

Electrical Power Generation, Transmission and Distribution (313333)

Model Question Paper — Set A · Model Answers

Q.1

a) Thermal and hydro power stations in Maharashtra.

2 M

Power station	Installed capacity (approx.)
Chandrapur Super Thermal Power Station (MAHAGENCO), Chandrapur	2920 MW
Koradi Thermal Power Station (MAHAGENCO), Nagpur	2190 MW
Koyna Hydro-Electric Project, Satara (Stages I–IV + dam foot)	1956 MW
Ghatghar Pumped Storage Scheme, Ahmednagar–Thane	250 MW

(Installed capacities are approximate and change when new units are added or old units are retired; any two correct stations with capacity get full marks.)

(Any two stations with capacity, 1 M each)

b) Cold reserve and spinning reserve.

2 M

- **Cold reserve:** It is that part of the reserve generating capacity which is **available for service but is not in operation** (machines are shut down and need time to start).
- **Spinning reserve:** It is that part of the reserve generating capacity which is **connected to the bus bars and ready to take load** (running in synchronism at no load / part load) to meet sudden load increase or loss of a unit.

(Each definition 1 M)

c) Standard voltage levels in India.

2 M

System	Standard voltage in India
Generation	11 kV (also 6.6, 13.8, 15.75, 21 kV for large alternators)
Primary transmission	132 kV, 220 kV, 400 kV, 765 kV (HVDC ± 500 kV, ± 800 kV)
Secondary transmission	66 kV, 33 kV (110 kV in some states)

(Correct voltages 2 M)

d) Types of line supports.

2 M

1. Wooden poles
2. RCC / PCC (pre-stressed concrete) poles
3. Steel poles (tubular, rail, rolled steel joist)
4. Steel lattice towers

(Any four, $\frac{1}{2}$ M each)

e) HVDC lines in India.

2 M

Transmission line (route)	Voltage level
Rihand – Dadri (UP to Delhi NCR)	± 500 kV, 1500 MW
Chandrapur – Padghe (Maharashtra)	± 500 kV, 1500 MW
Talcher – Kolar (Odisha to Karnataka)	± 500 kV, 2500 MW
Mundra – Mohindergarh (Gujarat to Haryana)	± 500 kV, 2500 MW

(Any two (or as asked) with voltage, 1 M each)

f) Need of transposition.

2 M

- Conductors of a 3-phase line are generally not equally spaced, so the inductance (and capacitance) of the three phases is unequal; this gives unequal voltage drops and an unbalanced receiving end voltage.
- Unbalanced phase currents induce voltages in nearby telephone / communication lines (interference). Transposition — interchanging the conductor positions at regular intervals — makes the average inductance of all phases equal, balances the line and reduces interference.

(Any two points, 1 M each)

g) Methods of wireless power transmission.

2 M

- **Near-field (non-radiative) methods:** (i) Inductive coupling, (ii) Magnetic resonant (resonant inductive) coupling, (iii) Capacitive coupling.
- **Far-field (radiative) methods:** (i) Microwave power transmission (antenna + rectenna), (ii) Laser / light beam power transmission.

(Any two methods with type, 1 M each)

Q.2

a) Layout of coal fired thermal power plant.

4 M

A steam (thermal) power plant converts the heat energy of coal into electrical energy using the Rankine cycle: coal → boiler (steam) → turbine → alternator.

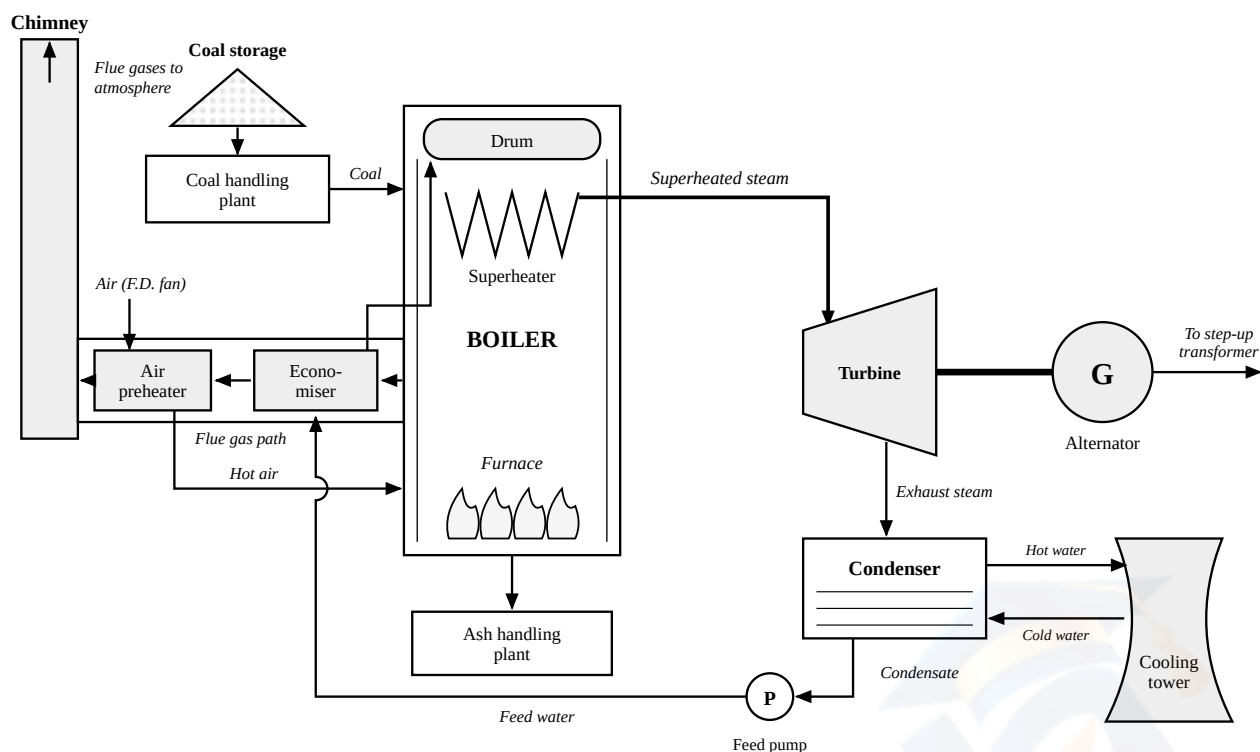


Fig.: Schematic layout of a coal fired (steam) thermal power plant

Working: Coal from the coal handling plant is burnt in the boiler furnace. The heat converts feed water into steam in the boiler tubes and drum. The steam is further heated in the **superheater** and the superheated steam drives the **steam turbine**, which rotates the **alternator** to generate electricity. Exhaust steam from the turbine is condensed in the **condenser** using cooling water (cooling tower), and the condensate is pumped back to the boiler through the **economiser** by the feed pump. Flue gases pass through the economiser and **air preheater** (heat recovery) and leave through the **chimney**; ash is removed by the **ash handling plant**.

