POWER PLANT ENGINEERING

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MECHANICAL

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UNIT I – Fundamentals of Power Plant (Advanced Notes)

1.1 Present Indian & Global Scenario of Demand and Supply of Conventional Power Plants

Definition & Context

A **power plant** is an assembly of systems and subsystems that convert one form of energy (often chemical/fuel energy) into electrical energy, economically and reliably. (Scribd)
Because electricity is the *carrier* of energy for nearly all modern economic & industrial activity, the growth of the power sector is tightly linked to national growth (as your rationale states).

Global & Indian Trends

- Globally, fossil fuels (coal, oil, gas) continue to contribute a large share of electricity generation; for example, conventional energy sources (coal, oil, gas, uranium) account for ~92 % of total commercial energy in older sources. (gpnuapada.in)
- India's transition: Non-fossil sources are increasing rapidly (solar, wind, hydro, nuclear) but conventional plants still form the bulk of installed capacity and generation.
- The growth of electricity demand in India is high, driven by urbanisation, industrialisation, digital services, electrification of rural areas.
- Implication for conventional plants: They must be more efficient, lower-emission, flexible (to work with variable renewables), and economically viable.

Key Metrics

- Installed capacity (India) as of recent years: ~476 GW (approx) with ~50% fossil fuel share.

- Load factors, capacity factors, plant availability matter: e.g., "availability factor" is defined as the ratio of time a power unit actually produces electricity to the time it *could* in principle. (Wikipedia)
- Efficiency of conversion, fuel cost per kWh, emission per kWh are critical metrics.

Advanced Considerations

- **Energy resource availability**: Coal reserves, natural gas imports, uranium/thorium for nuclear — each source has constraints (geological, geopolitical, transport).
- **Resource-use efficiency**: As marginal resources deplete or quality declines (e.g., low-grade coal), efficiency drops unless technology improves.
- **Environmental & regulatory pressure**: With global climate-change commitments (e.g., Paris Agreement), conventional plants must adopt cleaner technologies or retire early.
- **Integration with variable renewables**: Conventional plants must provide grid flexibility (start/stop, ramping) which affects their design, maintenance and economics.

1.2 Overview of Power Generating Plants – Government & Private Corporations in India

Ownership & Sector Classification

- **Public/Government sector**: Entities like NTPC Limited (thermal & renewables), NHPC Limited (hydro), Nuclear Power Corporation of India Limited (nuclear) etc.
- **Private sector / Independent Power Producers (IPPs)**: E.g., Adani Power, Tata Power, JSW Energy — they increasingly account for large-scale thermal, solar, wind capacity.
- **Captive power plants**: Industrial units that produce their own power (e.g., cement plants, steel plants) to secure supply.

Capacity & Generation Highlights

- Conventional (coal, gas) plants still dominate installed capacity in many states.

- Private sector plants often focus on large-scale imports (e.g., coal), gas-fired combined-cycle plants, or renewable hybrids.
- Government plants often have older infrastructure; private ones may adopt newer "supercritical"/"ultra-supercritical" boilers.

Engineering Relevance

- As a mechanical engineering student, understanding how different ownership/sector plants vary in design, maintenance regimes, plant load factors, and lifecycle cost is important.
- For example: a private IPP may operate on high load factor efficiently; a publicly-run older plant may operate at low load factor, experience more maintenance downtime.

1.3 Site Selection Criteria for Steam (Thermal) Power Plant

Why Site Selection is Critical

The site influences plant investment cost, fuel & water transport cost, environmental compliance cost, ash/effluent disposal cost, transmission losses, and future expansion possibilities. A poor site can make even a technically sound plant uneconomical.

