Electrical Power Generation, Transmission and Distribution (313333)

Model Question Paper — Set C · Model Answers

Q.1

a) Thermal 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
Khaperkheda Thermal Power Station (MAHAGENCO), Nagpur	1340 MW
Tiroda Thermal Power Station (Adani Power), Gondia	3300 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) Firm power and spinning reserve. 2 M

- **Firm power:** It is the power which is **always available** (guaranteed) from a plant or system, even under emergency conditions.
- **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 voltages in India. 2 M

System	Standard voltage in India
Generation	11 kV (also 6.6, 13.8, 15.75, 21 kV for large alternators)
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

(½ M each)

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, ½ 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
Biswanath Chariali – Agra (Assam to UP)	±800 kV, 6000 MW
Raigarh – Pugalur (Chhattisgarh to Tamil Nadu)	±800 kV, 6000 MW

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

f) Types of distribution schemes. 2 M

1. Radial distribution system
2. Ring main distribution system
3. Interconnected (grid) distribution system
4. Parallel feeder system

(Any three/four, ½ M each)

g) Symbols of CT and PT. 2 M

Standard symbols as used in single line diagrams:

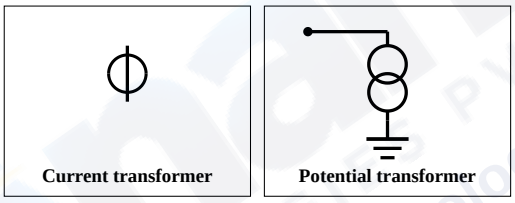


Fig.: Symbols

(Each symbol 1 M)

Q.2

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.

(Any four factors, 1 M each)

b) Maximum demand, average demand, load factor, plant use factor. 4 M

- **Maximum demand:** It is the **greatest of all the demands** (highest load) that occurred on the power station during a given period (day / month / year).
- **Average demand:** Average load = energy (units) generated in a given period ÷ number of hours in that period.
- **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.
- **Plant use factor:** Plant use factor = actual energy produced (kWh) ÷ [plant capacity (kW) × number of hours the plant has actually been in operation].

(Each definition 1 M)

c) Need of 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**.

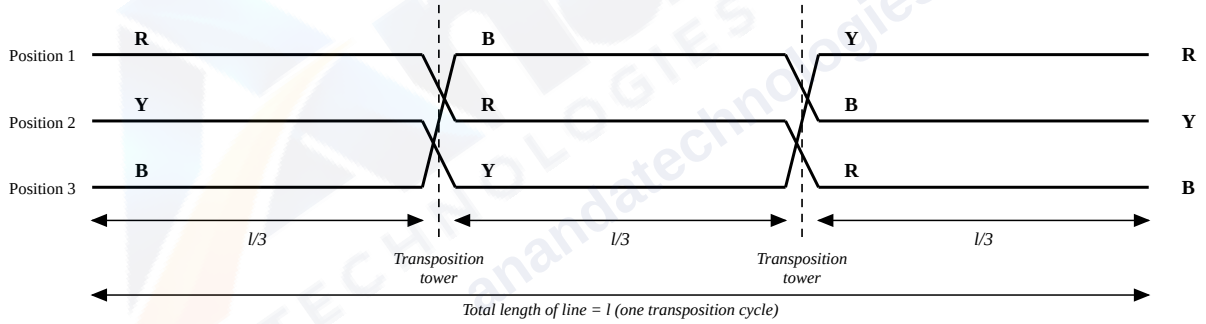


Fig.: Transposition of conductors of a 3-phase line

(Need 2 M, diagram 2 M)

d) 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.

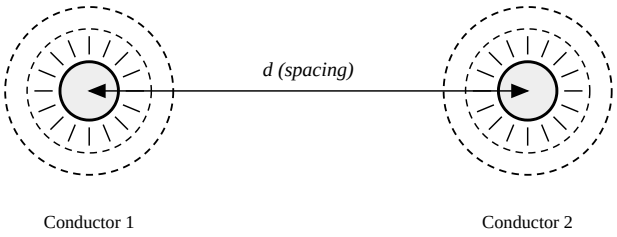


Fig.: Corona — violet glow (ionised air) around conductors of an overhead line

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.