- **Boiler:** Converts feed water into high pressure steam using the heat of burning coal.
- **Turbine:** Converts the heat (kinetic) energy of high pressure steam into mechanical rotation; it drives the alternator.
- **Economiser:** Heats the feed water by using the heat of outgoing flue gases before water enters the boiler drum; saves 15–20 % fuel and increases boiler efficiency.
- **Condenser:** Condenses the exhaust steam of the turbine into water; creates vacuum (low back pressure) at the turbine exhaust so more work is obtained, and the pure condensate is reused as feed water.

(Neat labelled layout 2 M, functions / labels 2 M)

b) Load factor, demand factor, diversity factor, plant capacity factor.

4 M

- **Load factor:** Load factor = average load ÷ maximum demand (for the same period). It is always less than 1; a high load factor reduces the cost per unit.
- **Demand factor:** Demand factor = maximum demand ÷ connected load. Its value is usually less than 1.
- **Diversity factor:** Diversity factor = sum of individual maximum demands ÷ maximum demand on the power station. It is always more than 1.

- **Plant capacity factor:** Plant capacity factor = average demand ÷ plant (installed) capacity = actual energy produced ÷ maximum energy that could have been produced in the same period.

(Each definition 1 M)

c) Single phase short line — V_S , losses, efficiency, regulation.

4 M

Given: $P = 1200 \text{ kW}$, $V_R = 11 \text{ kV}$, $\cos \phi_R = 0.8 \text{ lag}$, length 25 km , $r = 0.24 \Omega/\text{km}$, $x = 0.36 \Omega/\text{km}$ (loop values).

Total resistance (loop) $R = 0.24 \times 25 = \mathbf{6.00 \Omega}$; reactance $X = 0.36 \times 25 = \mathbf{9.00 \Omega}$

Line current $I = P / (V_R \cos \phi_R) = 1,200,000 / (11,000 \times 0.8) = \mathbf{136.36 \text{ A}}$

$\cos \phi_R = 0.8$, $\sin \phi_R = 0.6000$

Sending end voltage (taking V_R as reference, $I = 136.36 \angle -36.87^\circ \text{ A}$):

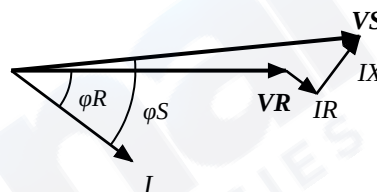
$V_S = V_R + I(R + jX) = 11,000.00 + (109.09 - j81.82)(6.00 + j9.00) = 12,390.91 + j490.91 = \mathbf{12,400.63 \text{ V } \angle 2.27^\circ}$

Check by approximate formula: $V_S \approx V_R + IR \cos \phi_R + IX \sin \phi_R = 11,000.00 + 654.55 + 736.36 = 12,390.91 \text{ V}$

Line losses = $I^2 R = (136.36)^2 \times 6.00 = \mathbf{111,570.2 \text{ W} = 111.57 \text{ kW}}$

Transmission efficiency $\eta = P / (P + \text{losses}) \times 100 = 1,200 / (1,200 + 111.57) \times 100 = \mathbf{91.49 \%}$

Voltage regulation = $(V_S - V_R) / V_R \times 100 = (12,400.63 - 11,000.00) / 11,000.00 \times 100 = \mathbf{12.73 \%}$



Phasor diagram (not to scale)

(I 1 M, V_S 1 M, efficiency 1 M, regulation 1 M)

d) Bipolar HVDC transmission system.

4 M

In HVDC transmission, AC is converted to DC by a rectifier at the sending end, sent over the DC line and converted back to AC by an inverter at the receiving end.

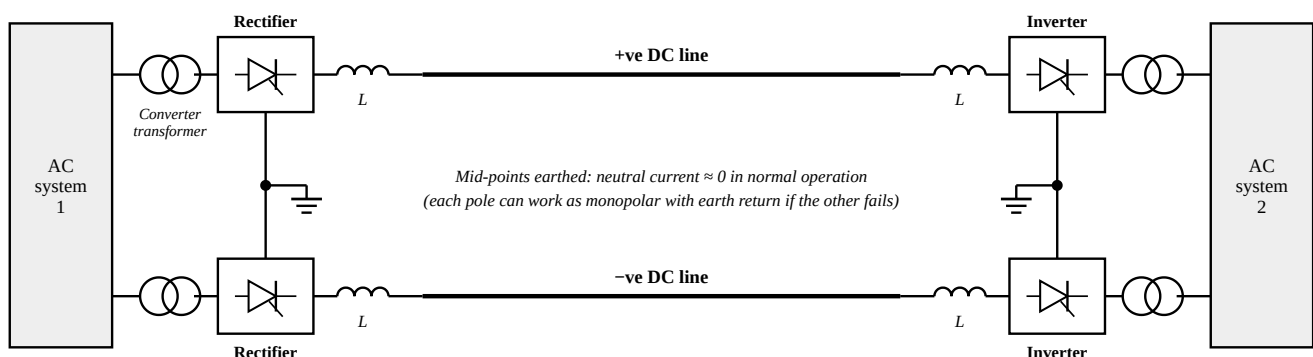


Fig.: Bipolar HVDC link

- **Bipolar link:** It has two conductors, one positive and one negative, each with its own converters connected in series at each end; the mid-points (neutrals) of the converters are earthed. Normally the currents in both poles are equal, so no current flows through the earth. Voltage between the poles is twice the pole voltage (e.g. ± 500 kV). Most common type — used in all major Indian HVDC lines.

