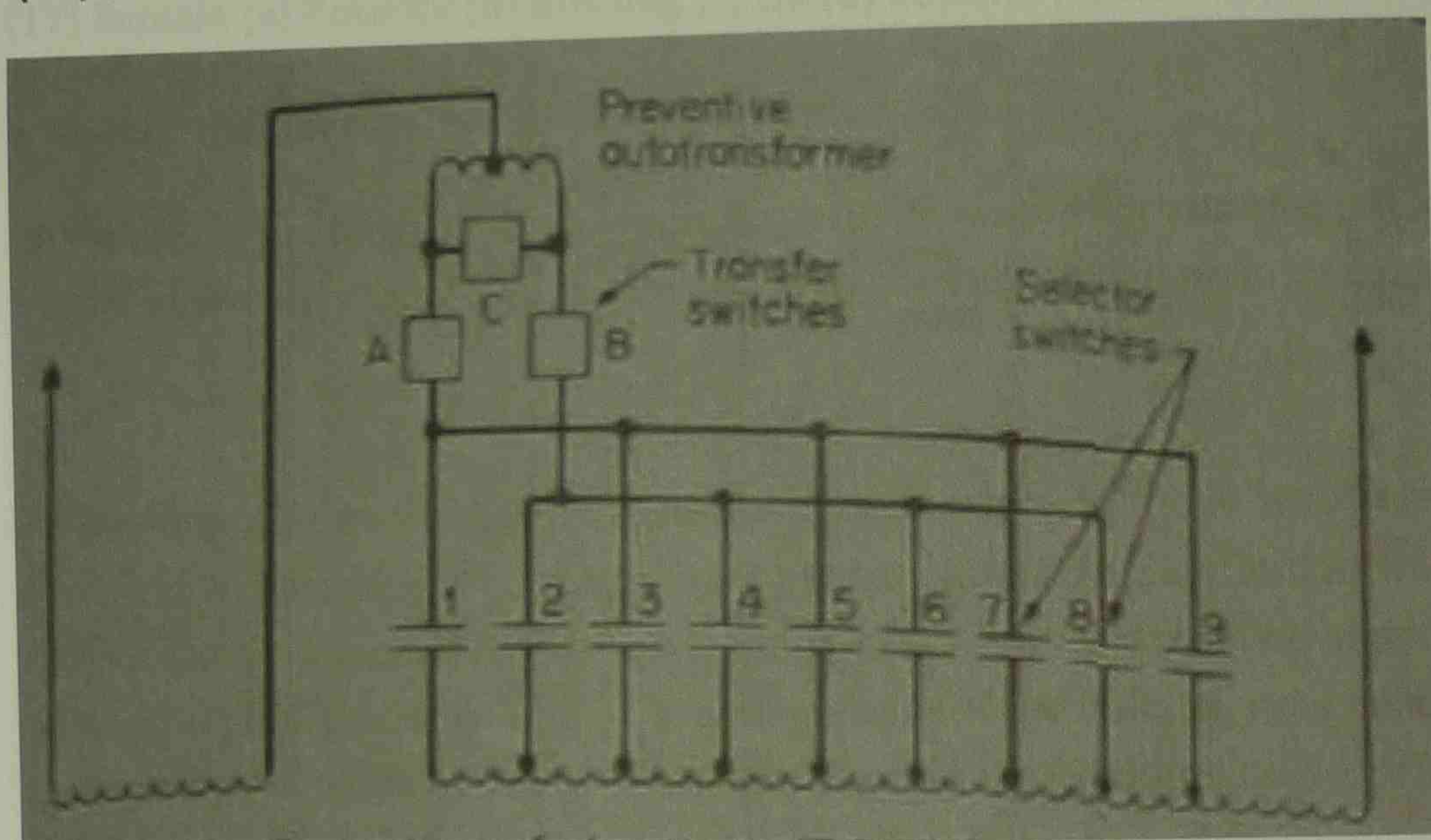
Insulator: Insulators, placed between energized conductors and the supporting structures, are not almost universally made of porcelain, although a great many glass insulators are still in service and will be for a long time. Fiberglass, epoxy, and other plastics are now beginning to be used in the manufacture of insulators.

(14) Explain (a) Distribution transformer (b) Underground transformer (c) Transformer cooling (d) Fuse cut-outs (e) Surge arresters

Fuse cutout are also used to disconnected faulted or overloaded parts of a primary circuits from the remaining unfaulted portion of the circuit. The size of the fuse is generally based on the size of the transformer or load on the primary section it is to protect.

(e) Surge arresters: Lightning or surge arresters serve to bleed a high-voltage urge to ground before it reaches the line or equipment which they are to protect. They do this by presenting a lower-impedance path to ground than the presented by the line or equipment. The voltage surge breaks down the insulation of the arrester momentarily, allowing the surge to go to ground and dissipate itself; the insulation of the arrester then recovers its properties, preventing further current from flowing to ground, and returning the arrester to a state ready for another operation.

(15) Sketch step type TCUL Regulator.



(16) Explain Air break switch, Oil switch.

Air break switch: Air-break switches are generally used to interrupt relatively small amounts of load current, such as in sectionalizing primary feeders or interrupting the exciting current of large transformers or a group of smaller transformers. The switches may be closed to pick uploads, but extreme care must be used in opening a circuit carrying load.

Air-break switches are essentially disconnecting switches equipped with so-called arcing horns. These are metal rods attached at an angle to the stationary terminal of the switch. As the blasé of the switch is opened under load, the arcing horns remain in contact with the blade until after the main contact has separated. As the blade continues to travel, an arc will form between it and the arcing horn. The arc will lengthen as the blade continues to travel, until it can no longer sustain itself and becomes extinguished. Pitting or burning from the arc occurs on the horn and part of the switch blade, where it can be tolerated.

Oil switch: Where load currents are to be interrupted relatively often, oil switches not designed to interrupt fault currents are used. Here, the switch is opened under oil. The oil serving to quench the arc that forms. Usually, however, a fuse is connected in series with the switch to clear the circuit should the switch fail to interrupt the circuit. Oil switches of this type, such a double-throw switches, are often used to transfer a primary service from one feeder to another and may be operated manually or automatically.

While the oil switch is more dependable then the air-break switch, it is more costly and its use is generally limited to those applications where other means are unsatisfactory.

(17) Explain (a) Polarity (b) Bushing (c) Oil (d) Cooling (e) Rating (f) Fuse (g) Surge or lightning arrester.

(a) Polarity: Substation transformers are usually wound for additive polarity, in accordance with EEI, NEMA, and other standards, contrasted with the subtractive polarity of distribution transformers.

(b) Bushing: The bushing of a substation transformers on the low-voltage side are usually made of porcelain and are similar to the primary bushing found on distribution transformers, but of greater current-carrying capacity. The high-voltage-side bushing, however, in addition to the greater current-carrying capability, depending on the magnitude of the voltage, may consist of a solid porcelain cylinder as insulation for voltages up to about 35 KV, or an oil-filled hollow porcelain cylinder for values up to about 69 KV; for 69 KV and higher voltages , the hollow porcelain cylinder may contain layers of oil-impregnated paper insulation with metal foil inserted at several location among the layers, forming a series of capacitors which serve to even out and equalize the electrostatic stresses set up within the bushing.

(c) Oil: Substation transformers may also show evidence of greater precaution taken in keeping air and moisture from the oil. In some units, an inert gas, such as nitrogen, fills the space above the oil, and the transformer tank is sealed. A "relief diaphragm" is sometimes installed in a vent in the sealed transformer which ruptures when the internal pressure exceeds some predetermined value, indicating possible deterioration of the insulation. In some units, a pressure relay is installed to give an indication of pressure rise in the tank.

Some outdoor units are equipped with a tank on top of the transformer, called a conservator, in which the expansion and contraction of the oil takes place. The rank is sometimes open to the atmosphere through a breathing device. The condensation of moisture and formation of sludge take place in the tank, which is also provided with a sump from which the condensation and sludge may be drawn off.

(d) Cooling: Substation transformers may be equipped with fins radiators to enhance the ability of the transformers to dissipate the heat generated by their copper and iron losses. Both the fins and the radiators increase the surface area transferring heat to the atmosphere. The radiator, in addition, increases the natural circulation of oil by the convection currents set up within the unit.

The cooling capability may be further increased by fans blowing against the fins and radiators, increasing the rate of heat transfer to the surrounding atmosphere. Further cooling may be obtained by pumps forcibly increasing the rate of circulation of oil in the radiators.

(e) Rating: In addition of the voltage classification, substation transformers may have several rating expressed in kVA, each rating associated with the type of cooling employed: a normal rating with no added means of cooling; a higher rating with forced air or forced oil circulation; and a still higher rating when both means are used in combination. Rating may also include permissible noise levels at maximum loads, expressed in decibels at standard distances from the unit.

(f) Fuse: Fuses types are

- ***High-Voltage Fuses***: In some smaller or rural substations, where possible short-circuit currents may be limited to relatively low values; a high-voltage fuse may be substituted for the incoming circuit breakers. The high-voltage fuse links are usually enclosed in a container, which tends to suppress and confine the arc and vaporizing metal, making the fuse capable of interrupting moderate short-circuit currents at the higher voltages.
- ***Liquid-Filled Fuses***: In liquid-filled construction, the fuse link enclosed in a tube that is filled with a fire-extinguishing fluid such as carbon tetrachloride. A spring holds the fuse under tension so that, when it blows, the resultant arc is quickly lengthened and quenched in the fluid, the gas formed is inert and aids in blowing out the arc. If the pressure becomes excessive, prevision is made to have the cap on the "outgoing" side of the fuse blow off, preventing the rupture of the tube and confining damage to the fuse itself.
- ***Solid- Filled Fuses***: The material surrounding the fuse element may be sand or powdered boric acid. In the sand-filled type, the heat and gasses generated when the fuse melts are absorbed by the sand, which tends to squelch the arc. In the boric acid type, the heat produced decomposes the boric acid, which forms steam under pressure that acts to squelch the etc.

(g) Surge or lightning arrester: They are rated not only on their normal voltage classification in kV, but also on their crest voltage capability in kV at a standard 1.5 x 40-μs wave, and their discharge-current capability in amperes or thousands of amperes. For high-voltage applications, surge arresters may consist of a number of unit-value value arresters connected in series in one overall unit.

