GGS COLLEGE OF MODERN TECHNOLOGY, KHARAR

DEPARTMENT OF

ELECTRICAL ENGINEERING

Lecture Notes

Power Generation and Economics

Subject code – BTEE-602-18

6th Semester B.Tech.

Module-1

Introduction

Loads

Concept of MW, MWh, Units, Million Units (MU)

Structure of Power System

Power Generation

Concept of Frequency

Prime movers and Generators

Salient Pole and Cylindrical type Alternators

Sources of Energy

- How can we keep providing humankind with energy-derived advantages without damaging the environment, affecting societal stability or threatening the wellbeing of future generation?
- Sustainable energy can be thought of as a living harmony between the equitable availability of energy sources to all people and the preservation of earth for future generations.
- Electricity is an intermediate energy product that is made from primary energy sources. Power is the rate of energy exchange between two systems.
- The various sources of energy in the Indian context are as follows. As is obvious, the major source of generation is coal based thermal power plant. Thermal, nuclear and hydro powers are known as conventional energy sources which is the subject matter of this course.
- Installed Capacity in India

Table 1: Installed Capacity as on 30-11-2014

Source	Subtype	Capacity (MW)	Remarks
Thermal	Coal	153571	
	Gas	22971	
	Diesel	1199	
	Total	177742	
Nuclear		4780	
Hydro		40798	
RES	Wind	21136	
	Solar	2632	
	Biopower	4119	

Hydro Power Potential

$P = g*\rho*Q*H$

Where

P = Power available in water

$g = 9.81\ m/s^2$

Q = flow or discharge (m^3/s)

H = Height of fall of water or head (m)

$P = 9.81*1000*Q*H*10^{-3}$ kW = 9.81 QH kW

P= 9.81 QHη kW where η = efficiency of the turbine-generator assembly

- Rain falling on earth's surface has potential energy relative to oceans.
- This energy is converted to shaft work when the water falls through a vertical distance.
- This shaft work is used to drive water turbines to generate electricity.

Hydrology

- First requirement – Q (discharge)
- Hydrology deals with occurrence and distribution of water over and under earth's surface.
  - Surface Water Hydrology
  - Ground Water Hydrology
- **Watershed, catchment area or drainage area:** length of the river, size and shape of the area it affects, tributaries, lakes, reservoirs etc.
- Investigation of **run-off** for past few years is required for power potential studies of a HPP.

Objectives of Hydrology

- To obtain data regarding the stream flow of water that would be available,
- To predict the yearly possible flow
- To calculate the mean annual rainfall in the area under consideration from a record of the annual rainfall for a number of years, say 25 to 30
- To note the frequency of dry years
- To find maximum rainfall and flood frequency

Various terms related to Hydrology

- Rainfall is also known as precipitation and can be measured by rain gauges.
- Some part of precipitation is lost due to evaporation, interception and transpiration.
- **Transpiration:** Plants absorbing moisture and giving it off to the atmosphere
- Stream flow = precipitation – losses
- Stream flow = surface flow + percolation to ground
- Surface flow is also known as **run-off.**

- **Hydrograph:**
  - shows the variation of stream flow in m^3/s with time for a particular river site. The time may be hour, week, month or a year.
  - The area under hydrograph gives the total volume of flow

- **Flow duration curve:**
  - shows the percentage of time during the period when the flow was equal to greater than the given flow.
  - The area under FDC gives the total quantity of run-off during a period

- **Mass curve**
  - indicates the total volume of run-off in cubic meters up to a certain time.
  - the slope of the curve at any point shows the rate of flow at that time
  - Used for estimating the capacity of storage reservoir
- **Storage:**
  - to ensure water availability during deficient flow and thus increasing the firm capacity
  - Storage also results in more energy production
- **Pondage:**
  - Storing water in small ponds near the power plant as the storage reservoir is away from plant
  - To meet the power demand fluctuations over a short period of time e.g. 24 hours

- **Primary Power:** power that will be available 90 % of the time
- **Secondary Power:** power that will be available 75 % of the time

- **Dump Power:** power that will be available 50 % of the time.
- **Maximum flow estimation:** gives estimation of floods and helps in design of dam and spillway.