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

Q.3

a) Functions of superheater, economiser, air preheater, condenser. 4 M

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.
3. **Air preheater:** Heats the air supplied to the furnace using the heat of flue gases (after economiser); gives better combustion, saves fuel and increases boiler efficiency.
4. **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.

(Each function 1 M)

b) Single phase short line — V_S, regulation, efficiency. 4 M

Given: P = 500 kW, V_R = 6.6 kV, cos φ_R = 0.85 lag, R = 2.5 Ω, X = 4 Ω (total).

Line current I = P / (V_R cos φ_R) = 500,000 / (6,600 × 0.85) = **89.13 A**

cos φ_R = 0.85, sin φ_R = 0.5268

Sending end voltage (taking V_R as reference, I = 89.13∠−31.79° A):

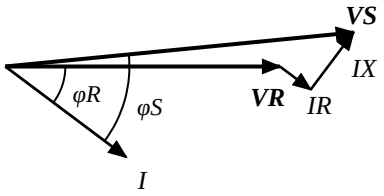
$V_S = V_R + I(R + jX)$ = 6,600.00 + (75.76 − j46.95)(2.50 + j4.00) = 6,977.20 + j185.65 = **6,979.66 V ∠1.52°**

Check by approximate formula: $V_S \approx V_R + IR\cos\varphi_R + IX\sin\varphi_R = 6{,}600.00 + 189.39 + 187.80 = 6{,}977.20$ V

Line losses = $I^2R = (89.13)^2 \times 2.50 =$ **19,858.9 W = 19.86 kW**

Transmission efficiency $\eta = P / (P + \text{losses}) \times 100 = 500 / (500 + 19.86) \times 100 =$ **96.18 %**

Voltage regulation = $(V_S - V_R)/V_R \times 100 = (6{,}979.66 - 6{,}600.00) / 6{,}600.00 \times 100 =$ **5.75 %**



Phasor diagram (not to scale)

(Current ½ M, V_S 1 M, regulation 1 M, efficiency 1 M, phasor ½ M)

c) Bipolar HVDC link and components. 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.

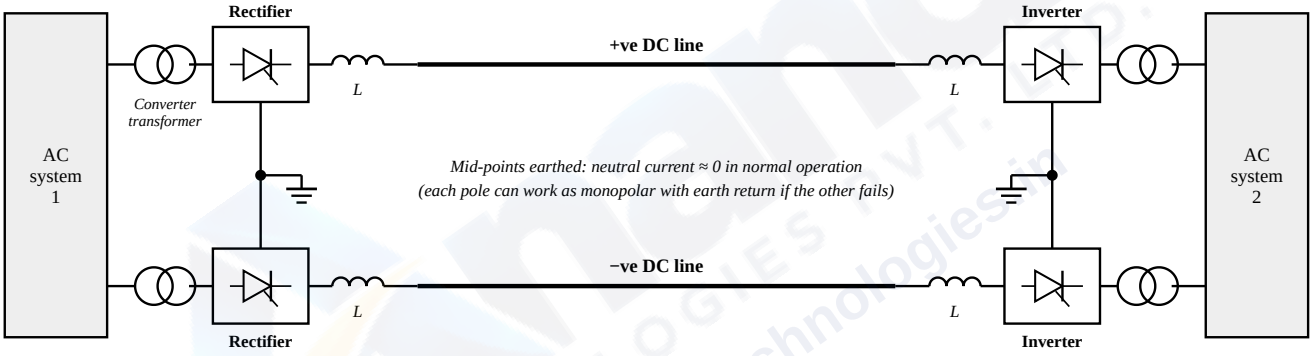


Fig.: Bipolar HVDC link

- **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.

