

Electrical Power Generation, Transmission and Distribution (313333)

Model Question Paper — Set B · Model Answers

Q.1

a) Hydro-electric power stations in Maharashtra.

2 M

Power station	Installed capacity (approx.)
Koyna Hydro-Electric Project, Satara (Stages I–IV + dam foot)	1956 MW
Ghatghar Pumped Storage Scheme, Ahmednagar–Thane	250 MW
Bhira Hydro Power Station (Tata Power), Raigad	300 MW
Tillari Hydro Power Station, Kolhapur	60 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) Hot reserve and connected load.

2 M

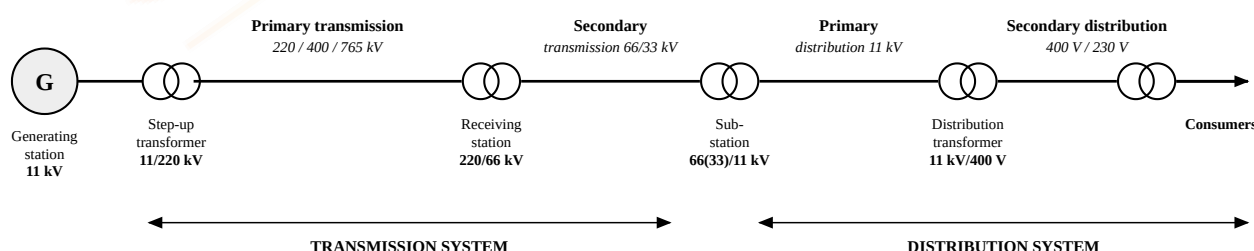
- **Hot reserve:** It is that part of the reserve generating capacity which is **in operation (running and hot) but not in service**; it can be put on load quickly.
- **Connected load:** It is the **sum of the continuous (name-plate) ratings of all the equipment** connected to the supply system.

(Each definition 1 M)

c) Standard voltage levels in India.

2 M

System	Standard voltage in India
Secondary transmission	66 kV, 33 kV (110 kV in some states)
Primary distribution	11 kV (also 22 kV, 33 kV)
Secondary distribution	400 V (415 V) three phase, 230 V single phase



(Generation voltage 11 kV in India: 6.6 / 11 / 13.8 / 15.75 / 21 / 33 kV depending on machine size)

Fig.: Single line diagram of a typical a.c. power supply system (standard voltages in India)

(Correct voltages 2 M)

d) 765 kV EHVAC lines in India.

2 M

Transmission line (route)	Voltage level
Raichur – Sholapur (Karnataka–Maharashtra)	765 kV AC (links Southern grid to national grid)
Wardha – Aurangabad (Maharashtra)	765 kV AC
Seoni – Bina (Madhya Pradesh)	765 kV AC
Agra – Gwalior	765 kV AC

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

e) Advantages and limitations of wireless power transmission.

2 M

Advantages:

- No wires — removes cost, losses and faults of wires and connectors; safe in wet / hazardous places.
- Convenient charging of mobiles, EVs, implants and sensors; no plug wear.
- Power can be sent to moving / inaccessible devices.

Limitations:

- Efficiency falls sharply with distance — suitable only for short distances.
- High initial cost; possible health / interference concerns with strong fields.

(Two advantages 1 M, two limitations 1 M)

f) Function of circuit breaker and current transformer.

2 M

- **Circuit breaker:** It makes and breaks the circuit under normal load and **automatically opens the circuit under fault** (short circuit / overload) on getting a trip signal from the relay; protects equipment.
- **Current transformer:** It steps down high line current to a low standard value (1 A or 5 A) for **measuring instruments and protective relays**, and isolates them from high voltage.

(Each function 1 M)

g) Features of HTLS conductors.

2 M

1. Can operate continuously at **high temperature** (about 150–250 °C) compared to about 75–85 °C for ACSR.
2. **Low sag** at high temperature because the core (carbon composite / invar steel / special alloy) has a very low coefficient of thermal expansion.

(Any two features, 1 M each)

Q.2

a) Pumped storage hydro power plant.

4 M

A pumped storage plant is a peak load hydro plant which stores off-peak energy by pumping water to a higher reservoir.