(18) Explain the circuit interrupting process. 2

The important steps in the circuit-interrupting process are

- The circuit Is complete with current flowing across the interface of two metallic bodies know as contacts.
- The contacts separate and an arc is established between the parting contacts. The voltage across the arc is low, usually much less than the crest value of the circuit voltage.
- In accordance with the normal cyclic changes in an ac circuit, the circuit current will come to zero.
- Immediately following the instant of current zero the voltage between the parting contacts will reserve in polarity. The arc current in the opposite direction, a finite value of voltage is necessary. The restriking voltage will be greater than the voltage originally across the arc.
- During this period the zero arc current the voltage between the arcing contacts rises at a rate depending on the nature of the circuit.
- During this same period the voltage required to reignite the arc increases with time.
- If the voltage of step 5 is greater than the voltage described in step 6, the arc restikes, they continue until the next current zero to repeat the process with greater gap spacing between the parting contacts.
- If, on the other hand, the voltage of step 6 is greater than that of 5 the arc fails to restrike and the circuit is interrupted.

(19) Explain the following ionising processes (a) Radiation (b) High temperature (c) Electron collision

(d) Emission from metal

(a) Radiation: All space on the earth is constantly bombarded and penetrated by very high energy submicroscopic particles. Some of these come from the sun and are known as cosmic rays. Others come from the disintegration of radioactive materials which are present in very minute quantities in the earth and even in all living organisms, including the human body. These high-energy particles, when passing near the electron of a neutral molecule, may knock off one or more electrons form the molecule. One or more free electrons are produced and one positive ion is generated.

(b) High temperature: As a gas is raised in temperature, the molecules constituting the gas move at higher velocity. If the temperature is high enough, the collision of two gas particles may result in the detachment of one or more electrons and the generation of a positive ion. It is found that gases constituting a high-temperature flame are highly conductive.

(c) Electron collision: If an electric field is set up in a gas volume by applying voltage between two electrodes, those electrons and positive ions generated by cosmic rays and radiation particles begin drifting; the electrons move toward the anode, the positive ions toward the cathode. As these particle drift, they collide with neutral gas molecules. If the energy gained by an electron in a free path between collisions is sufficient, the collision may result in the ionization of another gas molecule, hence the generation of another free electron and another positive ion. Ionization of electron collision increases rapidly as th voltage gradient in the gas volume is increased.

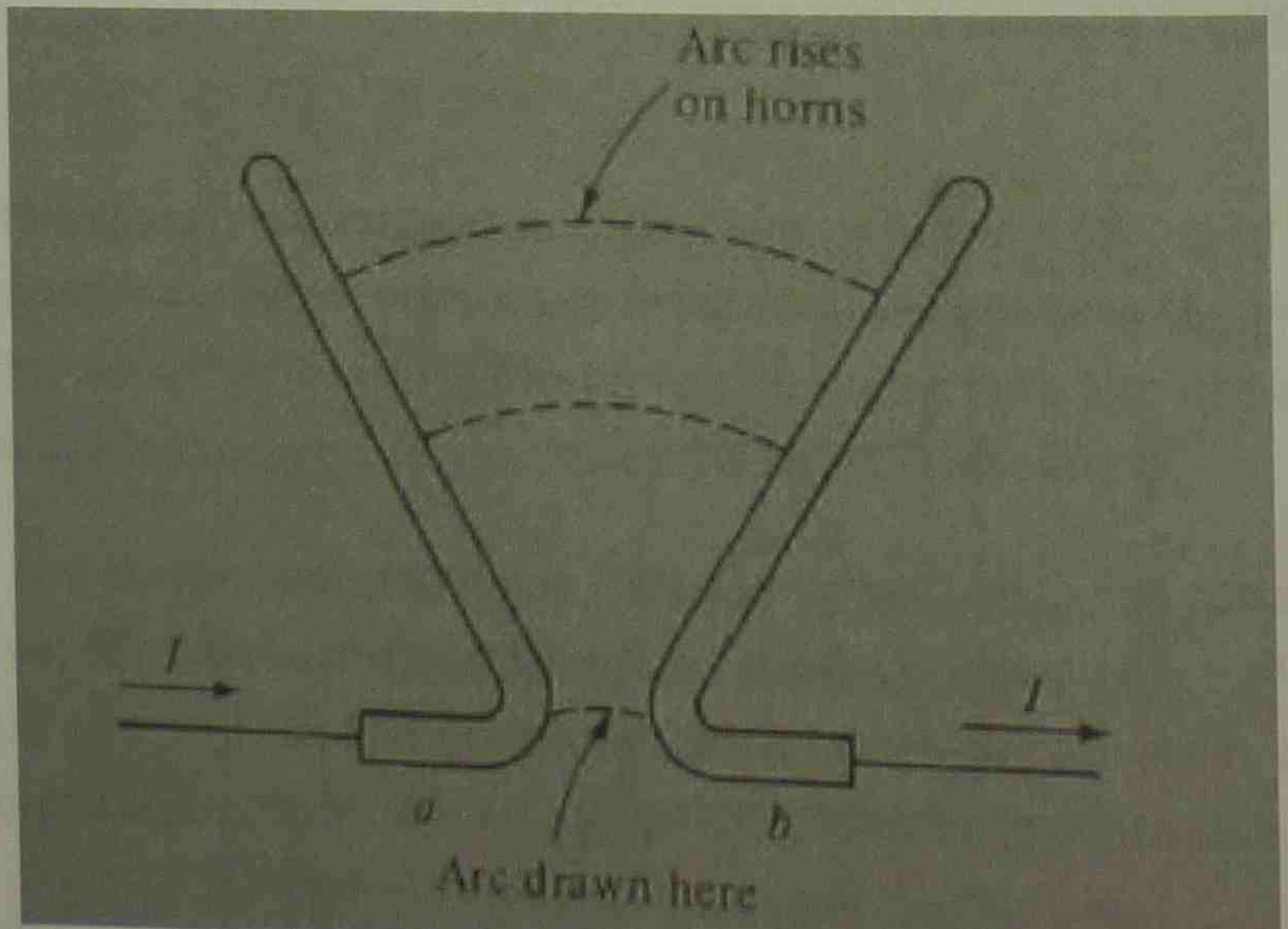
(d) Emission from metal: Electrons may be released into a gas volume from a metal surface. Metals that have high boiling points, such as tungsten or carbon, when raised to a high temperature by any method, may "boil out" many electrons into the gas volume. This is known as thermionic emission. High field emission may cause the discharge of electrons from a metal surface at a small area known as a cathode spot even at relatively temperatures.

(20)Explain arc and arc interruption.

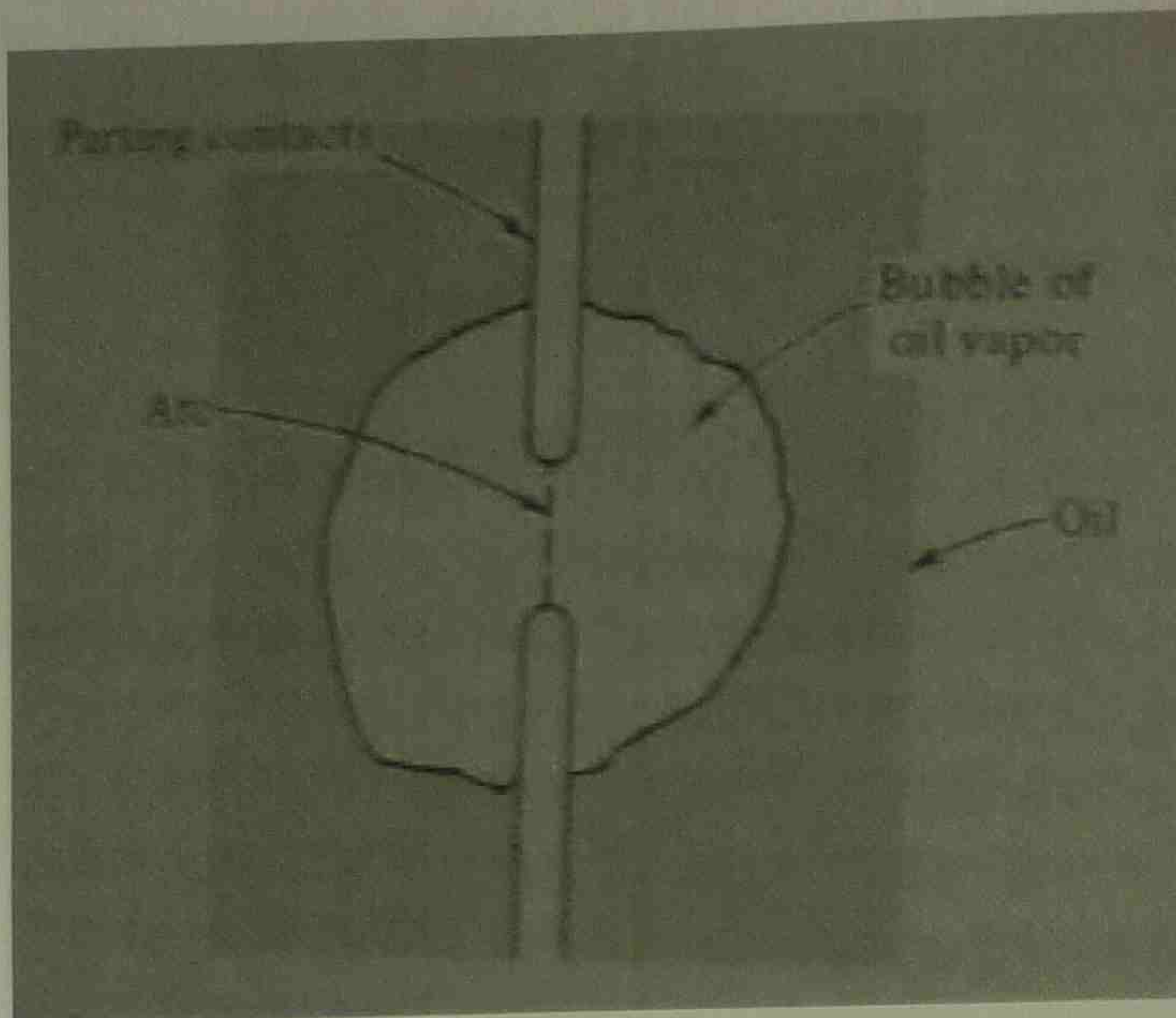
In the lightning flashover of transmission line insulators, the extremely high voltage causes electric potential gradients in the air of such value that ionization by collision produces a condition known as spark over. The spark quickly changes to the condition known as an arc as power-frequency current follows the breakdown path. In an electric welder system, the arc is started by separating two electrodes which are momentarily touched together. In a circuit breaker or fuse the separation of the contacts results in an arc drawn between them. The current in the arc may be a fraction of an ampere or many thousands of amperes. The cathode is of first importance in the arc because it emits electrons in great numbers. The movement of these electrons to the anode accounts for perhaps 90% of current. These electrons may be emitted from the cathode due to thermionic emission if the cathode is of high-melting-point material such as carbon or tungsten. They may be emitted from a cathode spot by field emission if the cathode is of copper or other material of relatively low melting temperature.

(21)Sketch (a) Air circuit breaker (b) Oil circuit breaker.