Main components of HVDC system:

1. Converter transformers (with on-load tap changers)
2. Converter valves (thyristor bridges) — rectifier and inverter
3. Smoothing reactors (reduce ripple in DC current)
4. AC and DC harmonic filters
5. Reactive power sources (capacitor banks / SVC)
6. DC line (overhead or cable) and earth electrodes
7. Control and protection system

(Layout 2 M, components 2 M)

d) SLD of 33/11 kV substation; isolator and CT. 4 M

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

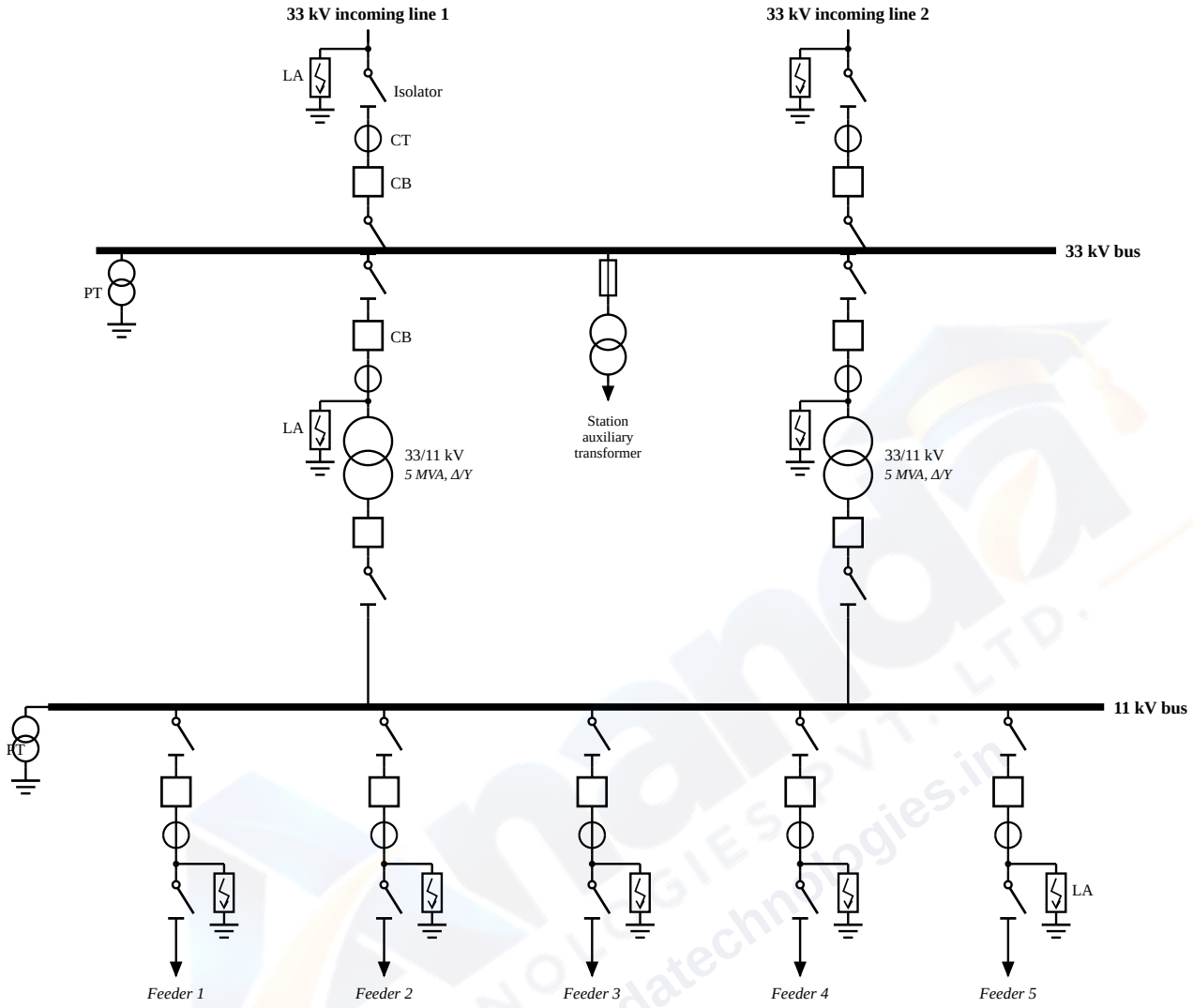


Fig.: Single line diagram (layout) of a 33/11 kV distribution substation

- **Isolator:** It disconnects (isolates) a part of the system for maintenance; it is operated only under **no-load** condition (after opening the CB).
- **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.