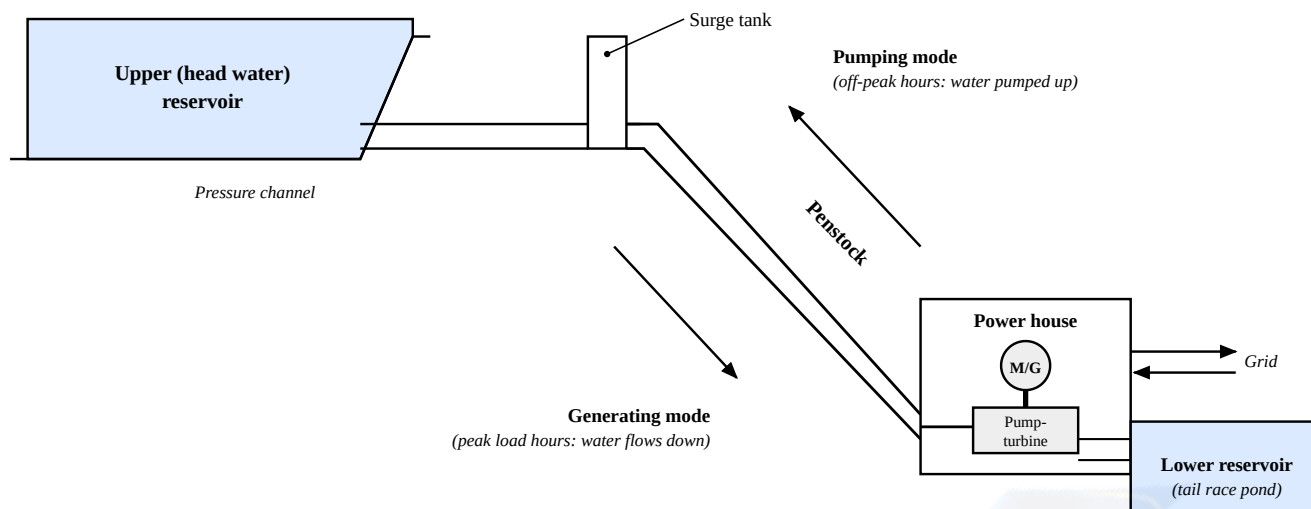


Fig.: Layout of a pumped storage hydro power plant

Working: A pumped storage plant has two reservoirs — an upper (head water) reservoir and a lower (tail water) reservoir. It uses a reversible pump-turbine coupled to a motor-generator.

- **Generating mode (peak load hours):** Water from the upper reservoir flows through the penstock and runs the turbine; the machine works as a generator and supplies peak load.
- **Pumping mode (off-peak hours / night):** Cheap surplus power from base load (thermal / nuclear) plants runs the machine as a motor-pump which pumps water from the lower reservoir back to the upper reservoir.
- Thus energy is stored as potential energy of water; overall efficiency is about 70–75 %.
- It improves the load factor of base load plants and is a quick-starting peak load plant. Example: Ghatghar pumped storage scheme (250 MW), Maharashtra.

(Layout 2 M, explanation 2 M)

b) Corona — factors and methods to reduce.

4 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.

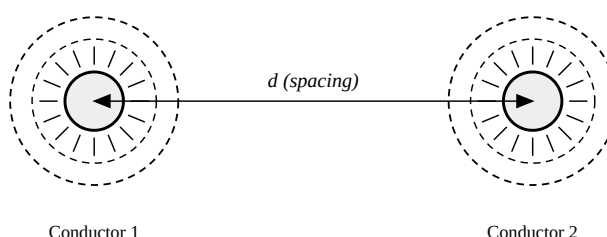


Fig.: Corona — violet glow (ionised air) around conductors of an overhead line

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.

Methods to reduce corona:

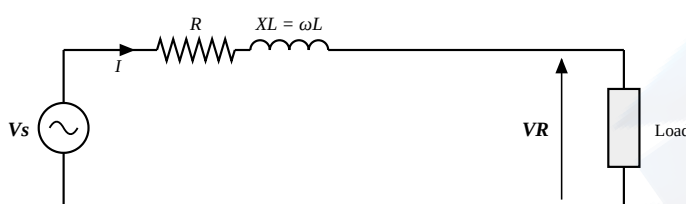
1. Increase the conductor diameter — use ACSR or hollow conductors.
2. Use **bundled conductors** (2, 4 or more sub-conductors per phase) in EHV lines.
3. Increase the spacing between conductors.
4. Use smooth conductors and fit **corona / grading rings** at insulator strings and fittings.

(Phenomenon 2 M, factors 1 M, methods 1 M)

c) Effect of load power factor on regulation.

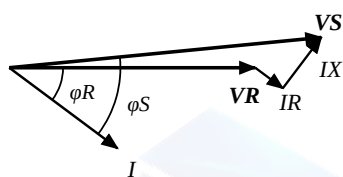
4 M

Voltage regulation of a line depends on the load power factor. With V_R as reference, the drops IR (in phase with I) and IX (90° ahead of I) are added to get V_S .

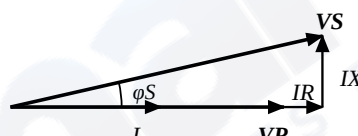


Line capacitance neglected (length up to about 80 km, voltage up to 20 kV)

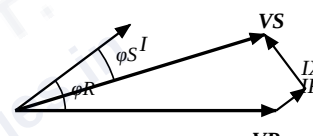
Fig.: Equivalent circuit of a short transmission line



(a) Lagging p.f.



(b) Unity p.f.



(c) Leading p.f.

For a short line, $V_S \approx V_R + IR \cos \phi_R \pm IX \sin \phi_R$, so regulation $\approx (IR \cos \phi_R \pm IX \sin \phi_R)/V_R$ (+ for lagging, – for leading).

- **Lagging p.f.:** both terms add; $V_S > V_R$; regulation is positive and large. Lower the lagging p.f., larger the regulation.
- **Unity p.f.:** only $IR \cos \phi$ term; regulation is small and positive.
- **Leading p.f.:** $IX \sin \phi$ term subtracts; regulation is small and may become zero or **negative** ($V_R > V_S$) at low leading p.f.

(Phasor diagrams 2 M, explanation 2 M)

d) Monopolar and homopolar HVDC links.

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.