(a) Air circuit breaker:



(b) Oil circuit breaker:



(22)What is resistance switching?

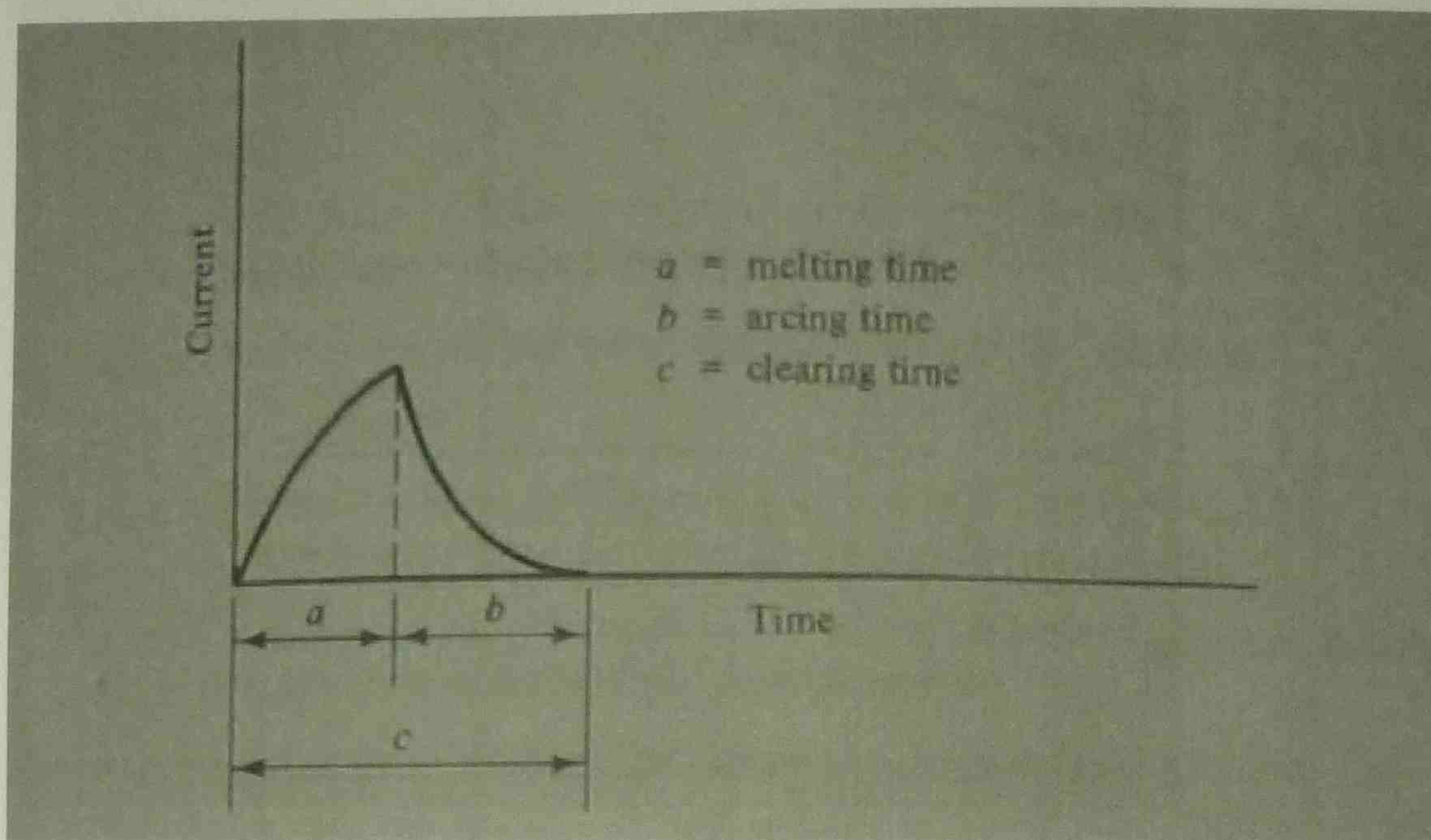
The resistance switching characteristics of polycrystalline Nb_2O_5 film prepared by pulsed-laser deposition (PLD) were investigated for nonvolatile memory application. Reversible resistance-switching behavior from a high resistance state to a lower state was observed by voltage stress with current compliance. The reproducible resistance-switching cycles were observed and the resistance ratio was as high as 50-100 times. The resistance switching was observed under voltage pulse as short as 10 ns. The estimated retention lifetime at 85°C was sufficiently longer than ten years. Considering its excellent electrical and reliability characteristics, Nb_2O_5 shows strong promise for future nonvolatile memory applications

(23)Sketch the performance of current limiting fuse.

Fuses are broadly classified as non-current-limiting or current limiting. Since all fuses limit excessive currents, these excessive currents, this classification refers in reality to the manner in which the rating of fuse is set forth in the standards. In most cases where it applied, a current-limiting fuse opens the circuit before the first peak of the short-circuit current; a non-current-limiting fuse opens it one cycle or more after the fault inception.

The continuous current rating, or simply current rating, of a fuse Is that current which it is capable of carrying indefinitely without deterioration or excessive temperature rise. Since the voltage affects there arcing occurring in a fuse after it has melted, a fuse also has a voltage rating. A fuse obviously cab operates a current and voltage levels lower than rated.

The current-limiting fuses, we have to deal first with certain fundamental concepts. The interrupting rating of a fuse is the maximum rms short-circuit current which may possible occur where fuse is used. Thus, at a point in the electric circuit, if the calculated short-circuit current is 75,000 amperes, no fuse should be sued with interrupting rating inferior to that value. Let a fuse be used with an interrupting rating of 100,000 amperes. This does not mean that the fuse would ever allow a 75,000. A fault current ot flow through it., even for one cycle; that brings us now to the next definition.