(SLD 2 M, functions 1 M each)

Q.4

a) Classification of hydro power plants. 4 M

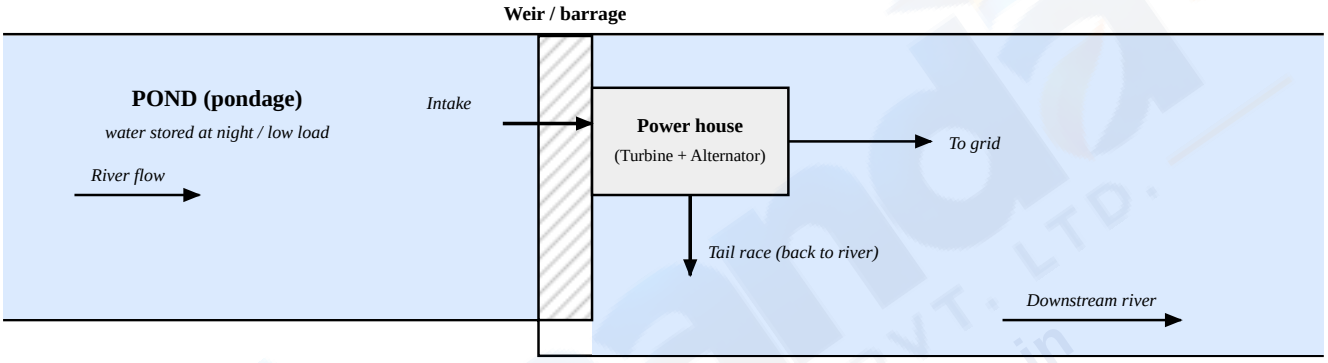
(i) According to water flow regulation:

- **Run-off river plant without pondage:** uses the water as it comes in the river; no storage — output varies with river flow.

- **Run-off river plant with pondage:** a small pond behind a weir stores water for hours / days to meet daily load variation.
- **Storage (reservoir) plant:** a large reservoir stores water of rainy season for use throughout the year (e.g. Koyna).
- **Pumped storage plant:** water is pumped to an upper reservoir during off-peak hours and used during peak hours (e.g. Ghatghar).

(ii) According to water head:

- **Low head plant:** head below about 30 m; uses Kaplan / propeller turbines; large quantity of water.
- **Medium head plant:** head about 30 m to 100 m; uses Francis turbine; forebay is provided.
- **High head plant:** head above about 100 m; uses Pelton wheel; surge tank and long penstock are needed.



(Plan view — without pondage the plant uses only the instantaneous river flow)

Fig.: Run-off river power plant with pondage

(Each classification 2 M)

b) Causes of grid failure; sample blackouts. 4 M

Grid failure (blackout): collapse of a large part of the interconnected grid, so that supply is lost over a wide area.

Causes:

1. Over-drawal of power by states / utilities beyond schedule, especially when frequency is low.
2. Tripping of heavily loaded transmission lines and cascade tripping of other lines (overloading).
3. Mal-operation or failure of protective relays; faults not cleared in time.
4. Lack of spinning reserve and poor coordination between load despatch centres.
5. Extreme weather (storms, lightning, heat waves) and equipment failure.

National example: 30–31 July 2012, India — Northern, Eastern and North-Eastern grids collapsed (about 600 million people affected), mainly due to over-drawal and tripping of overloaded inter-regional lines.

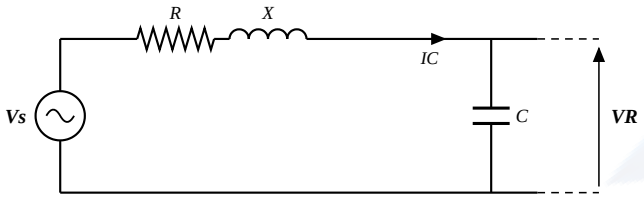
International example: 14 August 2003, North-East USA and Canada — about 50 million people affected (cascade tripping started by lines sagging into trees and alarm failure).