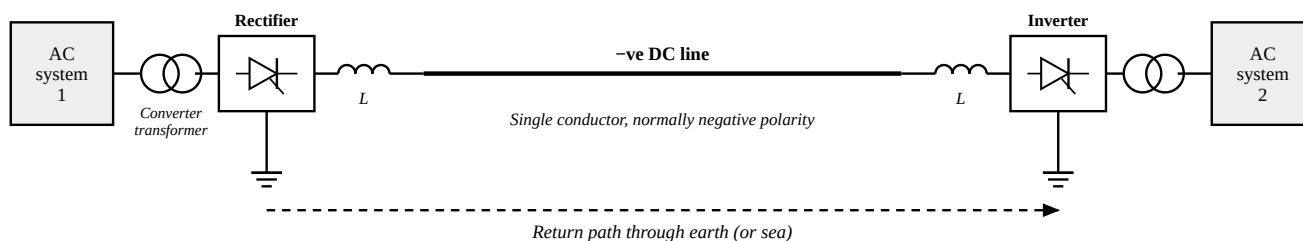


Fig.: Monopolar HVDC link

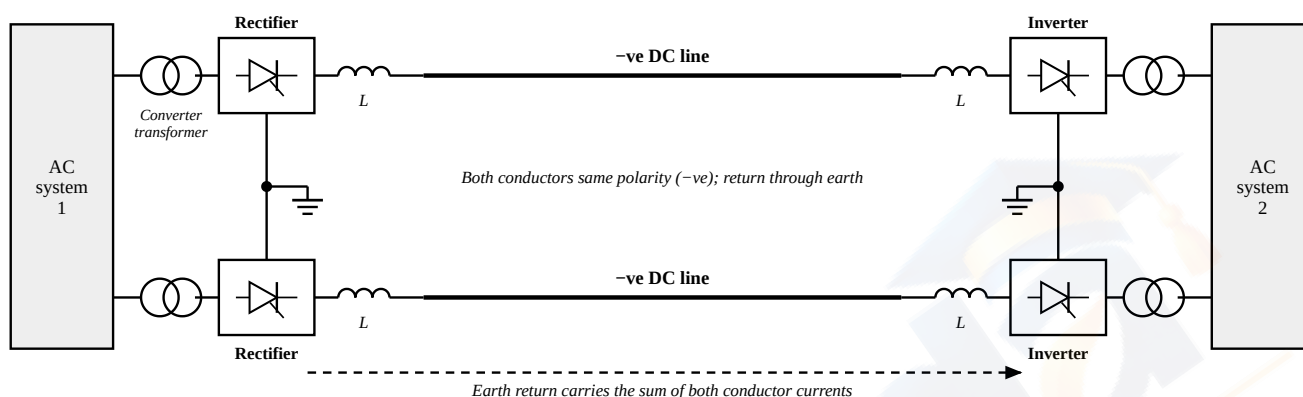


Fig.: Homopolar HVDC link

- **Monopolar link:** It has only one conductor (normally negative polarity, to reduce corona and radio interference) and the return path is through earth or sea using earth electrodes. Used for submarine cable links; cheaper but earth current causes corrosion of buried metal pipes.
- **Homopolar link:** It has two (or more) conductors of the **same polarity** (usually negative) and the return path is through earth. If one conductor fails, the other conductor can carry the load with the converters reconnected. Earth current is large (sum of both currents), so it is rarely used.

(Each layout with explanation 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) Numerical — average load, energy, demand factor, diversity factor.

4 M

Given: individual maximum demands = 30, 25, 20, 15 MW; connected load = 120 MW; maximum demand on station = 70 MW; annual load factor = 50 %; installed capacity = 100 MW.

i) Average load = load factor $\times$ maximum demand = $0.5 \times 70 = 35.00$ MW

ii) Energy generated per year = average load $\times$ 8760 h = $35.00 \times 8760 = 306,600$ MWh = 306.60×10^6 kWh

iii) Demand factor = maximum demand / connected load = $70 / 120 = 0.5833$

iv) Diversity factor = sum of individual maximum demands / maximum demand on station = $(30 + 25 + 20 + 15) / 70 = 90 / 70 = 1.2857$

Also, plant capacity factor = average load / installed capacity = $35.00 / 100 = 0.35 = 35.00$ %.

(Each result 1 M)

c) Types of line supports with applications.

4 M

Line supports hold the conductors at a safe height above ground with proper clearances. Main types are shown below.