Merits of bipolar system:

1. Power transmitted is double that of a monopolar link with the same conductor current.
2. If one pole develops a fault, the other pole continues to supply about half the power with earth return — high reliability.
3. No earth current in normal operation, so no corrosion / interference problems.
4. Lower losses and cost per MW for bulk power.

(Layout 2 M, explanation / merits 2 M)

Q.3

a) Site selection of thermal power plant.

4 M

1. **Availability of coal:** Plant should be near coal mines (pit-head) or have good rail connection, because about 5,000–7,000 tonnes of coal per day is needed for a large plant.
2. **Availability of water:** Huge quantity of water is required for the boiler and especially for the condenser (cooling); so the site should be near a river, lake or sea.
3. **Transport facility:** Railway / road facility is required for coal, heavy machinery and equipment.
4. **Cost and type of land:** Land should be cheap, level and with good bearing capacity to carry heavy equipment (boiler, turbine).
5. **Nearness to load centre:** Reduces transmission cost and losses.
6. **Ash disposal:** Large space (ash pond) is needed for disposal of ash.
7. **Away from thickly populated area:** To avoid effect of smoke, fly ash and pollution on people.
8. **Space for future expansion** and availability of labour.

(Any four factors, 1 M each)

b) Load curve numerical.

4 M

Time (h)	Duration (h)	Load (MW)	Energy = Load $\times$ duration (MWh)
0–6	6	30	180
6–10	4	60	240
10–14	4	80	320
14–18	4	70	280
18–22	4	90	360
22–24	2	40	80
Total	24		1,460

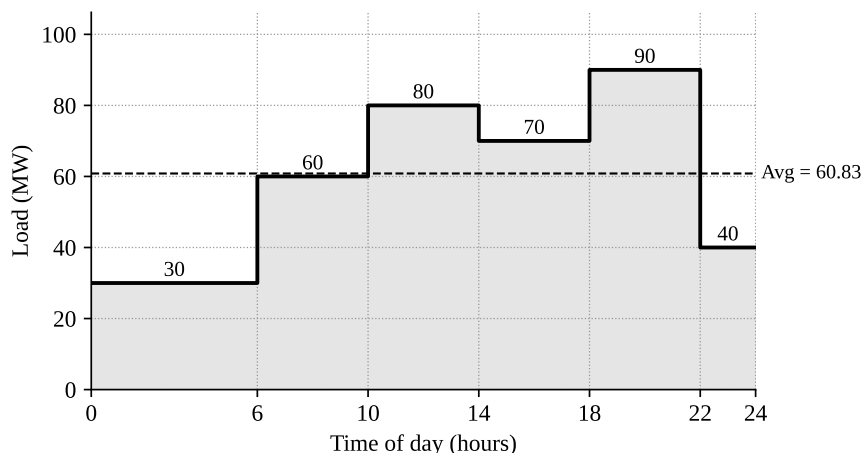


Fig.: Daily load curve (chronological)

- (i) **Maximum demand** = highest load on the curve = **90 MW**
- (ii) **Units generated per day** = area under load curve = $\Sigma (\text{load} \times \text{time}) = 1,460 \text{ MWh} = 1,460,000 \text{ kWh}$ (1.460×10^6 units)
- (iii) **Average load** = units generated per day / 24 = $1,460 / 24 = 60.83 \text{ MW}$
- (iv) **Load factor** = average load / maximum demand = $60.83 / 90 = 0.6759 = 67.59 \%$
- (Load curve 1 M, each result $\frac{3}{4}$ M)

c) Unsymmetrical spacing and transposition.

4 M

- In a 3-phase line the conductors are usually not placed at the corners of an equilateral triangle (unsymmetrical spacing). Therefore the **inductance and capacitance of the three phases are unequal**.
- Unequal reactances give **unequal voltage drops** and an unbalanced receiving end voltage even when the load is balanced.
- Unbalanced currents also induce voltages (**interference**) in nearby telephone / communication lines.
- Transposition:** the positions of the conductors are interchanged at regular intervals so that each conductor occupies each position for one-third of the length. Then the average inductance and capacitance of every phase becomes the same and the line becomes **balanced**.

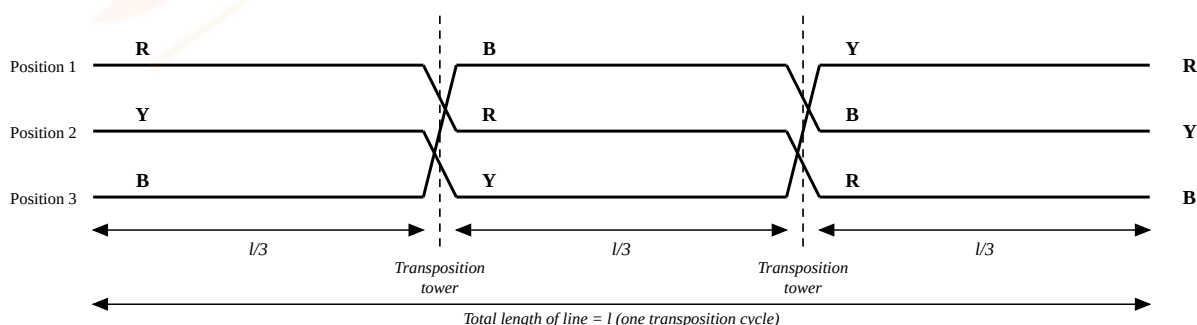


Fig.: Transposition of conductors of a 3-phase line

(Explanation 2 M, diagram 2 M)

d) SLD of 33/11 kV substation.

4 M

A 33/11 kV substation receives power at 33 kV and steps it down to 11 kV for primary distribution feeders.