(Causes 2 M, examples 1 M each)

c) Ferranti effect and methods to reduce. 4 M

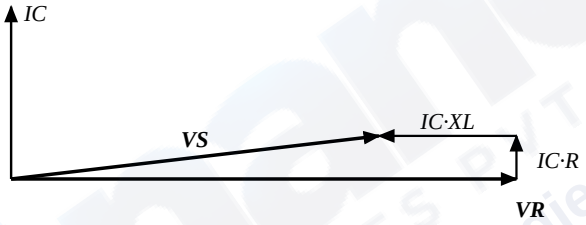
Ferranti effect: When a long (or medium) transmission line is on **no load or light load**, the **receiving end voltage becomes more than the sending end voltage**. This phenomenon is called Ferranti effect.

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_CR is in phase with I_C and the drop I_CX_L leads I_C by 90°, i.e. it is in **phase opposition** to V_R. Hence $V_S = V_R + I_CR + jI_CX_L$ 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 IC 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 (VR > VS)

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.

(Explanation with phasor 2 M, two methods 2 M)

d) EHVAC vs HVDC. 4 M

Basis	EHVAC transmission	HVDC transmission
Voltage level used	400 kV, 765 kV (AC)	±500 kV, ±800 kV (DC)
Line losses	More — skin effect, corona and charging (reactive) losses	Less — no skin effect, no charging current, low corona
Substation equipment	Simple: transformers, circuit breakers, isolators	Complex and costly: converters, converter transformers, filters, smoothing reactors
Initial cost	Terminal cost low but line cost high (3 conductors, bigger towers)	Terminal cost very high, line cost low (2 conductors, smaller towers)

(Each point 1 M)

e) Classification of distribution substations by service. 4 M

Distribution substations are classified according to service requirement as:

- **Transformer substation** (step-up, primary grid, secondary, distribution) — changes voltage level. *Application:* 33/11 kV substation supplying a town.
- **Switching substation** — only switching of lines, no voltage change. *Application:* sectionalising long EHV lines.
- **Power factor correction substation** — synchronous condensers / capacitor banks. *Application:* receiving end of long lines.
- **Converting substation** — AC to DC or frequency conversion. *Application:* railway traction, HVDC terminals.
- **Industrial substation** — supplies one large consumer. *Application:* steel plant, cement factory.

(Any four types with application, 1 M each)