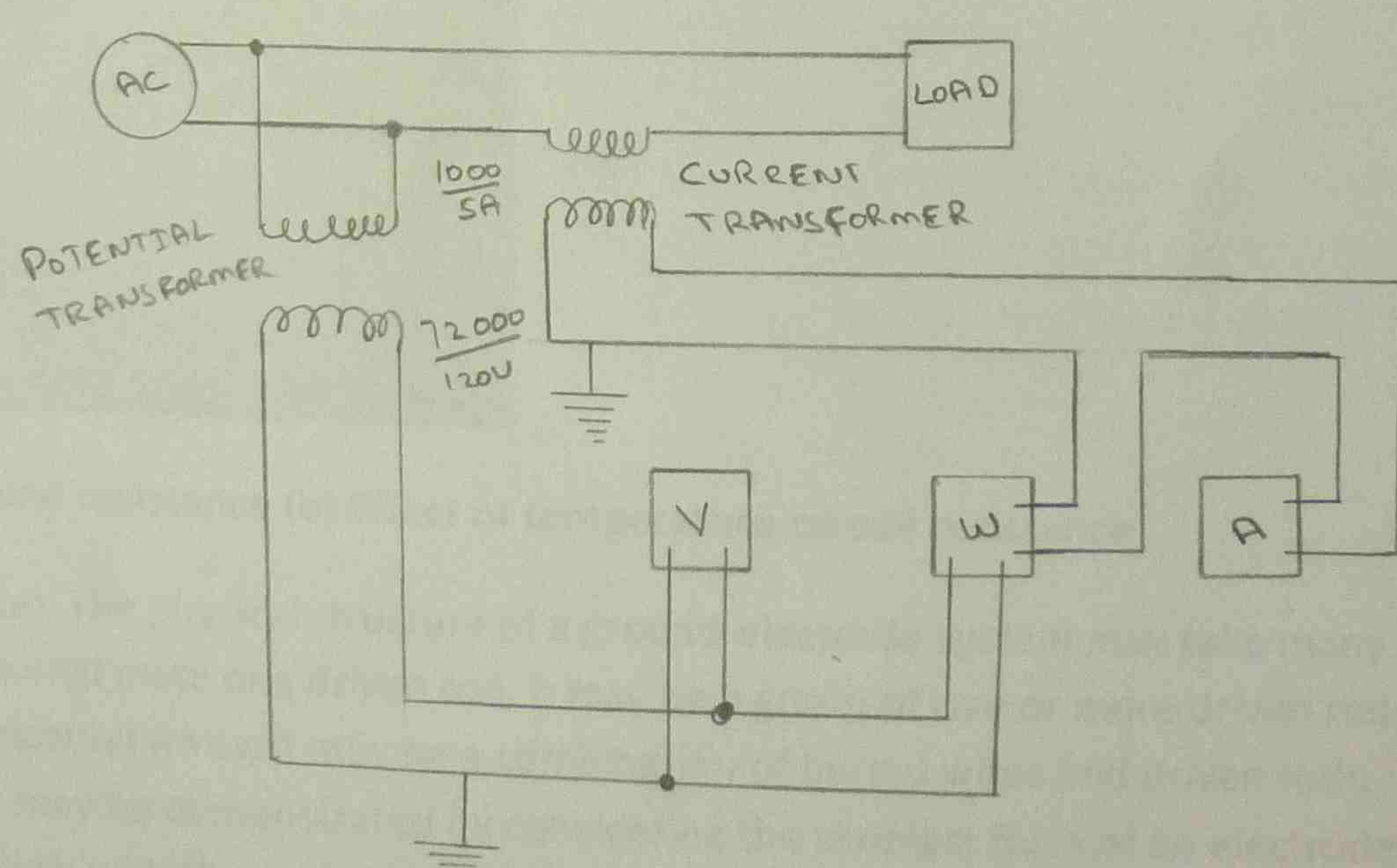


(24)List the instruments for system monitoring

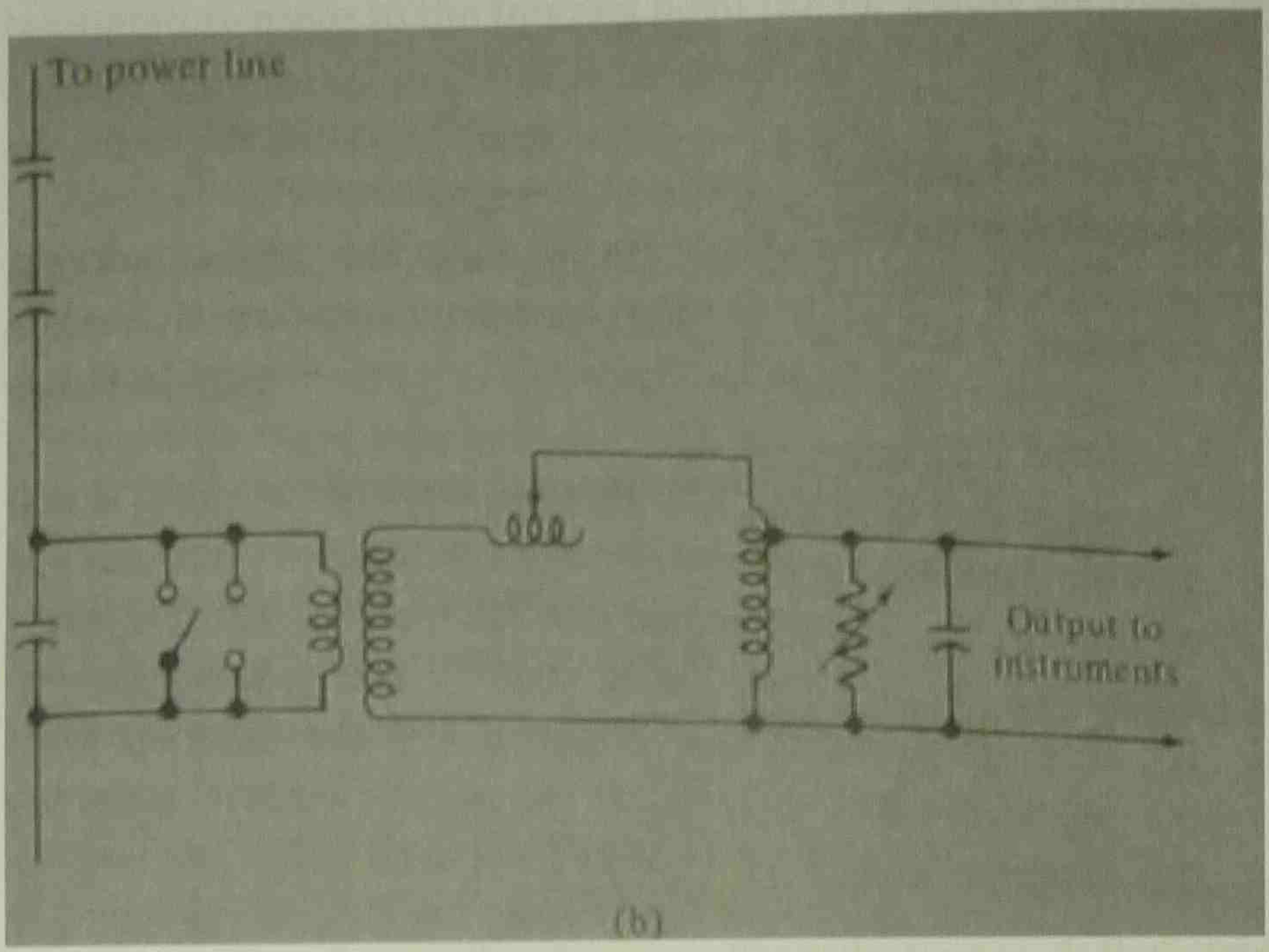
The instruments used for system monitoring include the following:

Voltmeters, Ammeters, Wattmeter's, Watt-hour meters, Frequency Meters, Synchroscopes, Relays, Varmeters, and Automatic Oscillographs.

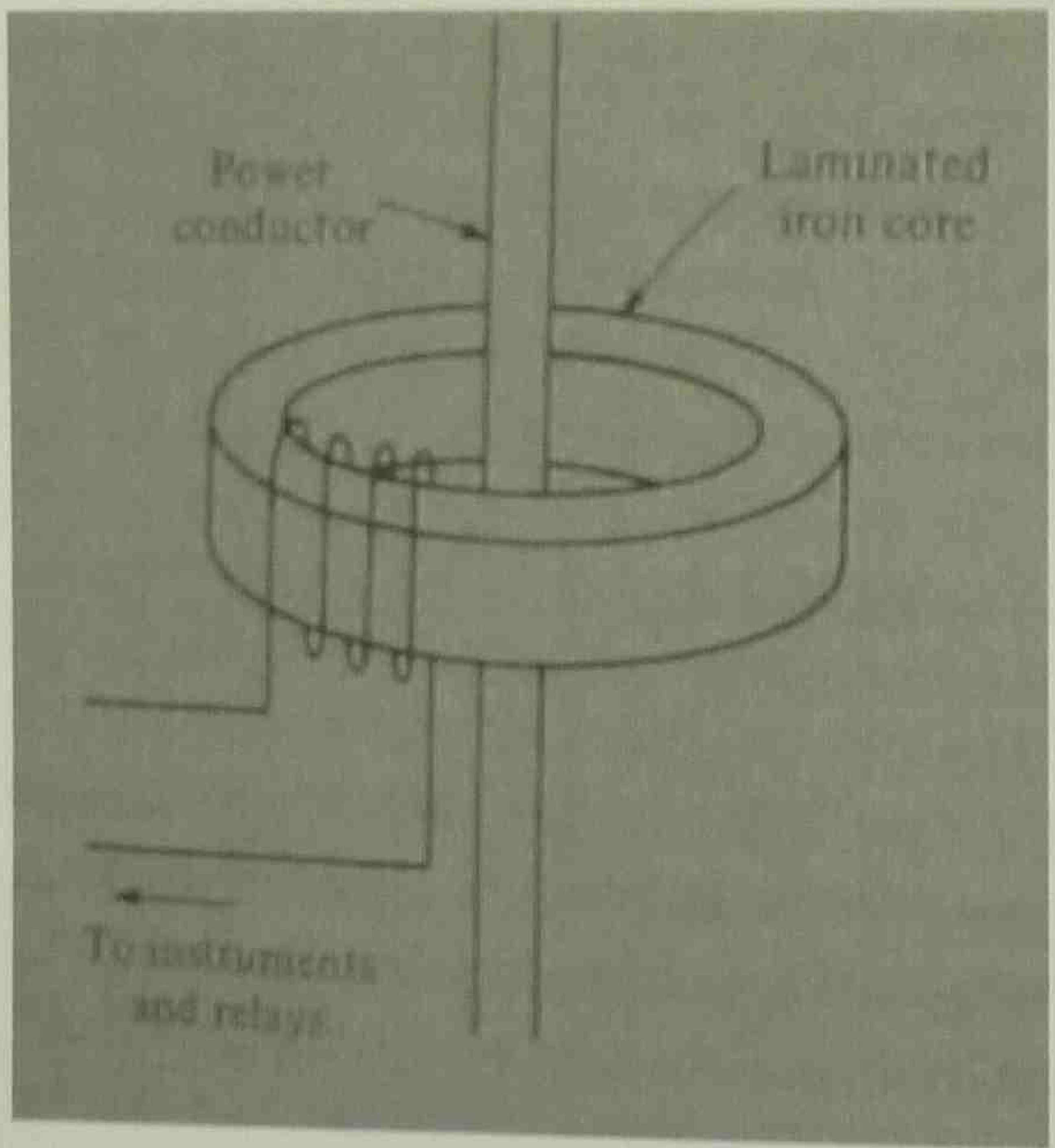
(25) Sketch V, I, W meter connection by using CT and PT.



(26) Sketch capacitor potential device.



(27) Sketch bushing type current transformer.



(28) Explain (a) Ground resistance (b) Effect of temperature on soil resistance.

(a) Ground resistance: The physical structure of a ground-electrode system may take many different forms. It may be a buried plate or a driven rod; it may be a group of two or more driven rods or a system of buried horizontal wires; it may be a combination of buried wires and driven rods. The concept of ground resistance may be demonstrated by considering the simplest form of an electrode, a metal hemisphere buried flush with the surface of the earth.

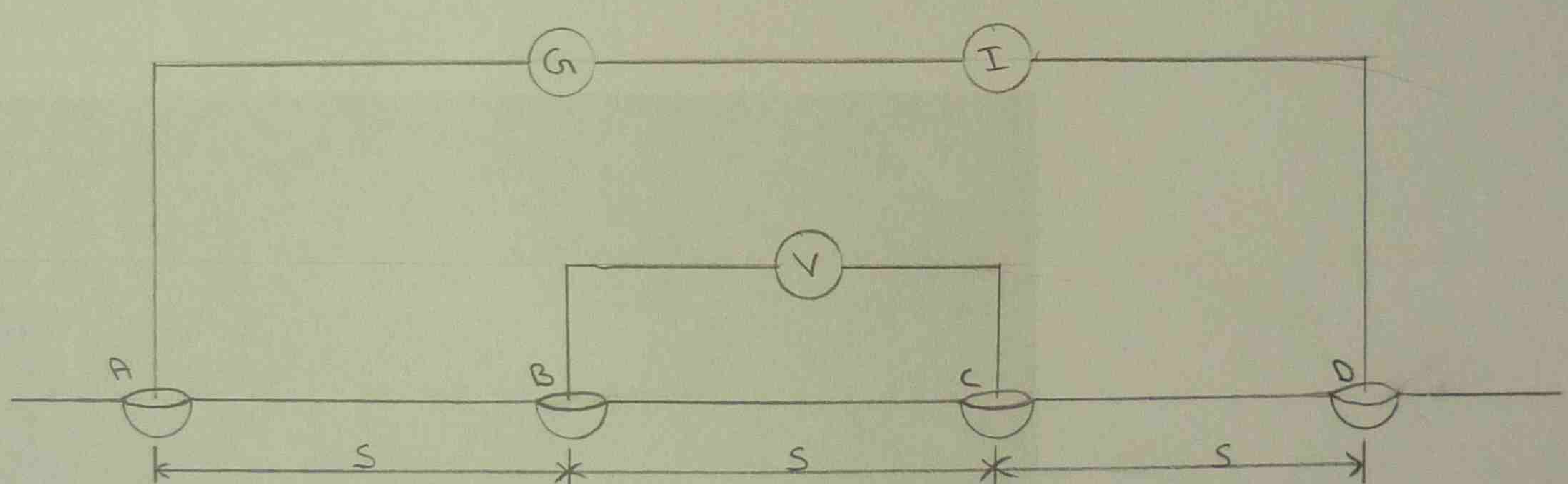
(b) Effect of temperature on soil resistance: The resistivity of soil increases rather slowly as temperature drops to the freezing point (32^0F). Below the freezing point the resistivity raises very capably with further decrease in temperature.

Since both temperature and moisture connect strongly affect the value of the resistivity of soil, seasonal variations of resistivity are to be expected, particularly in these soil layers near the surface. A ground-electrode system buried more deeply within the ground is obviously more stable in characteristics.

(29) Explain the methods to measure soil resistivity.