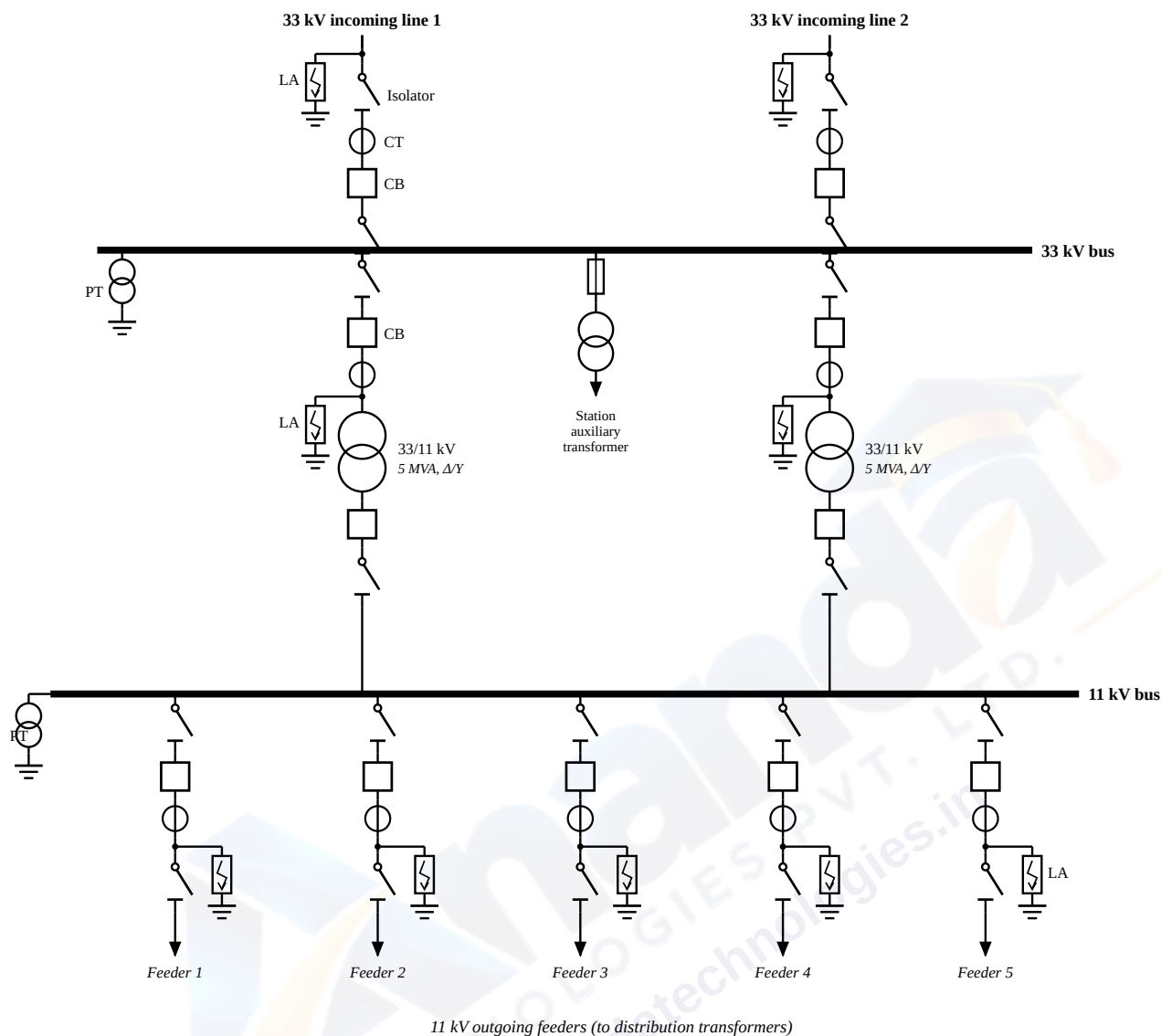


Fig.: Single line diagram (layout) of a 33/11 kV distribution substation

The labelled parts (power transformer, isolator, circuit breaker, lightning arrester) are shown in the diagram. **Power transformer** steps down 33 kV to 11 kV; **isolator** isolates equipment on no load; **circuit breaker** trips on faults; **lightning arrester** diverts surges to earth.

(Correct SLD 3 M, labels 1 M)

Q.4

a) Hydro-electric power plant layout; surge tank and penstock.

4 M

A hydro-electric plant converts the potential energy of water stored at a height into electrical energy using a water turbine and alternator.

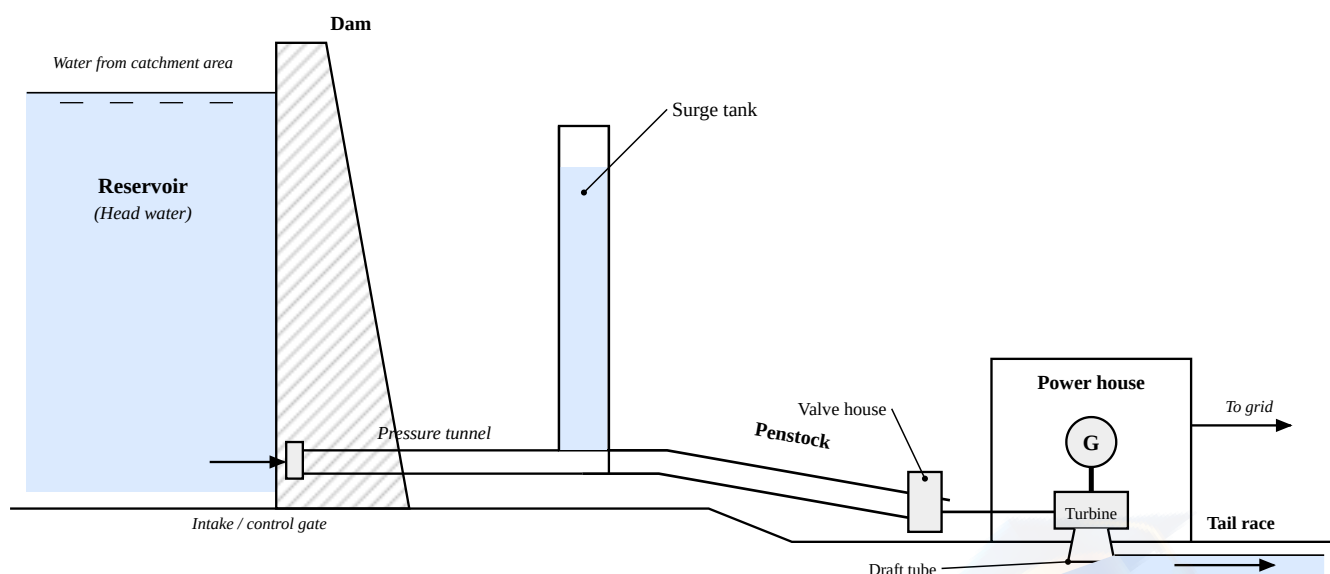


Fig.: Schematic layout of a hydro-electric power plant

Working: Water stored in the reservoir behind the dam flows through the intake (with trash rack and gate) and the pressure tunnel to the surge tank, and then through the penstock and valve house to the turbine. The potential energy of water is converted into kinetic / pressure energy which rotates the water turbine coupled to the alternator. Water leaves the turbine through the draft tube to the tail race.