Q.5

a) Thermal power plant layout; coal and ash handling. 6 M

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

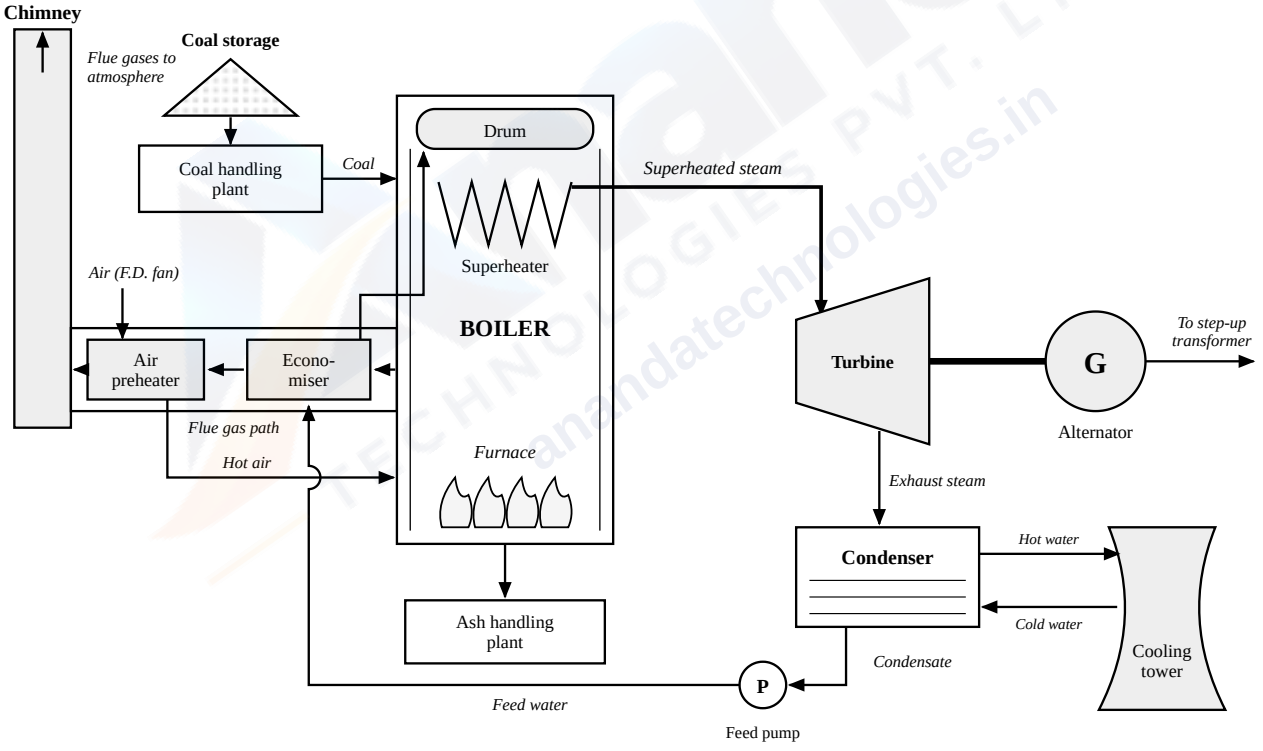


Fig.: Schematic layout of a coal fired (steam) thermal power plant

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**.

Coal handling plant: It receives coal from rail wagons / trucks, unloads it (wagon tipplers), crushes and sizes it, weighs it and carries it by belt conveyors to the storage yard (dead storage) and to the bunkers (live storage). From the bunkers coal goes to pulverising mills and then to the furnace. Stages: coal delivery → unloading → preparation (crushing, sizing, drying) → transfer (conveyors) → storage → in-plant handling and weighing → pulverising and firing.

Ash handling plant: About 30–40 % of Indian coal becomes ash. Bottom ash from the furnace is quenched with water; fly ash from flue gases is collected by electrostatic precipitators (ESP). The ash is carried by hydraulic (water sluicing), pneumatic or mechanical conveying systems to the ash pond / silos. Ash is used for making cement, bricks and for land filling. Proper ash handling prevents air pollution and keeps the plant clean.

(Layout 2 M, coal handling 2 M, ash handling 2 M)

b) Load curve, load duration curve and factors. 6 M

Time (h)	Duration (h)	Load (MW)	Energy = Load × duration (MWh)
0–6	6	25	150
6–10	4	50	200
10–16	6	70	420
16–20	4	85	340
20–24	4	45	180
Total	**24**		**1,290**

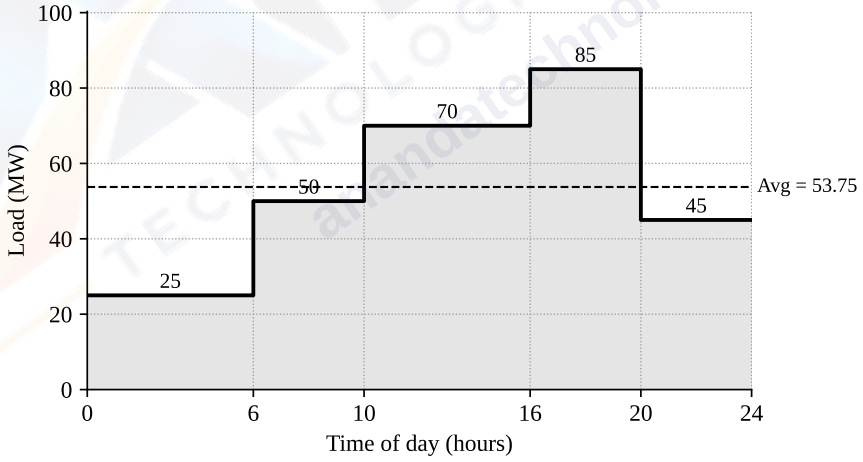


Fig.: Daily load curve (chronological)