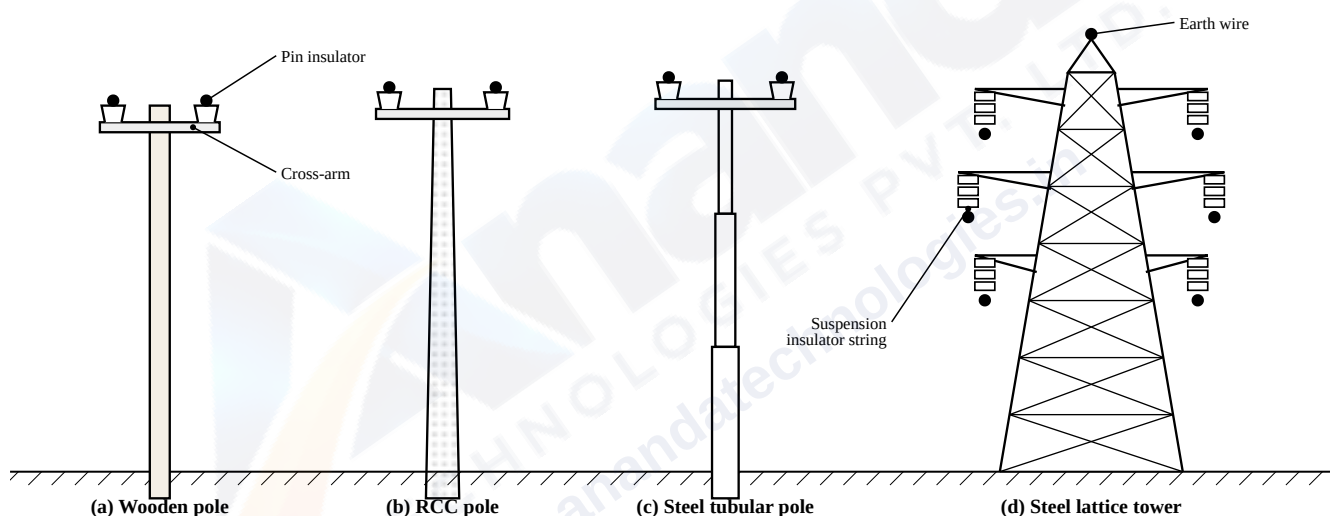


Fig.: Types of line supports

Type of support	Application
Wooden poles	LT lines and up to 11 kV in rural areas; spans 40–60 m; cheap but short life.
RCC / PCC (pre-stressed concrete) poles	LT, 11 kV and 33 kV lines; spans up to about 80–200 m; long life, widely used by MS&EDCL.
Steel poles (tubular, rail, rolled steel joist)	LT and 11 kV lines in cities; good appearance, strong.
Steel lattice towers	66 kV and above (132, 220, 400, 765 kV) and HVDC lines; spans 250–450 m; very strong, long life.

(Types with application 4 M (sketch optional))

d) SLD of 11 kV / 400 V distribution substation.

4 M

An 11 kV / 400 V substation (pole or plinth mounted) supplies LT consumers through a distribution transformer.

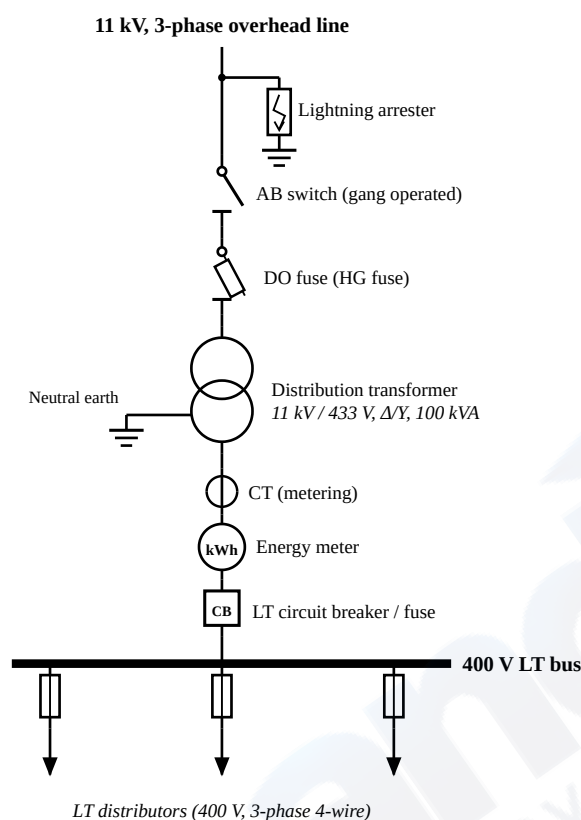


Fig.: Single line diagram of an 11 kV/400 V (pole mounted) distribution substation

Description: The 11 kV line is connected to the distribution transformer through a lightning arrester, a gang-operated air break (AB) switch and drop-out (DO) fuses. The transformer (Δ/Y , neutral earthed) steps down the voltage to 433 V / 400 V. On the LT side, metering CTs, an energy meter and an LT circuit breaker / fuse unit feed the LT bus, from which 3-phase 4-wire distributors supply the consumers.

- **Lightning arrester:** It protects the substation equipment from **lightning and switching surges** by diverting the surge current to earth.
- **DO fuse:** Drop-out (DO) fuse protects the distribution transformer from short circuit / overload on the HT side; when the fuse element blows, the fuse tube **drops down**, giving a visible break (indication) and isolation.

(Each function 1 M)

AB switch: gang-operated air break switch used to isolate the transformer from the 11 kV line under no load. **Distribution transformer:** steps down 11 kV to 433 V (Δ/Y , neutral earthed).

(Correct SLD 2 M, labels 2 M)

Q.4

a) Thermal power plant layout; superheater and economiser.

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.