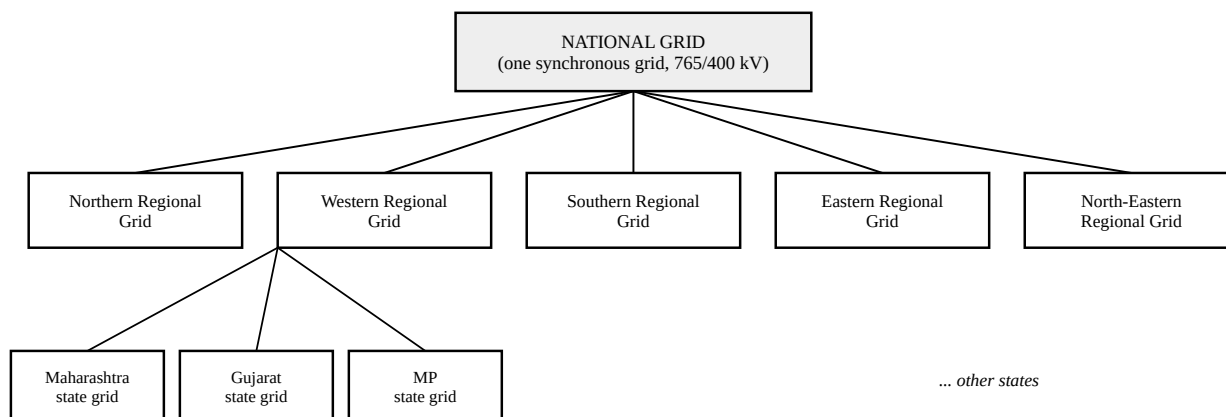
- **Function of surge tank:** It is a small open tank (reservoir) placed at the end of the pressure tunnel, just before the penstock. When the load decreases suddenly and the turbine gates close, the water rises in the surge tank and absorbs the pressure rise, so the penstock is protected from **water hammer**. When the load increases suddenly, it supplies extra water to the turbine till the flow in the tunnel increases.
- **Function of penstock:** It is a large steel (or RCC) pipe which carries water under high pressure from the surge tank / forebay to the turbine. It converts the potential energy (head) of water into pressure energy at the turbine inlet.

(Layout 2 M, functions 1 M each)

b) State grid, national grid; blackout vs brownout.

4 M

A grid is the interconnection of generating stations and substations by EHV lines so that they work in parallel.



Generating stations of a state are tied by the state grid; regional grids are tied into the national grid by inter-regional links.

Fig.: State grid and national grid (simplified)

- **State grid:** The interconnection of all the generating stations and major substations of a state by EHV (220 / 400 kV) lines, operated by the State Load Despatch Centre (e.g. MSETCL grid in Maharashtra).
- **National grid:** The interconnection of the five regional grids (Northern, Western, Southern, Eastern and North-Eastern) by inter-regional EHVAC and HVDC links so that power can be transferred anywhere in the country; India became 'One Nation – One Grid – One Frequency' in December 2013.
- **Blackout:** Complete loss of power supply over a large area due to collapse (tripping) of the grid; restoration takes hours.
- **Brownout:** A partial and temporary **drop in system voltage** (or deliberate reduction of voltage to reduce load) — lights become dim, but supply is not lost.

Blackout	Brownout
Total loss of supply	Only voltage drops (reduced voltage)
Caused by grid collapse / major fault	Caused by overload or done intentionally to reduce load
Restoration takes long time	Supply continues; normal voltage returns quickly

(Each term 1 M)

c) Pin and suspension insulators.

4 M

Insulators support the line conductors and insulate them from the supports (poles / towers). They are made of porcelain, toughened glass or polymer.

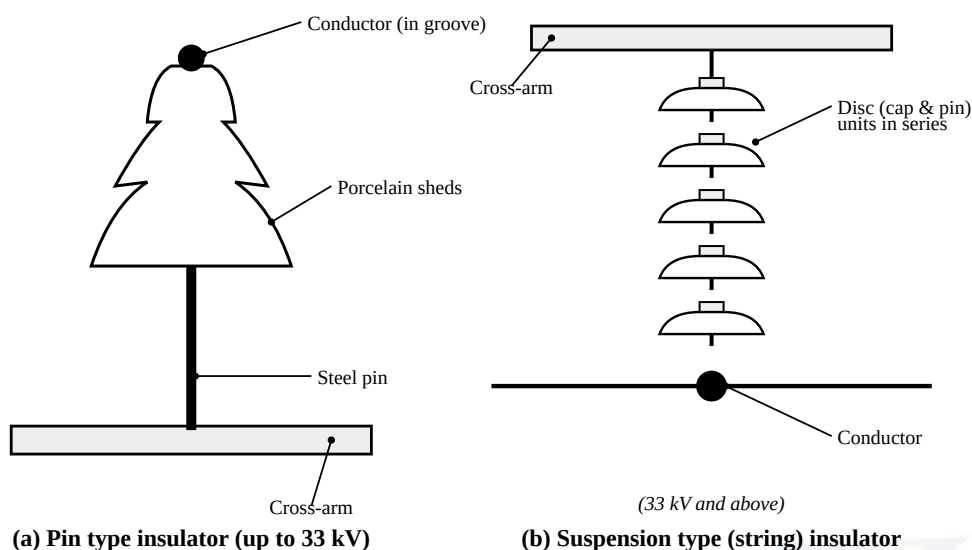


Fig.: Types of overhead line insulators

- **Pin type insulator:** Fixed on a steel pin on the cross-arm; the conductor sits in the top groove and is tied with binding wire. Used on distribution lines up to 33 kV (straight runs). Above 33 kV it becomes large, heavy and uneconomical.
- **Suspension type insulator:** A string of porcelain / glass discs connected by metal links hangs from the cross-arm and the conductor is clamped at the bottom. Each disc is designed for about 11 kV, so the number of discs is chosen as per voltage (e.g. 220 kV $\approx$ 14–15 discs). Used on 33 kV and above (straight portion of EHV lines). Failure of one disc affects only that disc; replacement is easy.