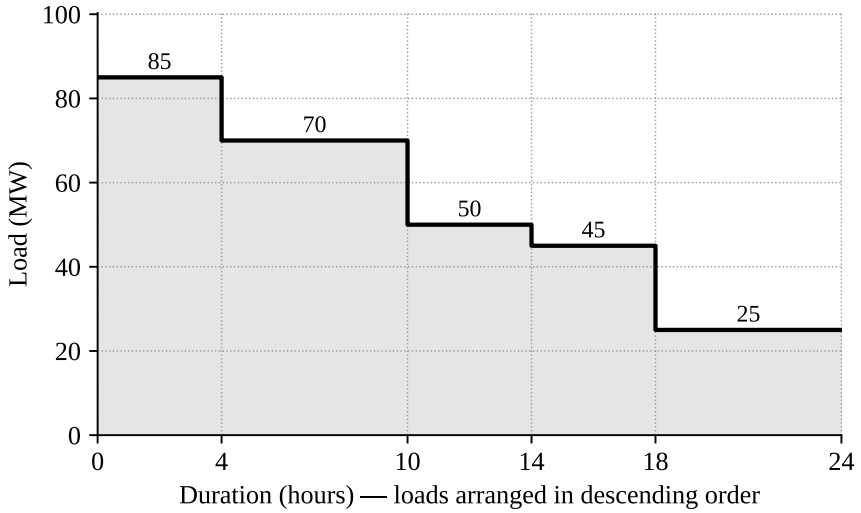


Fig.: Load duration curve (same loads in descending order)

(i) Maximum demand = highest load on the curve = **85 MW**

(ii) Units generated per day = area under load curve = Σ (load × time) = **1,290 MWh = 1,290,000 kWh (1.290×10^6 units)**

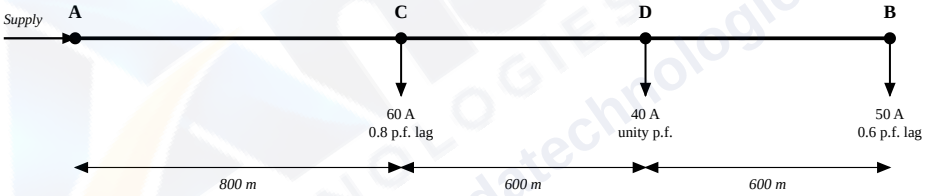
(iii) Average load = units generated per day / 24 = 1,290 / 24 = **53.75 MW**

(iv) Load factor = average load / maximum demand = 53.75 / 85 = **0.6324 = 63.24 %**

(v) Plant capacity factor = average load / installed capacity = 53.75 / 100 = **0.5375 = 53.75 %**

(Load curve 1 M, load duration curve 1 M, results 4 M)

c) Distributor — total drop and sending end voltage. 6 M



Given: total impedance (0.12 + j0.18) Ω for 2 km (go and return); V_B = 230 V; p.f. referred to V_B.

Impedance per km = (0.12 + j0.18) / 2 km = (0.060 + j0.090) Ω/km

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

- $I_C = 60(0.800 - j0.600) = 48.00 - j36.00$ A
- $I_D = 40(1.000 + j0.000) = 40.00 + j0.00$ A
- $I_B = 50(0.600 - j0.800) = 30.00 - j40.00$ A

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

Section	Length	Impedance Z (Ω)	Current (A)	Voltage drop (V)
AC	800 m	0.0480 + j0.0720	118.00 − j76.00	11.136 + j4.848
CD	600 m	0.0360 + j0.0540	70.00 − j40.00	4.680 + j2.340

DB	600 m	0.0360 + j0.0540	30.00 − j40.00	3.240 + j0.180

Total voltage drop = 19.056 + j7.368 V; magnitude = **20.43 V**

Sending end voltage $V_A = V_B$ + total drop = 230 + (19.056 + j7.368) = 249.056 + j7.368 = **249.16 V ∠1.69°**

Arithmetic difference $V_A - V_B$ = 249.16 − 230 = **19.16 V** (= 8.33 % of V_B)

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

Q.6

a) Safe practices — thermal and hydro plants. 6 M

Thermal power plant:

1. Use PPE (helmet, safety shoes, goggles, ear muffs) and follow permit-to-work / lock-out tag-out before maintenance.
2. Check boiler safety valves, pressure gauges and water level gauges regularly; never open pressurised lines.
3. Fire detection and fire fighting in coal yard, conveyors and oil storage; control coal dust by water spraying.