Detailed Criteria (with engineering rationale)

Criterion	Engineering/Operational Implication	Key Considerations
Fuel availability & cost	Shorter transport distance → lower cost; better quality fuel → higher efficiency	Proximity to coal-field or port, fuel quality (ash content, moisture)
Water supply & cooling	Large volumes of water needed for steam cycle and condenser cooling. Inadequate supply reduces efficiency or forces cooling tower or seawater use.	Availability of river/lake/sea; seasonal variability; environmental discharge limits

Land & topography	Flat land simplifies layout, reduces civil cost; land for ash disposal is vital for coal plants	Land acquisition cost; future expansion; geotechnical stability
Transport infrastructure	Boilers, turbines, heavy components require transport; coal/ash transport requires rail/road	Railway sidings, port access, road connectivity
Proximity to demand centre & grid	Reduced transmission losses, lower investment in long-distance lines	Near high-load states, urban centres; grid strength & voltage level
Cooling system & ambient conditions	Ambient temperature affects condenser performance → impacts cycle efficiency	Hot climates reduce condensing vacuum; need for forced draft cooling towers
Environmental & regulatory context	Emission limits, ash pond/FS approval, land mitigation — stricter norms raise cost	Air/water pollution standards, buffer zone from habitation, terrain (flood/earthquake)
Ash & waste disposal	For coal plants especially, ash handling, pond design, utilisation (fly-ash bricks, road fill)	Availability of nearby utilisation zones, environmental clearance
Expansion & flexibility	Future capacity additions, potential for upgrading to supercritical/ultra-supercritical	Provision for future boilers/turbines, change-over to residual fuel/gas
Security & logistics	Fuel supply chain security, water rights, potential for natural hazards	Risk of mine strikes, fuel import

		dependency, water-sharing disputes

Advanced Note

- Many modern coal-fired plants in India are located near major coalfields (e.g., in Chhattisgarh, Odisha) partly for lower transport cost and logistics.
- With stricter environmental norms and coal-quality worsening, some new plants prefer imported coal through ports despite higher transport cost, due to lower ash/ sulphur content.
- Coastal sites use seawater cooling (no freshwater required) but face corrosion, higher maintenance, and environmental constraints (thermal pollution of sea).

1.4 IBR (Indian Boiler Regulations) Norms for Steam Power Plant

What is IBR?

The Indian Boiler Regulations, 1950 (IBR) regulates design, construction, inspection, certification, safe operation of boilers and steam pressure parts in India. It applies to boilers under certain pressure and steam capacity thresholds.

Important Provisions & Engineering Implications

- **Registration**: Every boiler above a defined steam output/pressure must be registered with Chief Inspector of Boilers in the State.
- **Material standards**: Use of boiler steel, tubes, riveted/seamless pipes must conform to standards (e.g., IS codes) to ensure mechanical strength at high pressure and temperature.
- **Safety devices**: Boiler must include safety valve, water-level gauges, pressure gauge, feed pump, blow-off valve, and be inspected regularly.
- **Inspection & certification**: Pre-commissioning, periodic inspection (annual or more frequent for high-risk boilers) by authorised inspectors; defects must be rectified before operation.

- **Personnel certification**: Boiler attendant or operator must be certificated by state authority; unauthorized operation may cause accidents and penalties.
- **Design pressures & test pressures**: Boiler must be designed for working pressure; hydrostatic test typically 1.3 times working pressure for certain boilers.
- **Pressure parts & piping**: Release of steam under fault conditions must be safely managed; piping stress, thermal expansion & vibration must be properly designed (especially in power plants where boiler size is large).

Relevance in Power Plant Engineering

- For high-pressure, supercritical boilers (common in modern plants), compliance with IBR and other international standards (ASME, EN) becomes essential.
- Maintenance of boilers (tube leakage, scale formation, corrosion) is critical – adhering to IBR helps ensure reliability and safety.
- Plant safety culture, regular audit, preventive maintenance – all trace back to boiler regulation compliance.

1.5 CPCB & MPCB Norms for Power Plants

Regulatory Bodies

- Central Pollution Control Board (CPCB) – national; sets emission/discharge standards for industry including power plants.
- Maharashtra Pollution Control Board (MPCB) – one example of a state-level regulator enforcing CPCB norms locally.