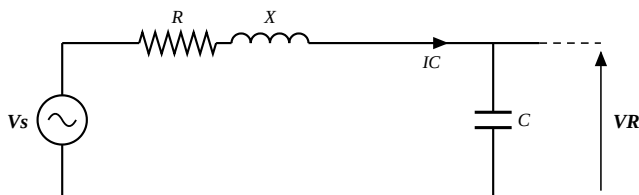
(Sketches 2 M, applications 2 M)

d) Ferranti effect.

4 M

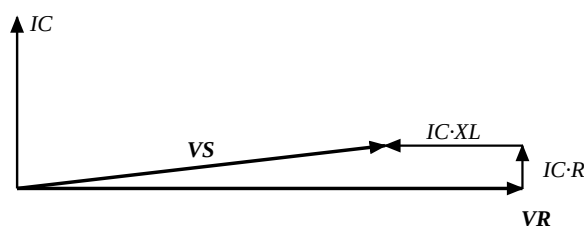
Ferranti effect: When a long (or medium) transmission line is on **no load or light load**, the **receiving end voltage becomes more than the sending end voltage**. This phenomenon is called Ferranti effect.

Explanation: At no load the line draws only the charging current I_C due to line capacitance; I_C leads V_R by 90° . The drop $I_C R$ is in phase with I_C and the drop $I_C X_L$ leads I_C by 90° , i.e. it is in **phase opposition** to V_R . Hence $V_S = V_R + I_C R + jI_C X_L$ becomes smaller than V_R . Since both L and C increase with length, the rise is roughly proportional to the square of the line length.



Receiving end open: only charging current I_C flows through the line

Fig.: Line on no load (receiving end open) — equivalent circuit



IC leads VR by 90°; drop IC·XL is opposite to VR, hence VS < VR

Fig.: Phasor diagram showing Ferranti effect ($V_R > V_S$)

When it occurs: in long EHV / UHV overhead lines (above about 200–250 km) and in underground cables, under no-load or light-load conditions (e.g. at night or when the line is charged from one end only).

(Explanation 2 M, circuit and phasor diagram 2 M)

e) Classification of distribution substations.

4 M

(i) According to service requirement:

- **Transformer substation:** changes voltage level — step-up (at generating station), primary grid, secondary and **distribution substations** (33/11 kV, 11 kV/400 V). *Application:* supply to towns and villages.
- **Switching substation:** only switching of lines (no voltage change). *Application:* sectionalising long lines, connecting lines in a grid.
- **Power factor correction substation:** uses synchronous condensers / capacitor banks. *Application:* at receiving end of lines to improve p.f.
- **Converting substation:** AC to DC (rectifier) or frequency change. *Application:* electric traction, HVDC terminals, electrolysis.
- **Industrial substation:** supplies a single large industry.

(ii) According to constructional features:

- **Indoor substation:** equipment inside a building; up to 11 kV (33 kV in polluted / coastal areas). *Application:* cities, industries.
- **Outdoor substation:** equipment in open yard; 33 kV and above. *Application:* 33/11 kV, 132/33 kV substations.
- **Underground substation:** in crowded city areas where land is not available. *Application:* metro cities.
- **Pole-mounted substation:** transformer up to about 200 kVA on two poles. *Application:* 11 kV/400 V distribution in residential / rural areas.
- **Plinth-mounted / compact substation:** transformer on a concrete plinth (above 200 kVA).

(Each classification 2 M (with applications))

Q.5

a) Corona — advantages, disadvantages, methods to reduce.

6 M

Corona: When the voltage between two conductors of an overhead line exceeds a certain value called the **critical disruptive voltage**, the air surrounding the conductors gets ionised. A faint **violet glow** appears around the conductors, with a **hissing noise** and production of **ozone gas**. This phenomenon is called corona.

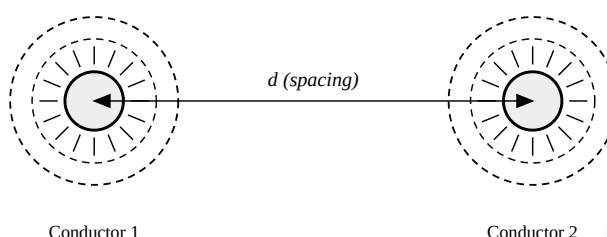


Fig.: Corona — violet glow (ionised air) around conductors of an overhead line

Factors affecting corona: supply voltage, conductor size and surface (rough / stranded surface gives more corona), spacing between conductors, atmospheric conditions (air density, rain, fog), frequency.

Advantages:

1. Corona increases the effective diameter of the conductor, so the electrostatic stress between conductors reduces.
2. It reduces the effects of transients produced by lightning / switching surges (acts like a safety valve).

Disadvantages:

1. Power loss in the line, so transmission efficiency reduces.
2. Ozone formed causes chemical corrosion of conductors.
3. Corona current is non-sinusoidal — produces harmonics and interference with nearby communication (radio / telephone) lines.
4. Hissing noise and light.