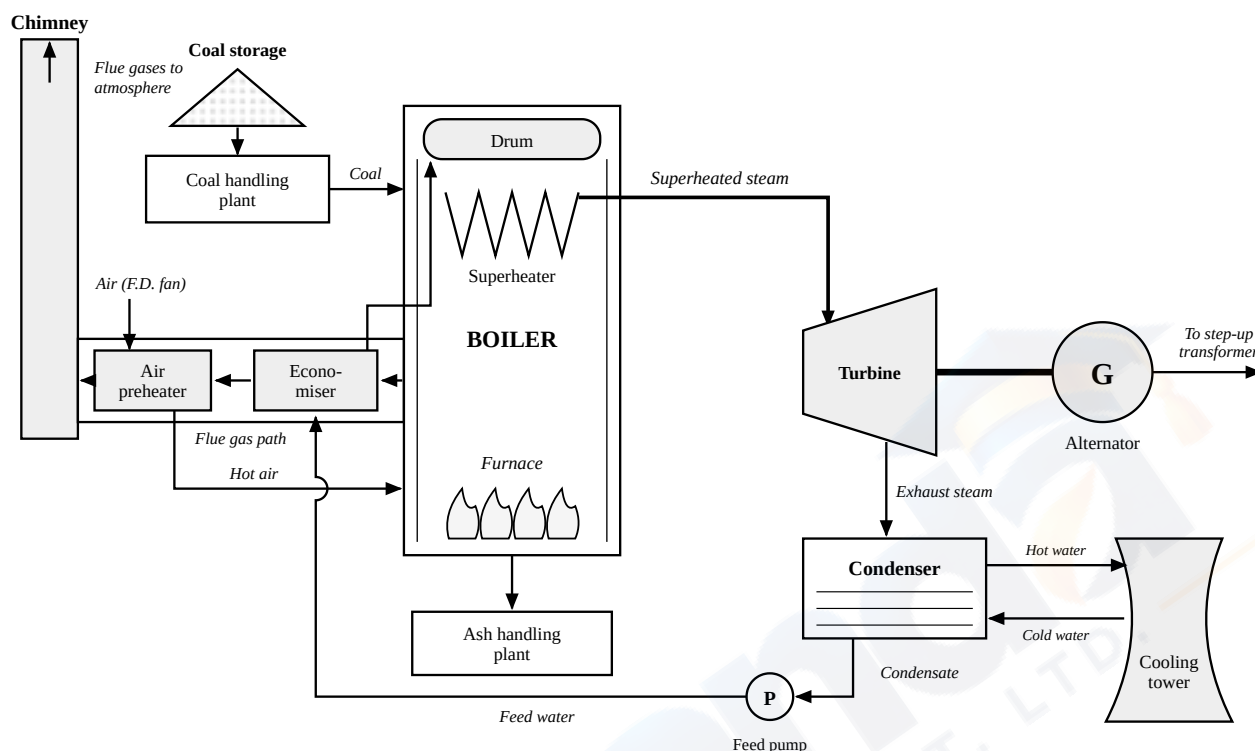


Fig.: Schematic layout of a coal fired (steam) thermal power plant

- 1. Superheater:** Raises the temperature of saturated steam above its saturation temperature (dry superheated steam); increases plant efficiency and prevents erosion of turbine blades due to moisture.
- 2. 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.

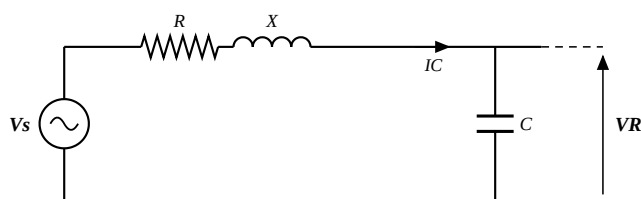
(Layout 2 M, functions 1 M each)

b) Ferranti effect — when it occurs and how reduced.

4 M

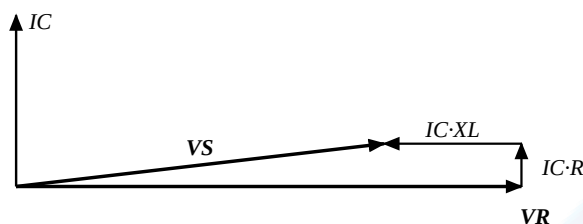
Ferranti effect: When a long (or medium) transmission line is on **no load or light load**, the **receiving end voltage becomes more than the sending end voltage**. This phenomenon is called Ferranti effect.

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



I_C leads V_R by 90° ; drop $I_C \cdot X_L$ is opposite to V_R , hence $V_S < V_R$

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).

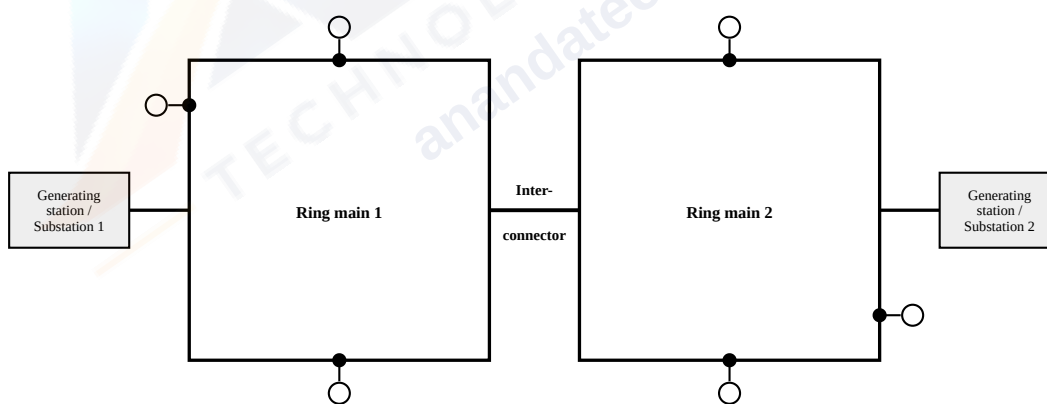
Methods to reduce: connect **shunt reactors** at the receiving end (they absorb the leading charging current); use static VAR compensators (SVC) / STATCOM; switch off shunt capacitors at light load.

(Definition / explanation 1 M, phasor 1 M, when 1 M, remedy 1 M)

c) Interconnected (grid) distribution system.

4 M

An interconnected system is a ring main system fed from two or more sources.



Two (or more) ring mains fed from different sources are tied together by an interconnector

Fig.: Interconnected (grid) distribution system

Interconnected (grid) system: When a ring main feeder is energised by two or more generating stations / substations, it is called an interconnected system. Two ring mains are tied together by an interconnector.

Advantages: very high reliability — any area can be fed from another source; peak loads are shared, so reserve capacity reduces; efficiency of the system increases; supply continues even if

one station fails.

(Diagram 2 M, explanation and advantages 2 M)

d) Constructional classification; indoor vs outdoor substation.

4 M

According to constructional features: (i) Indoor substation (ii) Outdoor substation (iii) Underground substation (iv) Pole-mounted substation (v) Plinth-mounted / compact substation.

Basis	Indoor substation	Outdoor substation
Space required	Less	More
Fault detection	Difficult (equipment enclosed)	Easy (equipment visible)
Erection cost / time	More cost, more time (building needed)	Less cost and time
Voltage level	Up to 11 kV (33 kV in special cases)	33 kV and above

(Classification 2 M, any two differences 2 M)

e) Need and benefits of line compensation.