Key Emission & Effluent Norms (for Thermal Power Plants)

Pollutant/Parameter	Typical Norm	Significance
Particulate Matter (PM) in Stack	≤ 50 mg/Nm^3 (some stricter)	Dust from flue gases; high PM → health & environmental hazard

Sulphur Dioxide (SO_2)	≤ 100 mg/Nm^3 (varies by region, fuel-sulphur)	From sulphur in coal; causes acid rain, respiratory issues
Nitrogen Oxides (NOx)	≤ 100 mg/Nm^3 (again region/fuel-specific)	From high temperature combustion; contributes to smog, ozone
Mercury & heavy metals	≤ 0.03 mg/Nm^3 (Indian norms)	Toxic, bio-accumulative
Flue Gas Desulfurization (FGD) & Ash handling	Mandatory for certain coal capacity units	Ensures reduction of SO_2 & proper ash disposal

Engineering Implications & Technologies

- To comply: installation of **Electrostatic Precipitators (ESP)** or bag filters for fly ash, **Flue Gas Desulfurization (FGD)** systems for SO_2, **Low-NOx burners or Selective Catalytic Reduction (SCR)** for NOx.
- Wastewater treatment: condensate polishing, effluent cooling, ash-pond seepage control.
- Ambient air quality monitoring: continuous emission monitoring systems (CEMS) must be installed and data submitted to CPCB.
- Sites now have to consider buffer zones, ash pond-leak risk, community health impact, environmental clearances (EIA/EC).

Note for Your Region (India) & Students

- Maharashtra has many large thermal plants (like in Chandrapur, Koradi). Hence MPCB enforcement is strict — places with old plants often face regulatory action for non-compliance.
- In your syllabus when you talk about maintenance (CO2, CO3) and operations, you'll need to consider how emission-control equipment affects maintenance schedules, operational cost, efficiency drop (FD/ID fans for FGD, extra pumping energy, ash transport).

1.6 Introduction to Power Plants: Importance & Classification

Importance (Revisited)

- Electric power drives industrial machines, digital infrastructure, cities, rural development, transportation (especially electric mobility) — makes it a *strategic resource*.
- Power plants convert high-grade energy (chemical, nuclear) into useful electricity — how they do it, how efficient & clean they are, how well they operate and maintain matters.
- For mechanical engineers, understanding large rotating machines (turbines, generators), fluid systems (boilers, condensers, cooling), thermal cycles and maintenance regimes is core.

Classification of Power Plants – with Advanced Detail

By Energy Source / Technology

- **Steam-Turbine (Thermal) Plants**: Use steam generated in boiler (fuel + combustion) to drive turbines; typical Rankine cycle.
- **Gas Turbine / Combined Cycle Plants**: Gas turbine (Brayton cycle) plus steam cycle (Rankine) using exhaust heat → higher efficiency. (Wikipedia)
- **Hydro-electric Plants**: Use potential & kinetic energy of water → turbine → generator; renewable, low variable cost.
- **Nuclear Power Plants**: Heat from nuclear fission (or future fusion) creates steam → turbines; high capital cost, low fuel cost, major safety/regulatory issues.
- **Diesel / Internal-Combustion Plants**: Smaller scale, often peaking or backup; quick start, high fuel cost.
- **Non-conventional / Renewable Plants**: Solar PV, wind, biomass, tidal, geothermal — increasingly integrated with conventional plants for flexible grid.

By Load Type / Operation

- **Base-load Plants**: Operate nearly continuously to supply the steady demand (e.g., large coal, hydro, nuclear).

- **Peaking Plants**: Operate during high-demand periods; often gas or diesel.
- **Intermediate Load / Load-following Plants**: Adjust output as demand varies (e.g., some gas plants, modern coal plants with ramp capability).