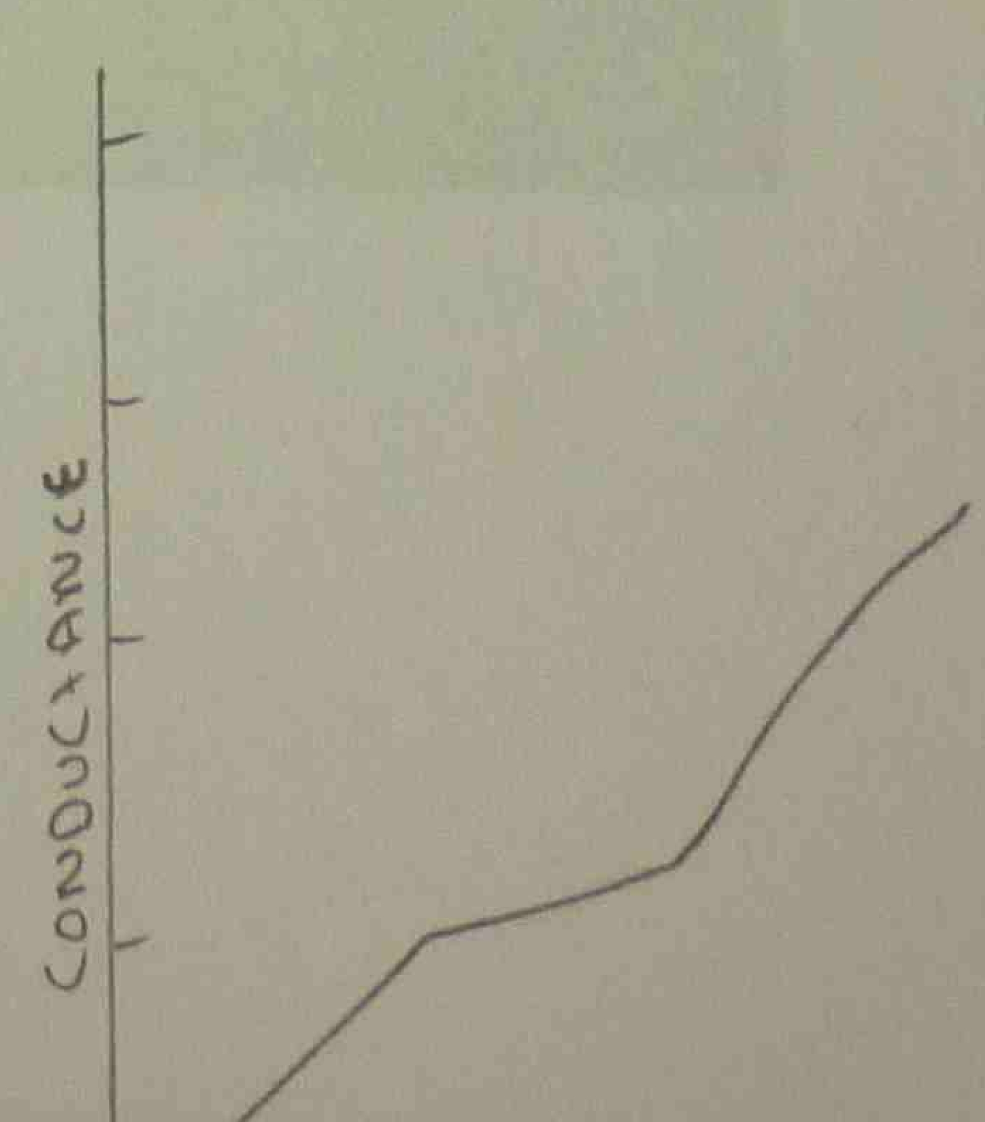
Soil resistivity may be measured by several different methods, two of which are described. As all the formulas for ground resistance, as a common factor, the resistivity of the soil, it is apparent that knowledge of soil resistivity is helpful to the designer of a ground-electrode system to be installed at a particular location

A) Four-Electrode Method of Measuring Resistivity: A commonly used method of measuring earth resistivity is described with reference. Four electrodes, A, B, C, and D, are placed in the ground in a straight line with spacing S. Short driven rods serve equally well and are more convenient to obtain and use. A current I is circulated through the ground between electrodes A and D. The voltage, V, Between B and C is measured.



(b) Driven-Ground-Rod Method: The resistivity of soil at varying depths may be determined quite accurately by driving a ground rod into the soil and making a measurement of its resistance, periodically, during the driving process. A curve is then plotted showing the rod conductance G plotted against depth L. The formula for the resistance of a driven ground rod was given as

$$R = \frac{\rho}{2\pi L}\left(\log_e \frac{4L}{a} - 1\right)$$



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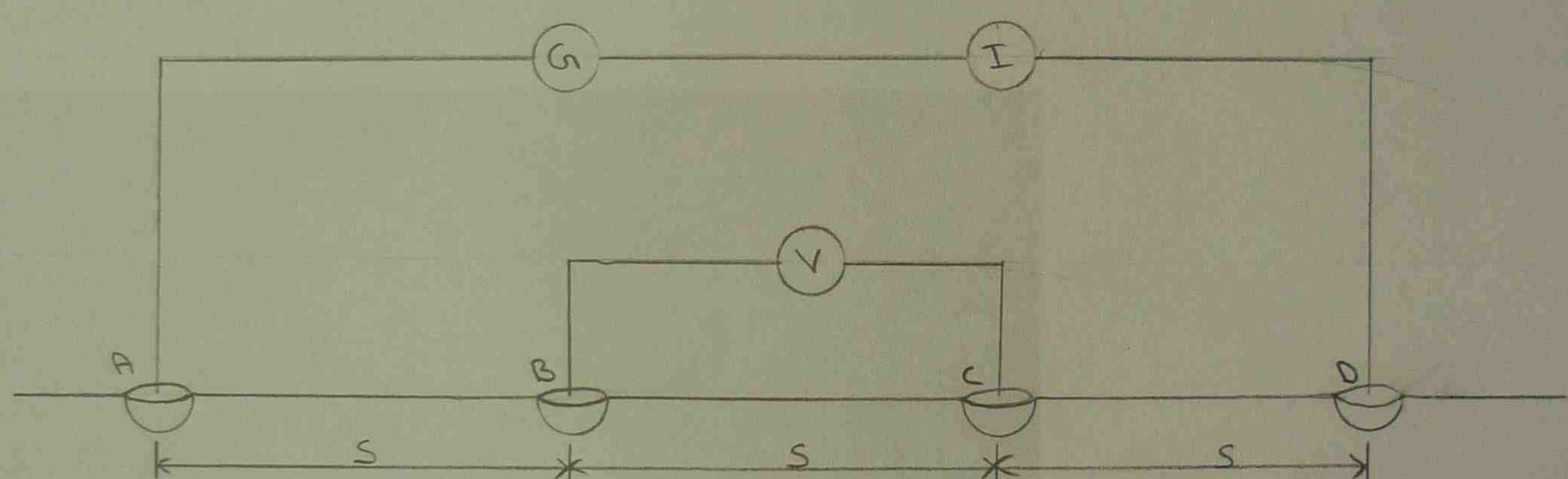

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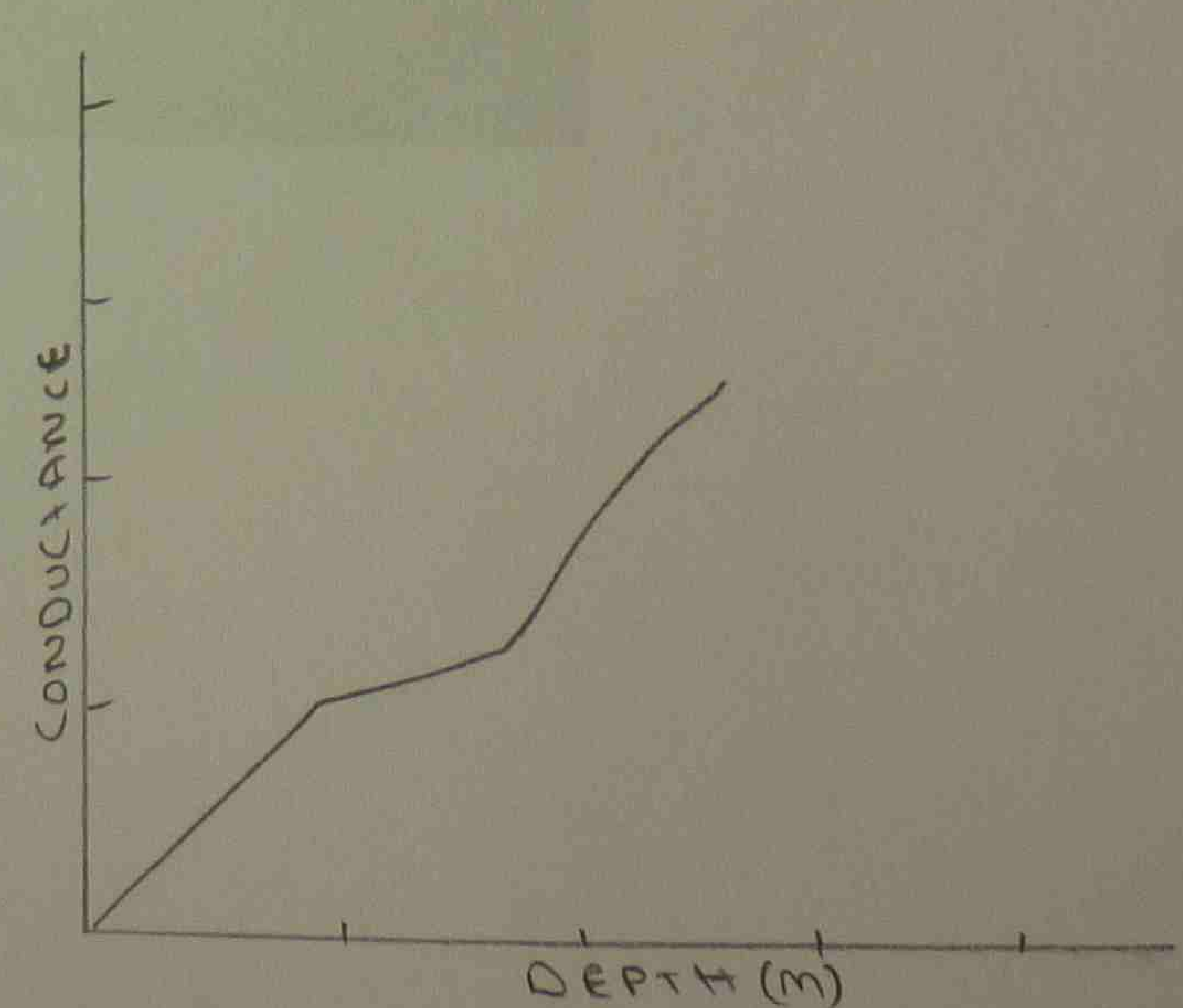
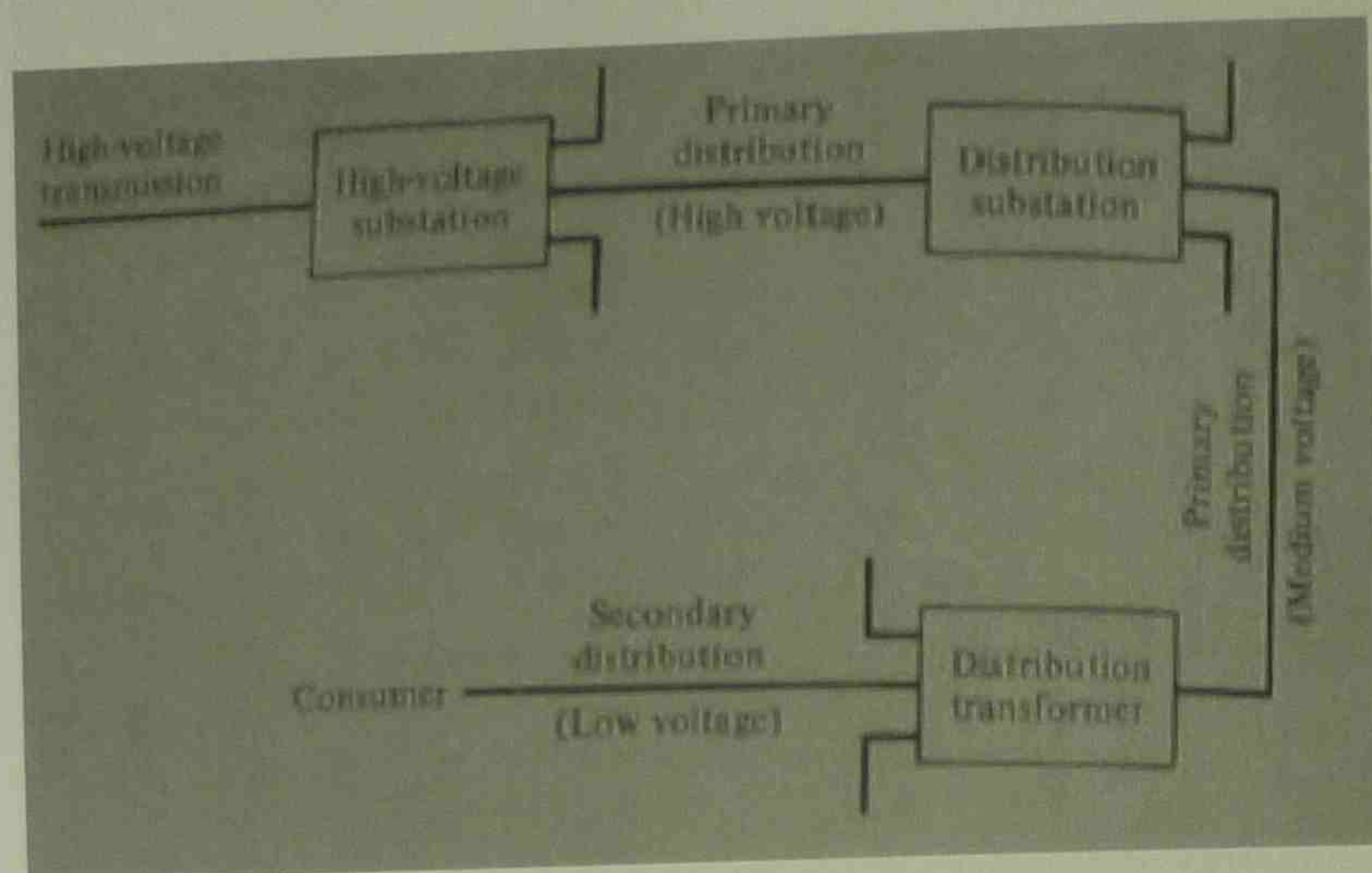
$$R = \frac{\rho}{2\pi L}\left(\log_e \frac{4L}{a} - 1\right)$$