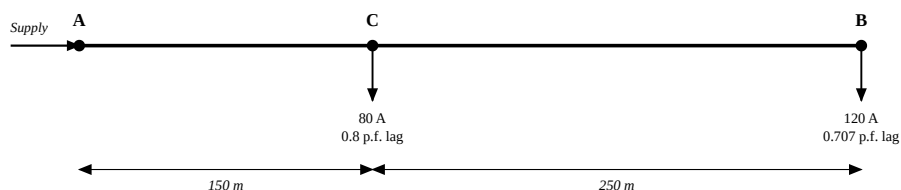
Methods to reduce corona:

1. Increase the conductor diameter — use ACSR or hollow conductors.
2. Use **bundled conductors** (2, 4 or more sub-conductors per phase) in EHV lines.
3. Increase the spacing between conductors.
4. Use smooth conductors and fit **corona / grading rings** at insulator strings and fittings.

(Explanation 2 M, advantages / disadvantages 2 M, methods 2 M)

b) Single phase distributor — voltage drop and sending end voltage.

6 M



Given: $r = 0.2 \, \Omega/\text{km}$, $x = 0.1 \, \Omega/\text{km}$ (go and return); $V_B = 230 \, \text{V}$; p.f. referred to V_B .

Taking the far-end voltage V_B as reference phasor, the load currents are:

- $I_C = 80(0.800 - j0.600) = 64.00 - j48.00 \, \text{A}$
- $I_B = 120(0.707 - j0.707) = 84.84 - j84.87 \, \text{A}$

Current in each section = sum of all load currents beyond it (fed from end A). Section drop = section current $\times$ section impedance:

Section	Length	Impedance $Z \, (\Omega)$	Current (A)	Voltage drop (V)
AC	150 m	$0.0300 + j0.0150$	$148.84 - j132.87$	$6.458 - j1.753$
CB	250 m	$0.0500 + j0.0250$	$84.84 - j84.87$	$6.364 - j2.122$

Total voltage drop = $12.822 - j3.876 \, \text{V}$; magnitude = **13.39 V**

Sending end voltage $V_A = V_B + \text{total drop} = 230 + (12.822 - j3.876) = 242.822 - j3.876 = \mathbf{242.85 \, \text{V} \angle -0.91^\circ}$

Arithmetic difference $V_A - V_B = 242.85 - 230 = \mathbf{12.85 \, \text{V}}$ (= 5.59 % of V_B)

(Load currents 1 M, section currents 1 M, section drops 2 M, total drop and V_A 2 M)

c) Construction of 3-core belted cable.

6 M

An underground cable consists of conductors insulated from each other and from the earth, enclosed in protective coverings. A 3-core belted cable (up to 11 kV) is shown.

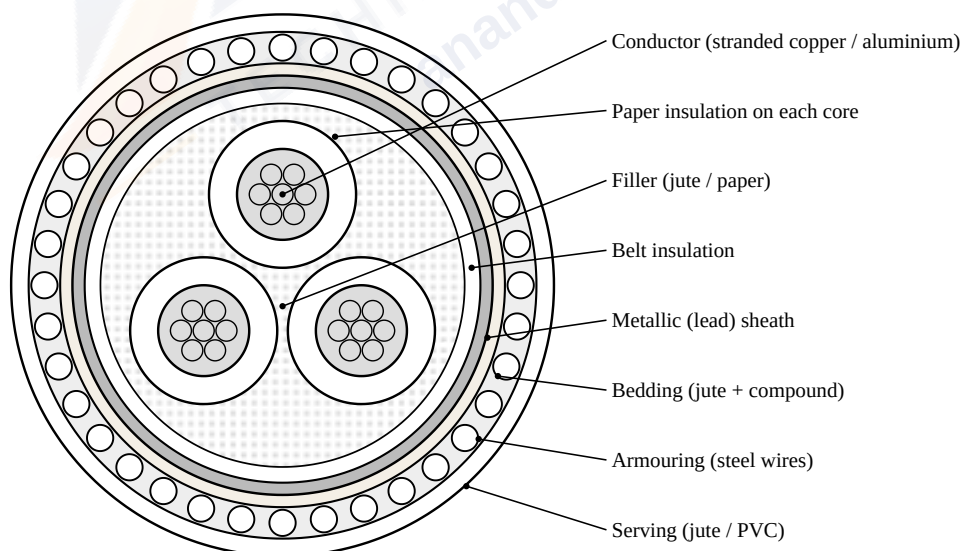


Fig.: Cross-section of a 3-core belted underground cable

- **Cores / conductors:** stranded copper or aluminium conductors (one, three or four cores) carrying the current.
- **Insulation:** impregnated paper, varnished cambric, PVC or XLPE around each core; withstands the working voltage.
- **Metallic sheath:** lead or aluminium sheath over the insulation; protects the cable from moisture, gases and chemicals.
- **Bedding:** layer of jute / paper tape with bituminous compound over the sheath; protects the sheath from corrosion and mechanical injury by the armour.
- **Armouring:** galvanised steel wires or steel tape; gives mechanical protection while laying and handling.
- **Serving:** outer layer of jute / PVC; protects the armour from atmospheric corrosion.

(Diagram 3 M, parts explanation 3 M)

Q.6

a) Safe practices in thermal power plant.

6 M

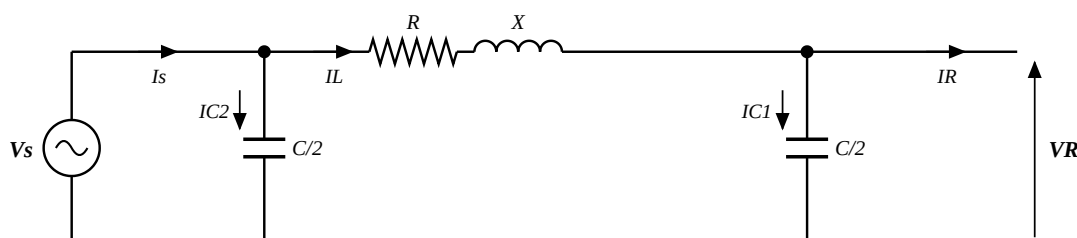
1. Use proper personal protective equipment (PPE): safety helmet, safety shoes, goggles, gloves, ear muffs in turbine hall and dust masks in coal handling area.
2. Follow the **permit-to-work** system and lock-out / tag-out (LOTO) before working on any boiler, turbine or electrical equipment.
3. Boiler safety valves, pressure gauges and water level indicators must be checked regularly; never work on pressurised steam lines.
4. Coal yard and conveyors must have fire detection and fire fighting arrangements (coal can catch fire by spontaneous combustion); keep dust under control by water spraying.
5. Proper earthing of all electrical equipment; only authorised persons should operate switchgear; use insulated tools and rubber mats.
6. Hot steam pipes and surfaces must be insulated and marked; keep guards on all rotating machinery (conveyors, fans, pumps).