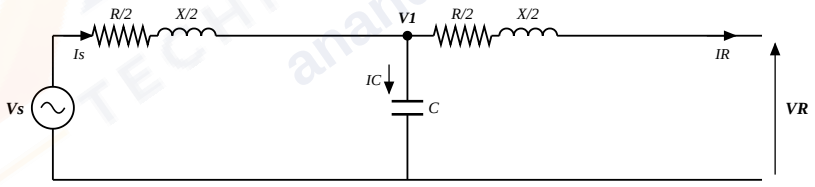
Hydro power plant:

1. Close and lock intake gates and drain the penstock before entering penstock / turbine / draft tube (confined space precautions).
2. Use life jackets and safety belts near reservoir, gates and tail race; provide railings.
3. Warn people downstream with sirens before opening spillway gates or releasing water.

(Three practices for each plant, 1 M each)

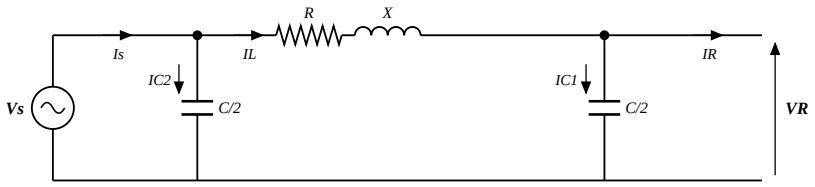
b) Nominal T vs nominal π. 6 M

Both are approximate methods of representing a medium line (80–200 km) by lumped constants.



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

Fig.: Nominal T representation of a medium transmission line



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

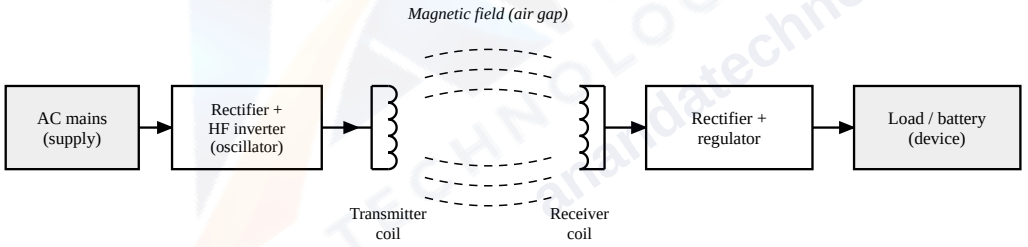
Fig.: Nominal π representation of a medium transmission line

Point	Nominal T method	Nominal π method
Capacitance	Whole capacitance C at the middle of the line	Capacitance divided into two halves (C/2) at sending and receiving ends
Series impedance	Divided into two halves (Z/2 each side of C)	Whole impedance Z in the middle
Nodes	Three nodes (V_S, V_1, V_R) — extra node V_1	Only two nodes (V_S, V_R)
Charging current	I_C flows through half the line	I_{C1} flows through whole line; I_{C2} does not flow through line
Calculation	V_1 must be found first; more steps	Simpler; preferred for load-flow studies
Constants	A = D = 1 + YZ/2, B = Z(1 + YZ/4), C = Y	A = D = 1 + YZ/2, B = Z, C = Y(1 + YZ/4)
Losses	$(I_R^2 + I_S^2)R/2$	I_L^2R

(Any six points, 1 M each)

c) Wireless transmission of electrical power. 6 M

Wireless power transmission (WPT): Transfer of electrical energy from a source to a load **without connecting wires**, using time-varying electric, magnetic or electromagnetic fields. In inductive / resonant WPT, a high frequency AC current in the transmitter coil produces an alternating magnetic field; this field links the receiver coil and induces an emf in it (mutual induction). The induced AC is rectified and regulated to supply the load or charge a battery. Tuning both coils to the same resonant frequency increases the distance and efficiency.



Far-field methods (microwave / laser) use a transmitting antenna and a rectenna instead of coils

Fig.: Block diagram of wireless (inductive / resonant) power transmission

Methods:

- **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.

Advantages / features:

- 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.

Applications: wireless mobile chargers, electric vehicle charging pads, medical implants, RFID, space solar power (proposed).

(Concept 2 M, block diagram 1 M, methods 1 M, advantages / applications 2 M)

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