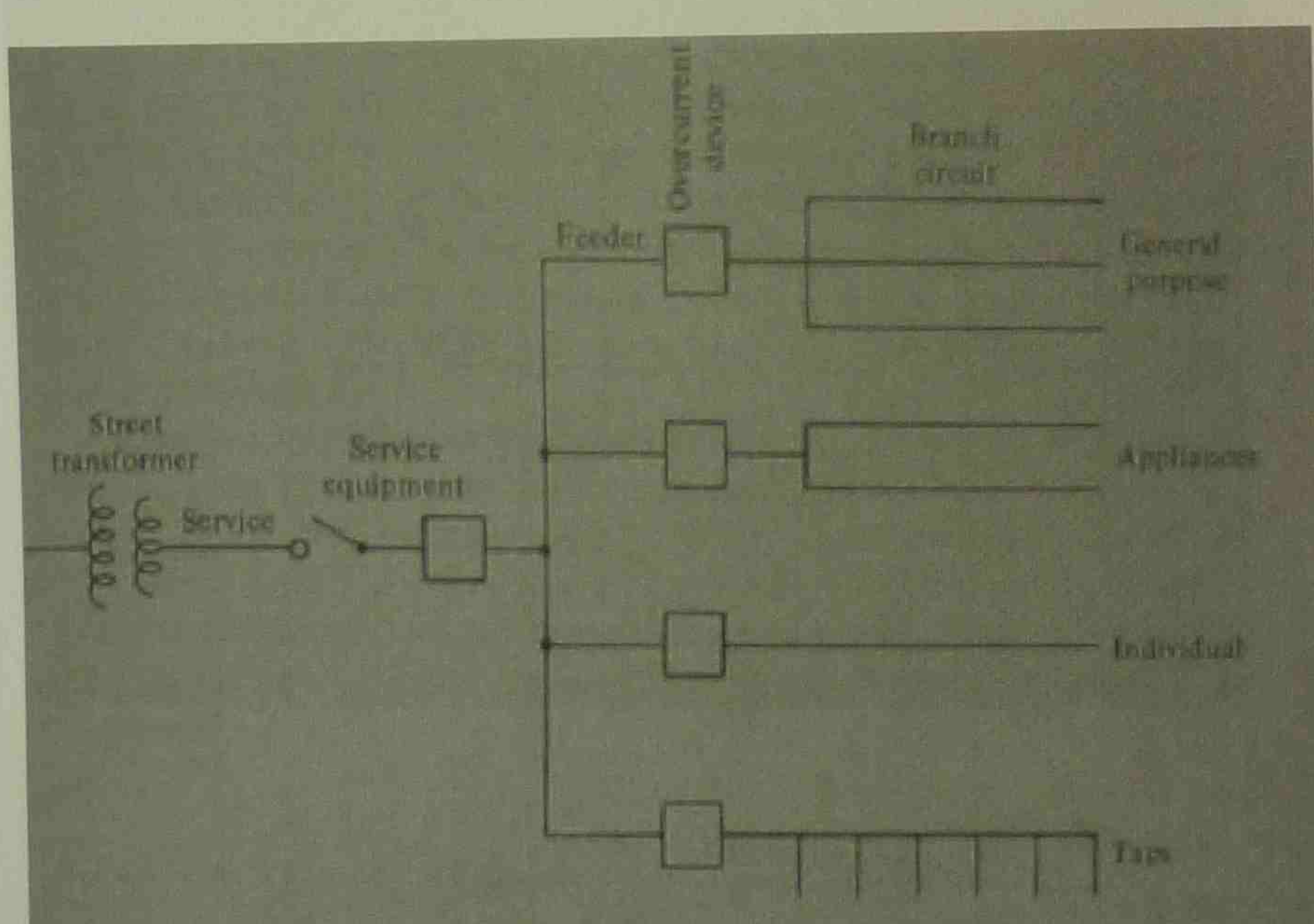


(30) Sketch basic distribution consumer connection to distribution transformer, layout of power Distribution system in large industrial plant

Basic distribution connection:



Consumer connection to a distribution transformer:



layout of power Distribution system in large industrial plant

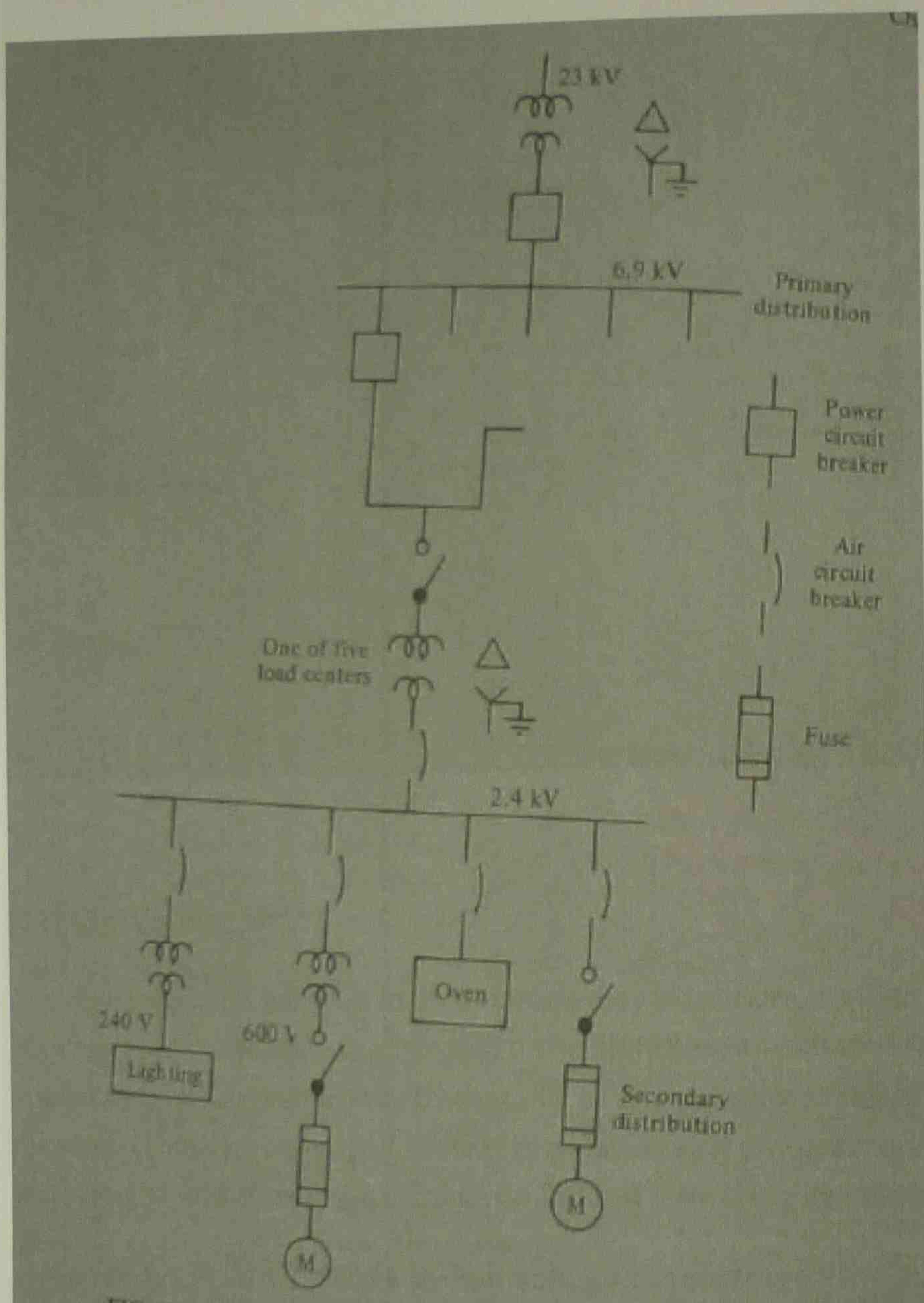


FIG. 14-3. Layout of the power distribution system in a large industrial plant

(31) Sketch secondary loop configuration.