(Any six practices, 1 M each)

b) Nominal π method.

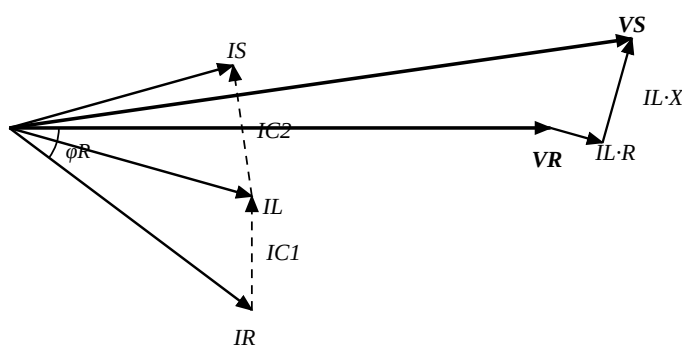
6 M

In the nominal π method, the line capacitance is divided into two equal halves placed at the sending and receiving ends, and the whole series impedance is placed in the middle.



Total capacitance C is divided into two halves placed at sending and receiving ends

Fig.: Nominal π representation of a medium transmission line



IC_1 leads VR and IC_2 leads VS by 90° ; $VS = VR + IL(R + jX)$ (drops exaggerated)

Fig.: Phasor diagram — nominal π method (lagging p.f.)

Analysis (per phase): $V_R = V_R + j0$ (reference); $I_R = I_R(\cos \phi_R - j \sin \phi_R)$; $Z = R + jX$; $Y = j\omega C$.

Current in receiving end capacitor: $I_{C1} = j\omega(C/2) \cdot V_R = (Y/2)V_R$

Line current: $I_L = I_R + I_{C1}$

Sending end voltage: $V_S = V_R + I_L(R + jX) = V_R(1 + YZ/2) + I_R Z$

Current in sending end capacitor: $I_{C2} = j\omega(C/2) \cdot V_S$

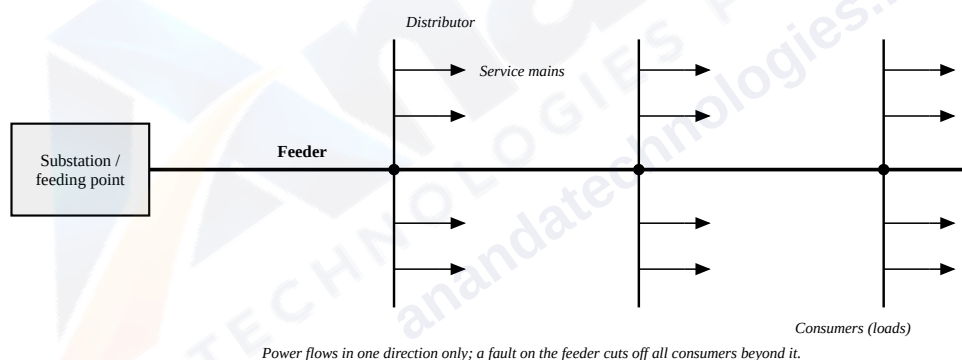
Sending end current: $I_S = I_L + I_{C2}$

(Circuit 2 M, phasor diagram 2 M, expressions 2 M)

c) Radial and ring main distribution systems.

6 M

(i) Radial distribution system



Power flows in one direction only; a fault on the feeder cuts off all consumers beyond it.

Fig.: Radial distribution system

Radial system: Separate feeders radiate from the substation and feed the distributors at one end only; power flows in one direction.

Advantages: simple, lowest initial cost, easy protection. **Disadvantages:** a fault on the feeder interrupts supply to all consumers beyond it; consumers at the far end get low voltage when load changes. Used for short distances / rural areas.

(ii) Ring main distribution system

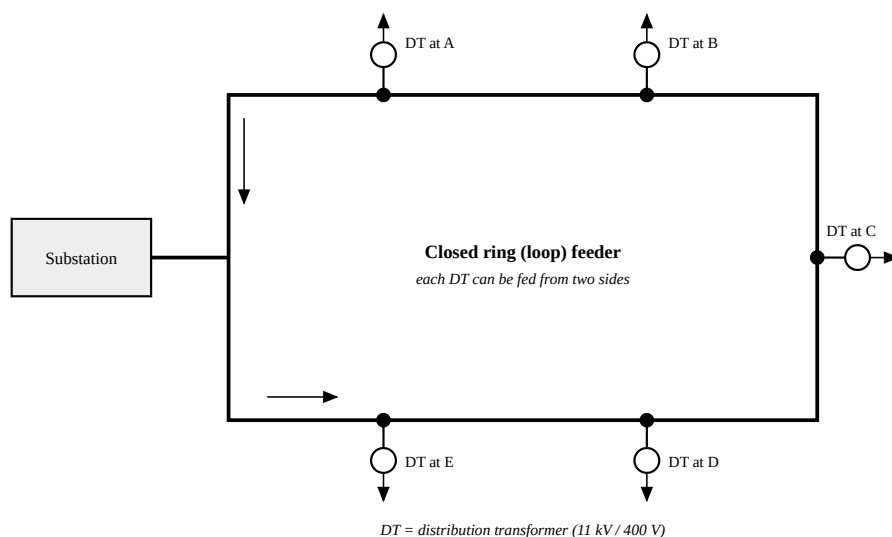


Fig.: Ring main distribution system

Ring main system: The primaries of the distribution transformers form a closed loop (ring) starting from the substation and returning to it. Each distribution transformer can be fed from two sides.

Advantages: less voltage fluctuation at consumers' terminals; a faulty section can be isolated and supply continues from the other side — **high reliability**; better voltage regulation. **Disadvantage:** more conductor and switchgear — higher cost. Used in towns and cities.

(Each system: diagram 1½ M, explanation and advantages 1½ M)

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