4 M

Line compensation means connecting series capacitors and / or shunt reactors / capacitors to an EHV line to control its reactive power and voltage.



Fig.: Series capacitor and shunt reactor compensation of a line

Need of line compensation: Long EHV lines have large series inductive reactance and large shunt capacitance. The series reactance limits the power transfer and stability, while the shunt capacitance causes Ferranti over-voltage at light load and reactive power problems at heavy load.

Benefits:

1. **Series capacitors** reduce the effective line reactance → more power transfer capacity and better stability.
2. **Shunt reactors** absorb the charging reactive power → control voltage rise (Ferranti effect) at light load.
3. **Shunt capacitors / SVC / STATCOM** supply reactive power at heavy load → maintain receiving end voltage, improve power factor.
4. Overall: better voltage profile, lower losses, increased efficiency and loadability of the line.

(Need 2 M, benefits 2 M)

Q.5

a) Fire tube and water tube boilers.

6 M

Boilers are classified as fire tube and water tube boilers depending on whether hot gases or water flow inside the tubes.

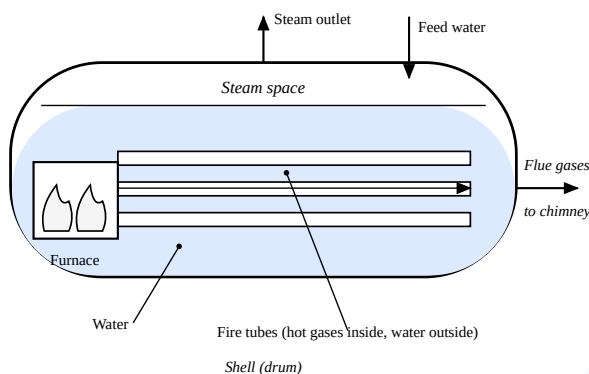


Fig.: Fire tube boiler (simple horizontal / Lancashire type)

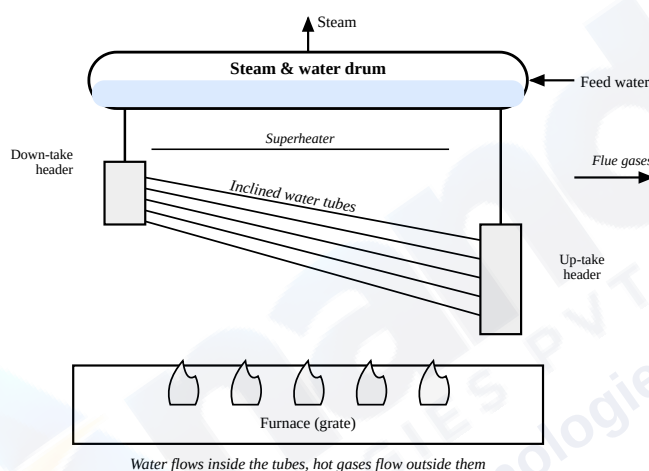


Fig.: Water tube boiler (Babcock & Wilcox type, simplified)

Fire tube boiler: The hot flue gases from the furnace pass **through the tubes** and water surrounds the tubes inside the shell. Heat is transferred from gases to water through the tube walls and steam collects in the upper steam space. Examples: Cochran, Lancashire, Locomotive boiler. Used for low pressure (up to about 20 bar) and small capacity — process industries, not for large power plants.

Water tube boiler: Water flows **inside the tubes** and hot gases flow outside the tubes. Water from the drum comes down through the down-take header, rises through the inclined tubes over the furnace (natural circulation) and the steam-water mixture returns to the drum. Examples: Babcock & Wilcox, Stirling boilers. Used in thermal power stations for high pressure (above 100 bar) and large capacity.

Fire tube boiler	Water tube boiler
Hot gases inside tubes, water outside	Water inside tubes, hot gases outside
Low pressure, small capacity	High pressure, large capacity
Slow steam raising	Quick steam raising

Not used in large power plants	Used in thermal power stations
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(Each boiler: diagram 2 M + explanation 1 M)

b) 3-phase short line — V_S , efficiency, regulation.

6 M

Given: $P = 1.5 \text{ MW}$, $V_R \text{ (line)} = 11 \text{ kV}$, $\cos \phi_R = 0.8 \text{ lag}$, length 12 km , $r = 0.22 \Omega/\text{km}$, $x = 0.35 \Omega/\text{km}$ per conductor. Work per phase (star equivalent).

Total resistance per phase $R = 0.22 \times 12 = \mathbf{2.64 \Omega}$; reactance $X = 0.35 \times 12 = \mathbf{4.20 \Omega}$

Receiving end phase voltage $V_R = 11,000/\sqrt{3} = \mathbf{6,350.85 \text{ V}}$

Line current $I = P / (\sqrt{3} V_L \cos \phi_R) = 1,500,000 / (\sqrt{3} \times 11,000 \times 0.8) = \mathbf{98.41 \text{ A}}$

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

Sending end voltage (taking V_R as reference, $I = 98.41 \angle -36.87^\circ \text{ A}$):

$V_S = V_R + I(R + jX) = 6,350.85 + (78.73 - j59.05)(2.64 + j4.20) = 6,806.70 + j174.78 = \mathbf{6,808.94 \text{ V} } \angle 1.47^\circ$ per phase

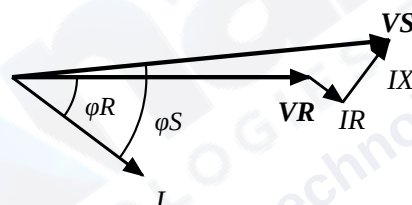
Sending end line voltage $= \sqrt{3} \times 6,808.94 = \mathbf{11,793.43 \text{ V} = 11.793 \text{ kV}}$