By Ownership & Operation

- **Public utility plants**
- **Private / IPP (Independent Power Producers)**
- **Captive plants** (for a single industry)
- **Merchant plants** (selling into market rather than having long-term PPA)

Why Classification Matters (from a learning/engineering perspective)

- Different technologies have different **thermodynamics**, **mechanical design**, **auxiliary systems**, **maintenance regimes**, **efficiencies**, **emission profiles**.
- For example, a supercritical coal-fired plant (high pressure & temperature) has very different turbine, boiler, materials issues compared to a small diesel plant.
- When you later study site-selection, fuel choice, cycle efficiency, cost analysis — classification helps you choose the right approach.

1.7 Types of Fuels Used in Conventional Power Plants, Their Properties & Relative Cost per kWh

Fuel Types Overview

- **Solid Fuels**: Coal (anthracite, bituminous, sub-bituminous, lignite), peat.
- **Liquid Fuels**: Furnace oil, diesel, heavy fuel oil.
- **Gaseous Fuels**: Natural gas, LNG, biogas.
- **Nuclear Fuel**: Uranium-235, Thorium (in advanced reactors).
- (Although not strictly "conventional", biomass, municipal solid waste also matter in "traditional" plants in some contexts.)

Important Fuel Properties & What They Mean

Property	Definition	Relevance to Plant Design/Operation
Calorific Value (CV)	Heat energy released per unit mass (or volume) on complete combustion (kcal/kg or MJ/kg)	Higher CV → more energy per ton → lower fuel handling cost, larger output.
Gross & Net Calorific Value	Gross includes latent heat of water vapour; net excludes it	Important for efficiency calculations.
Flash Point / Fire Point	Minimum temperature at which fuel vapour ignites (flash) and continues burning (fire)	Safety, storage design (especially liquids)
Ash Content (for solids)	% by mass of ash after combustion	Impacts ash-handling systems, disposal cost, wear & tear of boiler tubes
Sulphur & Moisture Content	Sulphur → SO_2 emissions; moisture reduces net CV	Affects emission control cost, fuel transport cost, boiler efficiency
Volatile Matter / Fixed Carbon	For coal: indicates reactivity, flame properties, ash behaviour	For furnace design, flame stability, slagging/fouling issues

Typical Values (Indicative)

- Indian bituminous coal: ~5500 - 6500 kcal/kg (varies widely)
- Natural gas: ~35-45 MJ/m³ (~8000-11000 kcal/kg equivalent)
- Diesel: ~10000 kcal/kg; flash point ~60 °C
  Note: These are ballpark values; actual values vary by lot, mine, region.

Relative Cost per kWh – Fuel Basis

While actual cost varies by region, plant efficiency, fuel transport, etc., one can compare approximate relative costs:

- Coal: Generally lowest cost per kWh among fossil fuels in India (for large scale plants).
- Natural Gas: Higher fuel cost + infrastructure (pipelines, LNG terminals) → higher cost per kWh.
- Diesel/Furnace Oil: Highest fuel cost; used only for peaking or small plants.
- Nuclear Fuel: Very low fuel cost per kWh (due to very high energy density and longer life of fuel), but very high capital cost, long lead times.
- Hydroelectric (if considered fuel-free) has very low variable cost, but large upfront cost, site constraints.

Engineering Implications & Advanced Notes

- **Fuel choice**: For CO1 (in your course), you must evaluate not just cost but availability, transport, fuel quality, ash/slag behaviour, environmental effects, plant efficiency and future availability.
- **Efficiency link**: Plant efficiency matters more when fuel cost is high – e.g., moving from sub-critical to supercritical boiler saves fuel per kWh, thus reducing cost.
- **Environmental cost**: Low-grade coal with high ash and sulphur may have cheaper nominal cost but higher hidden costs (ash disposal, emissions control, slagging/erosion of tubes).
- **Fuel flexibility**: Modern plants may be designed to burn biomass/coal blends, LNG/coal mix — increases flexibility but increases design complexity.
- **Life-cycle cost**: When you compute cost per kWh, include capital cost (amortised), fuel cost, O&M cost, emission control cost, downtime cost, ash disposal cost. This ties into CO5 (calculate economic parameters).

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