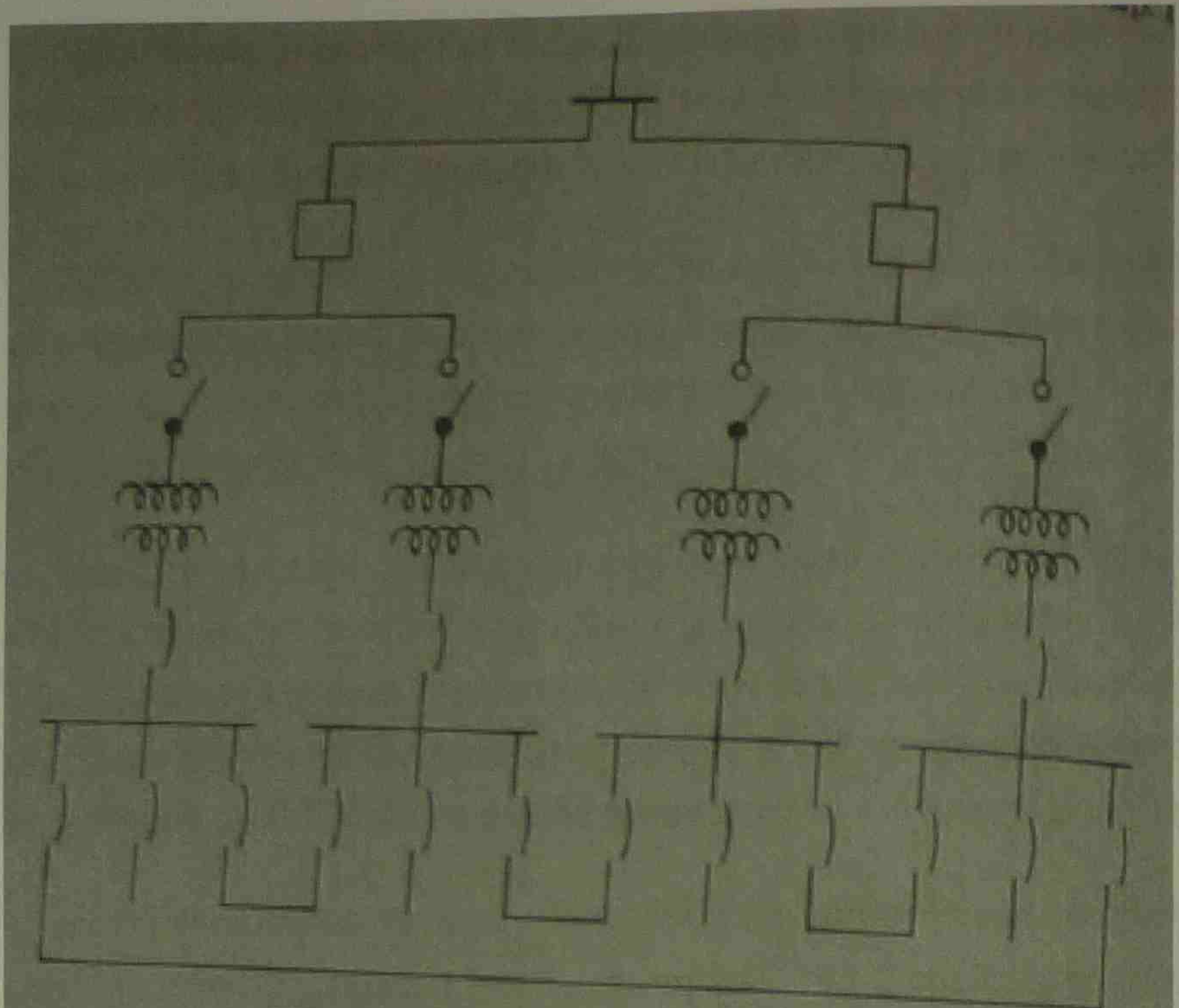


FIG. 14-7. Secondary loop configuration.

(32) Explain race way.

Cables may run isolated in air supported by insulators, stapled to boards, through holes in boards, or in raceways. A raceway is a general terms denoting any channel used expressly for holding bare or insulated conductors. It may be metallic or of insulating material. The number of conductors in a raceway is limited by reason of heat dissipation and physical considerations such as the necessity of installing or withdrawing a conductor without damaging its insulation.

Raceways must be shared by low-voltage conductors and high-voltage conductors for reasons of safety. Low-voltage conductors sharing a raceway must be of the same voltage class. Thus, low-voltage conductors of light and power systems may run in the same raceway provided all conductors are insulated for the highest voltage in that raceway.

Ducts used to carry dust, loose materials, steam, or flammable vapors may not be used as raceways. However, ducts used for environmental air may contain wiring systems enclosed in rigid metal conduits.

Raceways may come in the form of cable trays of various shapes. Cables normally run freely on horizontal trays but are fastened securely to sloping trays. If each phase or neutral of a circuit is made up of more than one single-conductor cable, groups of cables are formed such that each group consists of a single conductor per phase or neutral. This reduces mutual inductance between parallel conductors and concomitant current unbalance. Cables within a group are securely field together to reduce their movement due to magnetic forces arising from fault currents.

(33) Explain grounding.

Circuits are grounded in order to prevent high voltages from building up on the conductors, while equipment grounding aims at preventing enclosures from reaching voltages above ground. Grounding thus improves system protection and reliability and provides safety to people standing by.

Grounding every circuit, however, makes the system susceptible to excessive currents should a short circuit develop between a live conductor and ground. Thus not all neutrals of wye-connected loads should be grounded. Grounding should then be practiced selectively, especially on the primary distribution system.

The cross section of the grounded conductor should not be less than one-eighth that of the largest phase conductor in order to ensure a good conducting path if a live conductor gets shorted to ground. The equipment grounding conductor runs to the enclosures of the various equipments used on the premises in order to provide them with a good connection to ground. The mere standing of a piece of equipment on the floor does not mean that its enclosure is well grounded.

Metal enclosures, raceways and fixed equipments are normally grounded. However, motors and generators well insulated from ground and metal enclosures used to protect cables or equipments from physical damage may be left ungrounded. Also portable tools and home appliances, such as refrigerators and air conditioners need not be grounded if constructed with double insulation.

(34) Explain the following substation equipments (a) Busbar (b) Regulator (c) CB (d) Instrument transformer (e) Relay (f) Differential relaying (g) Pilot protection (h) Microwave relaying (i) Ground relay (j) Voltage surge (k) Basic Insulation Level

(a) Busbar: Busbar is term used for a main bar or conductor carrying an electric current to which many connections may be made.

Buses are merely convenient means of connecting switches and other equipment into various arrangements. The usual arrangement of connections in most substations permits working on almost any piece of equipment without interruption to incoming or outgoing feeders.

(b) Regulator: A regulator is really a transformer with a variable ratio. When the outgoing voltage becomes too high or too low for any reason, the apparatus automatically adjusts the ratio of transformation to bring the voltage back to the predetermined value. The adjustment in ratio is accomplished by tapping the winding, varying the ratio by connecting to the several taps. A panel mounted in front of the regulator contains the relays and the other equipment that control the operation of the regulator.

(c) Circuit Breakers: Oil circuit breakers were sued to interrupt load or fault current by making or breaking electrical contact. The oil served to quench the arc as the contacts opened. Transmission breakers are designed to operate very fast as compared to distribution circuit breakers. Transmission circuit breakers operate automatically through relay protection arrangements, or manually by remote control from a nearby control panel in the substation.

(d) Instrument transformer: When values of current or voltage are large, or when it is desired to insulate the meter or relay from the circuit in which they are to operate an instrument transformer is used. The ratio of transformation reduces the high-current circuit, which in this case is the primary of the transformer, to a smaller current in the secondary connected to the ammeter or relay.

(e) Relay: A relay is a low-powered device used to activate a high-powered device. In a transmission or distribution system, it is the job of relays to give the tripping commands to the right circuit breakers. Relays are used to protect the feeders and the equipment from damage in the event of fault. In effect, these relays are measuring instruments but equipped with auxiliary contacts that operate when the quantities flowing through them exceed or go below some predetermined value.

(f) Differential relaying: In providing protection against faults or buses, current supplied to the bus is measured against current flowing from it. These should be equal. When a fault develops on such a bs this balance is disturbed, and a relay will operate, usually clearing both incoming and outgoing feeds from the bus. This is known as differential relay.

(g) Pilot protection: The simultaneous opening of circuit breakers at the terminal of transmission lines may be accomplished by means of a communication link between the circuit breakers involved

This link may consist of physically separate pilot wires. Two schemes employing over current relays at each end. All of these employ three to six pilot wires. One scheme employing only two pilot wires, polyphase directional relays at each end, and a direct current source.

(h) Microwave relaying: In microwave relaying, the pilot systems are transmitted over microwave radio channels. This system is not subject to line faults, and it may also accommodate several other separate functions. Because the transmissions are affected by line-of-sight limitations, several units may be required for long and tortuous lines. The intermediate units receive their signals and retransmit them to the next unit.

The pilot schemes are operate to keep the circuit breakers closed. When the line is faulted, the signals are interrupted, and the relays operate to open the circuit breakers. Similarly, if the pilot systems, including carrier and microwave system, fail for any reason, the circuit breakers open deenergize the lines and transmission system 'fail-safe'.

(i) Ground relay: Other schemes measure the flow of so-called ground current. In a transmission line, the currents flowing in each of the conductors are usually fairly well balanced in magnitude. The return or ground conductor carries little or no current. By measuring this directly, or by measuring each conductor and determining the difference, this ground current can be made to actuate relays when it exceeds certain predetermined values. Other more sophisticated schemes are sometimes used, but generally they employ one or more of the described basic ideas.