Check by approximate formula: $V_S \approx V_R + IR \cos \phi_R + IX \sin \phi_R = 6,350.85 + 207.85 + 248.00 = 6,806.70 \text{ V}$

Line losses $= 3 \times I^2 R = 3 \times (98.41)^2 \times 2.64 = \mathbf{76,704.5 \text{ W} = 76.70 \text{ kW}}$

Transmission efficiency $\eta = P / (P + \text{losses}) \times 100 = 1,500 / (1,500 + 76.70) \times 100 = \mathbf{95.14 \%}$

Voltage regulation $= (V_S - V_R)/V_R \times 100 = (6,808.94 - 6,350.85) / 6,350.85 \times 100 = \mathbf{7.21 \%}$



Phasor diagram per phase (not to scale): V_R reference, I lags by ϕ_R

(Current 1 M, V_S 2 M, efficiency 1 M, regulation 1 M, phasor 1 M)

c) Load curve and load duration curve numerical.

6 M

Time (h)	Duration (h)	Load (MW)	Energy = Load $\times$ duration (MWh)
0–5	5	20	100
5–9	4	45	180
9–13	4	65	260
13–17	4	55	220
17–21	4	75	300
21–24	3	35	105
Total	24		1,165

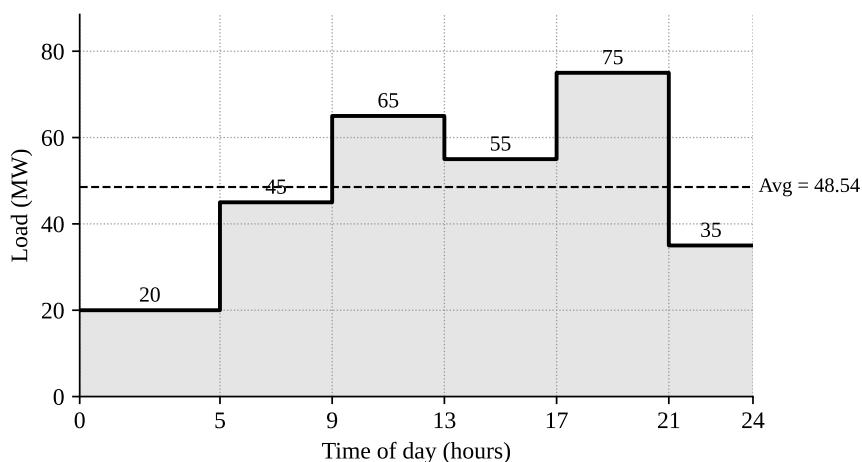


Fig.: Daily load curve (chronological)

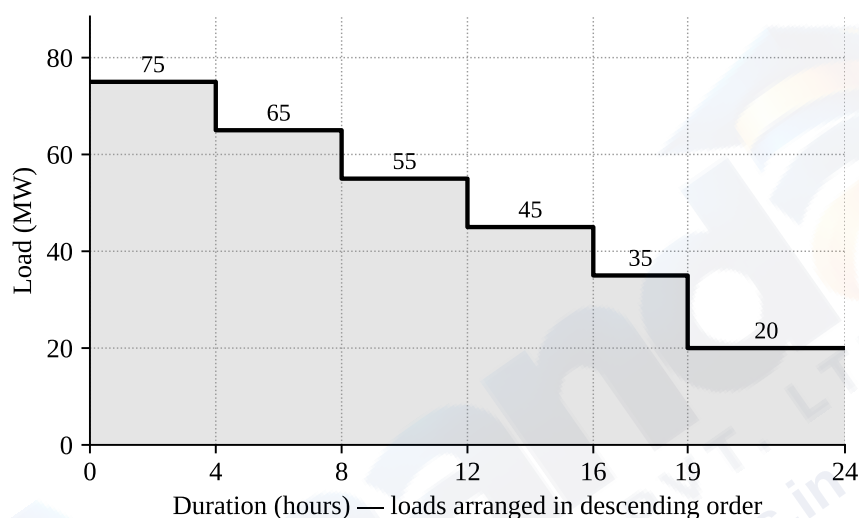


Fig.: Load duration curve (same loads in descending order)

- (i) **Maximum demand** = highest load on the curve = **75 MW**
- (ii) **Units generated per day** = area under load curve = $\Sigma (\text{load} \times \text{time}) = 1,165 \text{ MWh} = 1,165,000 \text{ kWh}$ (1.165×10^6 units)
- (iii) **Average load** = units generated per day / 24 = $1,165 / 24 = 48.54 \text{ MW}$
- (iv) **Load factor** = average load / maximum demand = $48.54 / 75 = 0.6472 = 64.72 \%$

(Load curve 1½ M, load duration curve 1½ M, results 3 M)

Q.6

a) Safe practices in hydro power plants.

6 M

- Follow the permit-to-work system and lock-out / tag-out (LOTO); close and lock the intake gates and drain the penstock before entering penstock, spiral casing or draft tube.
- Treat penstock, scroll case and draft tube as **confined spaces**: check ventilation / oxygen level and keep a standby person outside.
- Use PPE — helmet, safety shoes, gloves, ear protection; use **life jackets** and safety belts while working near reservoir, gates or tail race.