(j) Voltage surge: Voltage surges can occur from lighting, switching, or fault conditions. Whatever the source, it is necessary to consider the effects not only on the transmission lines themselves, but also on the equipment that may be connected to them. These include switches, circuit breakers, transformers, generators, buses, regulators and any other device that may be connected to them. Generally, these are situated at generating stations and substations. Much of this equipment is similar to and operates in the same manner as that found in distribution substations; however, several are of greater importance for the transmission system.

(k) Basic Insulation Level: The operating voltages in a transmission system are relatively high, special attention is given to the insulation associated with the several parts of the system. This is true both in the lines as well as in the stations. The insulation here has to withstand not only the normally applied operating voltages.

Levels of insulation that will safely sustain the surge voltages, known as basic insulation levels (BIL), have been set up for electrical apparatuses, such as transformers, circuits breakers, and switches. These designated minimum levels may be from 2-3-1/2 times the normal operating voltage, depending on the degree of reliability desired. The minimum insulation level should prevail under wet conditions, and in general, should be the same for line insulation as for apparatus insulation.

(35) Explain (a) Short circuit duty (b) Stability (c) Lightning surge protection (d) UG Transmission (e) DC Transmission.

(a) Short circuit duty: When a fault or short circuit occurs on transmission linen, the amount of current that will flow will be inordinately great. This current flow not only through the transmission line conductors, but through all the apparatuses connected to it. This high-magnitude current produces magnetic fields of great intensity with corresponding great forces. These forces tend to pull conductors apart and damage lines and equipment. Hence, equipment, particularly circuit breakers, must be rugged enough to withstand these disruptive forces. These measures of the ruggedness of the equipment is referred to as the interrupting capacity or "short-circuit duty". It is generally expressed in kVA or mVA.

(b) Stability: When fault occurs on a transmission grid supplied by two or more generators, the current flow to the fault will be proportioned to the distance of the several generators. Thus, the generator closest to the fault will supply the greatest share. As these heavy currents are imposed on the several generators, it will cause them to slow down, but not equally. Again, the one supplying the greatest share of current will slow down the most.

These generators will no longer operate "instep". The one that slow down least will attempt now to supply the other generators connected to grid, which are now "bucking" it. This will cause it to sow down and the process reverses. A rocking back and forth effect between generators will ensue.

(c) Lightning surge protection: Voltage surges caused by lightning or switching are more apt to result in flashover across insulator strings and to the tower or support structure. They involve problems of clearances and insulator swing geometrics.

Lighting striking at or near an overhead transmission line creates surges of voltage that travel along the line. This action is the same for all overhead lines exposed to lighting. Extra-high-voltage transmission lines differ in that the line current that flows in the flashover tends to be much greater because of the greater line voltage. This greater current imposes greater stress on the equipment through which it may flow with possible damage to equipment. This is especially true of the circuit breaks called upon to interrupt such currents.

(d) UG Transmission: The capacitance or condenser effect of high-voltage cable absorbs energy and limits the amount of useful energy as well as the distance over which it may be transmitted. To reduce this capacitance effect, compressed gas at 50 pounds per square inch pressure is employed as insulation in extra-high-voltage cables. While satisfactory for this purpose it introduces problems of maintenance. This form of insulation can withstand the great stress of high voltages under varying temperature and current loading conditions.

(e) DC Transmission: Many benefits can be realized by using DC for high-voltage transmission. In AC circuits, the effective voltage is 70.7% of the peak value the line carries in DC circuits, the effective and peak values are one and the same. Hence, for a particular voltage rating, the DC circuit requires only 70.7% of insulation required by AC circuit. Conversely, with the same size cables and the same insulators, a DC line can carry about 40% more power. Further, the conductors are not subject to skin effect, although corona discharge continues to be a problem.

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(36) Explain (a) Built in CB (b) ABCB (C) OCB (d) Vacuum interrupter

(a) Built in CB: A cross-section of an oil circuit breaker with all three phases in one tank. There are two sets of contacts per phase. The lower and moving contacts are usually cylindrical copper rods and make contact with the upper fixed contacts. The fixed contacts consist of spring-loaded copper segments which exert pressure on the lower contact rod, when closed to form a good electrical contact. On opening, the lower contacts move rapidly downwards and draw an arc. When the circuit breaker opens under fault conditions many thousands of amperes pass though the contacts and the extinction of the arc are major engineering problems.

Effective opening is only possible because the instantaneous voltage and current per phase reduces to zero during each alternating current cycle. The arc her cause the evolution of hydrogen bubble in the oil and this high pressure gas pushes the arc against special vents in device surrounding the contacts and called a “turbulator”.

(b) ABCB: for voltages above 120 kV the air-blast breaker has been popular because of the feasibility of having several contact gaps in series per phase. Schematic diagrams of two types of air-blast head. Air normally stored at 1.38 MN/m^2 is released and directed at the arc at high velocities, thus extinguishing it. The air also actuates the mechanism of the movable contact. A 132kV air-breaker with two breaks per phase and its associated isolator or series switch. Although air-blast circuit breakers have been developed and installed up to the highest voltages they have been largely superseded by the SF_6 gas circuit breaker.

(C) OCB: The quenching mechanisms are enclosed in vertical porcelain insulation compartments and the arc is extinguished by a jet of oil issuing from the moving as it opens. The volume of oil is much smaller than in the bulk-oil type, thereby reducing hazards from explosion and fire. Although many oil circuit breakers are in use, particularly at distribution voltages, modern practice is to use SF_6 or vacuum breaker to avoid the presence of flammable liquids for circuit-interruption purposes.

(d) Vacuum interrupter: A pair of contacts opening in vacuum draws an arc which burns in the vaporized contact material. The contact material and its arcing root shape are crucial to the design of commercial interrupter.

The main advantages of a vacuum interrupter are:

- The very small damage normally caused to the contacts on operation, so that a life of 30 years can be expected without maintenance;
- The small mechanical energy required for tripping; and
- The low noise caused on operation. The nature of the vacuum arc depends on the current; at low current the arc is diffuse and can readily be interrupted, but high currents the arc tends to be constricted.

(37) What are qualities required for protection

A few terms often used to describe the effectiveness of protective gear will now be described:

- *Selectivity or discrimination:* its effectiveness in isolating only the faulty part of the system.
- *Stability:* the property of remaining inoperative with faults occurring outside the protected zone.
- *Speed of operation:* this property is more obvious. The longer the fault current continues to flow, the greater the damage to equipment. Of great importance is the necessity to open fault sections before the connected synchronous generators lose synchronism with the rest of the system.
- *Sensitivity:* this is the level of magnitude of fault current at which operation occurs, which may be expressed in current in the actual network or as a percentage of the current-transformer secondary current.

(a) Distribution transformer: Distribution transformers may be installed on poles, on the ground on pads and under the ground directly or in manholes and vaults. The transformers used in these types of installations differ mainly in their packaging, as the internal operating features are very much the same.

The overhead type of distribution transformer is mounted directly on a pole by means of two lugs, welded to the transformer tank that engage two bolts on the pole. This is known as direct mounting. Transformers may be mounted on concrete pads at or slightly below, ground level within an enclosure or compartment that may be locked for protection.

(b) Underground transformer: In the underground type of transformer, also called the subway type, the tank is not only hermetically sealed for water tightness, but its walls, bottom, and cover are made thicker to withstand higher internal and external pressures; the cover is bolted to the tank by a relatively large number of bolts, and in some instances, welding is used. These units are designed to operate completely submerged in water.

In larger units, where cooling of the tank itself is not sufficient, radiator fins are welded to the tank to provide additional cooling surface, or pipes are welded to the tank for the circulation of oil through them; in the latter case, the additional surface of the pipes as well as the circulating oil is useful for cooling.

Connections to the supply cables are made by means of watertight wiped joints between a fluid-tight bushing and the cable sheath. Another means provides for the making of connections in a chamber attached to the transformer tank in which the primary-voltage transformer windings are brought out in fluid tight bushings.

(c) Transformer cooling: Most distribution transformers, whether overhead, pad-mounted, or subway types, have their cores and coils submerged in insulating oil. The heat produced by the iron and copper losses is carried by convection currents in the oil to the tank and there dissipated into the atmosphere. Excessive temperatures and the formation of hot spots are thus prevented, avoiding damage to the insulation and conductors.

Moisture and sludge formed from the effect of the oxygen in the air on hot oil tend to reduce the dielectric quality of the oil. Where the use of oil undesirable, principally because of fire hazard, air-cooled or askarel-cooled units may be employed, although these are generally limited to larger sizes and to transformers installed in vaults.

(d) Fuse cut-outs: Distribution transformers are usually connected to the primary supply lines through a fuse cutout. The cutout contains a fusible element whose melting automatically disconnects the transformer from the primary to prevent damage from overloads; it also disconnects the line from the transformer in the event of a fault in the transformer, not only preventing spread of damage in the faulted transformer, but also preventing interrupting to the primary supply circuit that would affect other transformers and consumers served from the circuit.

- *Economic consideration:* in distribution system the economic aspect almost overrides the technical one, owing to the large number of feeders, transformers, etc., provided that basic safety requirements are met. In transmission systems the technical aspects are more important. The protection is relatively expensive, but so is the system or equipment protected and security of supply is vital. In transmission two separate protective systems are used, one main and one back-up.

- *Reliability:* this property is self-evident. A major cause of circuit 'outages' is mal-operation of the protection itself. On average, in the British system, nearly 10% of outages are due to this cause.

(38) Explain system monitoring & control

For a power system to be able to supply all its customers within normal voltage and frequently limits, it must be able to ride through unavoidable disturbances, some of which could be quire abnormal. Examples of abnormal, but nevertheless credible, disturbances are:

- Shunt faults and consequent line outages;
- Equipment failure with subsequent isolation
- Switching surges and lightning strikes;
- Mechanical damage

Some of these disturbances can be dealt with by protective devices, as discussed in previous sections, and the system restored to normal within a few cycles. In these cases no further control action Is needed. Others may cause transient oscillations which could last for several seconds, producing large oscillations in power flow, abnormal voltages and frequency, and subsequent tripping of plant items. If tripping occurs, then corrective control actions are required. For this purpose, an Energy Management System (EMS) is vital for any power system.

(39) What is system security and emergency control?

It has already been stated that the reason for designing and operating a system in meshed form is to provide a path form every generator to every load, despite the possibility that one or two circuits could be outage. A network configuration and loading state which enables any one circuit to be outage without loss of supply to any load is called $n-1$ secure. To determine the secure network configuration and state required for reach hour of the day is a daunting task, even with large and powerful computers. Normally, secure network states are calculated for a few representative loading conditions, including the daily peak, night minimum, and intermediate sub peak conditions.

Optimal power flows with many constraints are employed to determine the secure network configuration and economic loading, including any constrained-on or constrained-off plant. Security calculations are made at least 24h ahead by a.c or d.c, load flows, taking out critical circuits one-by-one.