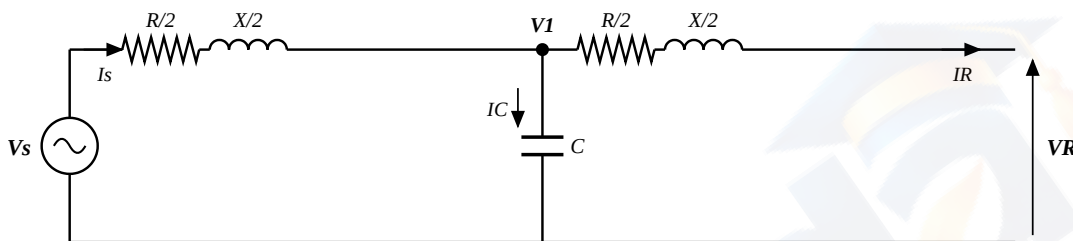
4. Sound sirens / give warning to people downstream before opening spillway gates or releasing water; follow flood warning procedures.
5. Provide handrails, guards on rotating shafts, and keep floors free from oil and water to avoid slipping; check oil leakage of governors and bearings.
6. Regular inspection of dam, gates, surge tank and penstock for cracks, seepage and corrosion; check emergency (auto) closing valves.

(Any six practices, 1 M each)

b) Nominal T method.

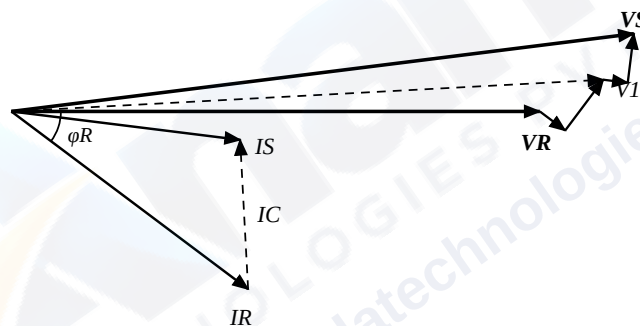
6 M

In the nominal T method, the whole line capacitance is assumed to be concentrated at the middle of the line and half the line resistance and reactance is placed on either side.



Whole capacitance C is placed at the middle; series impedance is divided into two halves

Fig.: Nominal T representation of a medium transmission line



$V_1 = V_R + I_R(R/2 + jX/2)$; $I_S = I_R + I_C$; $V_S = V_1 + I_S(R/2 + jX/2)$ (drops exaggerated)

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

Analysis (per phase): Let V_R = receiving end voltage (reference), I_R = load current lagging by ϕ_R , $Z = R + jX$, $Y = j\omega C$.

$$V_R = V_R + j0 ; I_R = I_R(\cos \phi_R - j \sin \phi_R)$$

$$\text{Voltage across } C: V_1 = V_R + I_R(Z/2)$$

$$\text{Capacitor current: } I_C = j\omega C \cdot V_1 = Y V_1 \text{ (leads } V_1 \text{ by } 90^\circ)$$

$$\text{Sending end current: } I_S = I_R + I_C$$

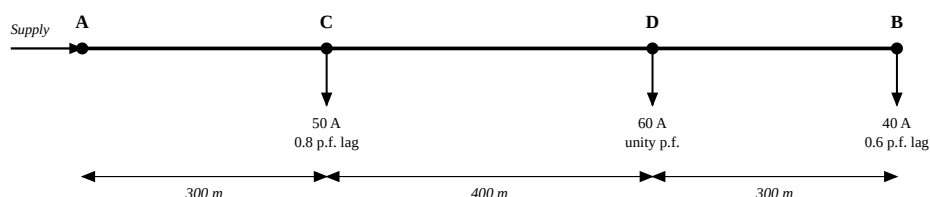
$$\text{Sending end voltage: } V_S = V_1 + I_S(Z/2) = V_R(1 + YZ/2) + I_R Z(1 + YZ/4)$$

$$\text{Regulation} = (|V_S| - |V_R|)/|V_R| \times 100 ; \text{Efficiency} = \text{output} / (\text{output} + \text{losses}), \text{losses} = (I_R^2 + I_S^2) \cdot R/2 \text{ per phase.}$$

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

c) Distributor fed at 240 V — far end voltage and drop.

6 M



Given: $z = (0.1 + j0.15) \Omega/\text{km}$ (go and return); $V_A = 240 \text{ V}$; p.f. referred to V_B .

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

- $I_C = 50(0.800 - j0.600) = 40.00 - j30.00 \text{ A}$
- $I_D = 60(1.000 + j0.000) = 60.00 + j0.00 \text{ A}$
- $I_B = 40(0.600 - j0.800) = 24.00 - j32.00 \text{ A}$

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	300 m	$0.0300 + j0.0450$	$124.00 - j62.00$	$6.510 + j3.720$
CD	400 m	$0.0400 + j0.0600$	$84.00 - j32.00$	$5.280 + j3.760$
DB	300 m	$0.0300 + j0.0450$	$24.00 - j32.00$	$2.160 + j0.120$

Total voltage drop = $13.950 + j7.600 \text{ V}$; magnitude = **15.89 V**

Far-end voltage: $V_A = V_B + (13.950 + j7.600)$, with $|V_A| = 240 \text{ V}$ and V_B as reference:

$$(7.600)^2 + (V_B + 13.950)^2 = 240^2 \Rightarrow V_B = \sqrt{(240^2 - 7.600^2)} - 13.950 = \mathbf{225.93 \text{ V}}$$

Voltage drop $V_A - V_B = 240 - 225.93 = \mathbf{14.07 \text{ V}}$. (Approximate method: $V_B \approx V_A - \text{real part of drop} = 240 - 13.95 = 226.05 \text{ V}$ — practically the same.)

(Load currents 1 M, section currents and drops 3 M, V_B and drop 2 M)

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