Site Selection for Hydropower Plants

- **Availability of Water:** Run-off data for many years available
- **Water Storage:** for water availability throughout the year
- **Head of Water:** most economic head, possibility of constructing a dam to get required head
- **Geological Investigations:** strong foundation, earthquake frequency is less
- **Water Pollution:** excessive corrosion and damage to metallic structures
- **Sedimentation:** capacity reduces due to gradual deposition of silt
- **Social and Environmental Effects:** submergence of areas, effect on biodiversity (e.g. western ghat), cultural and historic aspects
- **Access to Site:** for transportation of construction material and heavy machinery new railway lines or roads may be needed
- **Multipurpose:** power generation, irrigation, flood control, navigation, recreation; because initial cost of power plant is high because of civil engineering construction work

Types of Dams

Figure 1: Earth and Rockfill Dam

Figure 2: Arc Dam

Figure 3: Arc Gravity Dam

Classification of Hydropower Plants

According to water flow regulation:

1. Runoff river plants without pondage
2. Runoff river plants with pondage
3. Hydroelectric plants with storage reservoir

According to Load:

1. Base load plants
2. Peak load plants
3. Pumped storage plants

According to head:

1. High head plants (>100m)
2. Medium head plants (30-100 m)
3. Low head plants (<30 m)

Components of a HPP

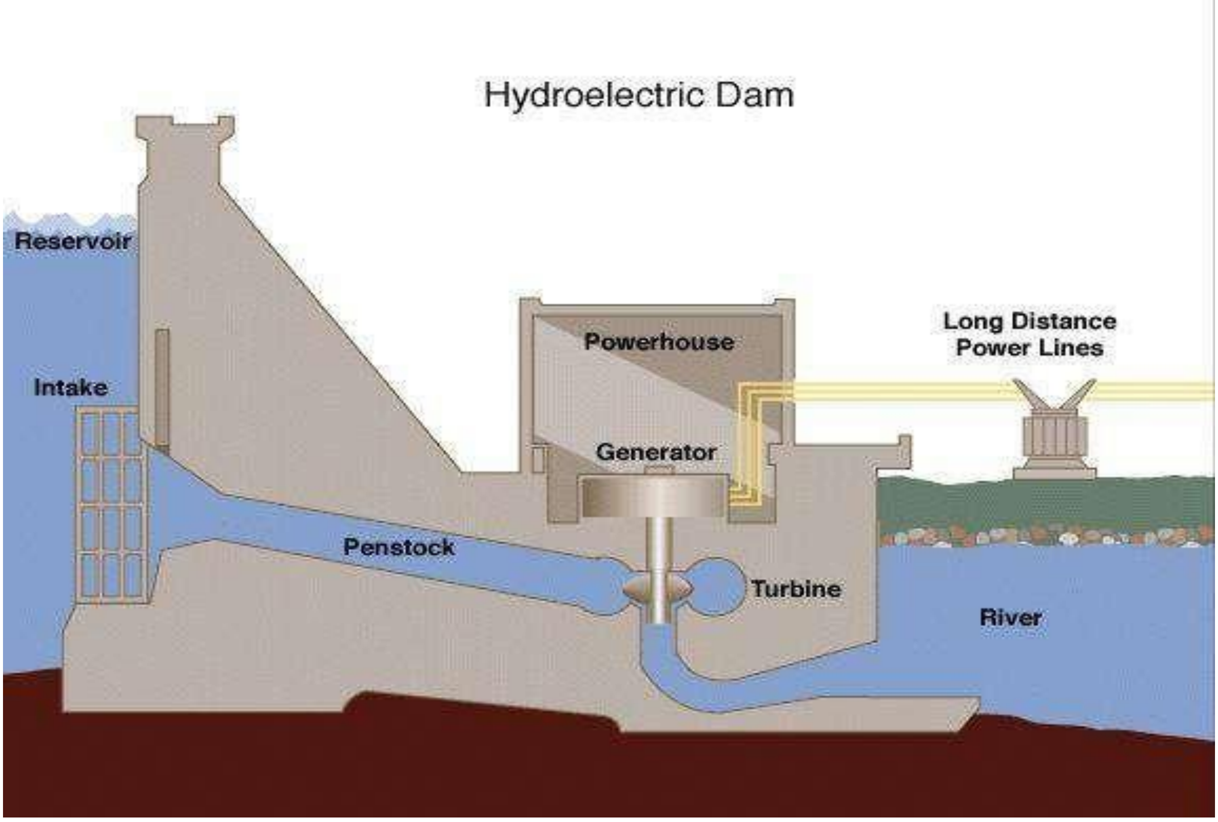


Figure 4: Schmatic of a Hydropower Plant

The various components of HPP are as follows:

1. Catchment area
2. Reservoir
3. Dam
4. Spillways
5. Conduits
6. Surge tanks
7. Draft tubes
8. Power house
9. Switchyard for power evacuation

Dam

- Develops a reservoir to store water
- Builds up head for power generation

Spillway

- To safeguard the dam when water level in the reservoir rises

Intake

- Contains trash racks to filter out debris which may damage the turbine

Forebay

- Enlarged body of water just above the intake

Figure 5: Forebay

Conduits

- Headrace is a channel which lead the water to the turbine
- Tailrace is a channel which carries water from the turbine
- A canal is an open waterway excavated in natural ground following its contour.
- A flume is an open channel erected on a surface above ground.
- A tunnel is a closed channel excavated through an obstruction.
- A pipeline is a closed conduit supported on the ground.
- **Penstocks** are closed conduits for supplying water "under pressure" from head pond to the turbines.

Figure 6: Forebay with Penstock

Figure 7: Penstocks

Surge Tank

- A surge tank is a small reservoir in which the water level rises or falls to reduce the pressure swings so that they are not transmitted to the penstock.
- Water Hammer
    - Load on the turbine is suddenly reduced

    - Governor closes turbine gates
    - Sudden increase of pressure in the penstock
- Negative Pressure
    - Load on the generator is suddenly increased
    - Governor opens the turbine gates
    - Tends to cause a vacuum in the penstock
- When the gates are closed, water level rises in the surge tank and when the gates are suddenly opened, surge tank provides the initial water supply.

Figure 8: Surge Tank

Draft Tubes

The function of the draft tube is to

- To reduce the velocity head losses of the water
- To allow the turbine to be set above the tailrace to facilitate inspection and maintenance

Figure 9: Elbow Type Draft Tube

Figure 10: Straight conical type draft tubes

Scroll Casing:
Takes the water from penstock to turbine blades

Figure 11: Scroll Casing

Tailrace:

- A tailrace is required to discharge the water leaving the turbine into the river.
- The design of the tail race should be such that water has a free exit.

Figure 12: Tail race

Power House
1. Hydraulic turbines
2. Electric generators
3. Governors
4. Gate valves
5. Relief valves
6. Water circulation pumps
7. Air ducts
8. Switch board and instruments
9. Storage batteries
10. Cranes

Switchyard
1. Step up transformers
2. Instrument transformers
3. Transmission lines

Figure 13: A switchyard under construction

Hydraulic Turbines

Types of Hydraulic Turbines

1. According to the head and quantity of water available
    a. Low head (2-15m)
    b. Medium head (16-70m)
    c. High head (71-500m)
    d. Very high head (>500m)
2. According to the name of the originator
    a. Francis
    b. Kaplan
    c. Pelton
3. According to the nature of working of water on blades

Table 2: Impulse and Reaction Turbines

Impulse	Reaction
Available head of water converted into kinetic energy in a nozzle	Flow of water takes place in a closed conduit system
The free jet strikes a bucket which revolves around a shaft	Part of P.E. is converted into K.E. and part into pressure energy
Turbines are above ground	Water flows in a closed conduit system and turbines are submerged in water
After energy production, water falls freely through the passage into tail race	Water falls through a draft tube

4. According to the direction of flow of water
    a. Radial
    b. Axial
    c. Tangential (Deriaz)
5. According to the axis of the turbine shaft: vertical, horizontal

Comparison of Turbines

Table 3: Comparison of Turbines

Turbine	Head (m)	Specific Speed (metric)
Kaplan	30 to 70	300 to 1000
Francis	40 to 400	60 to 300
Pelton	>400 m	10 to 50

Figure 14: Kaplan Turbine

Figure 15: Kaplan Turbine

Figure 16: Francis Runner

Figure 17: Francis Runner

Figure 18: Francis Runner

Figure 19: Francis Runner

Figure 20: Pelton Turbine

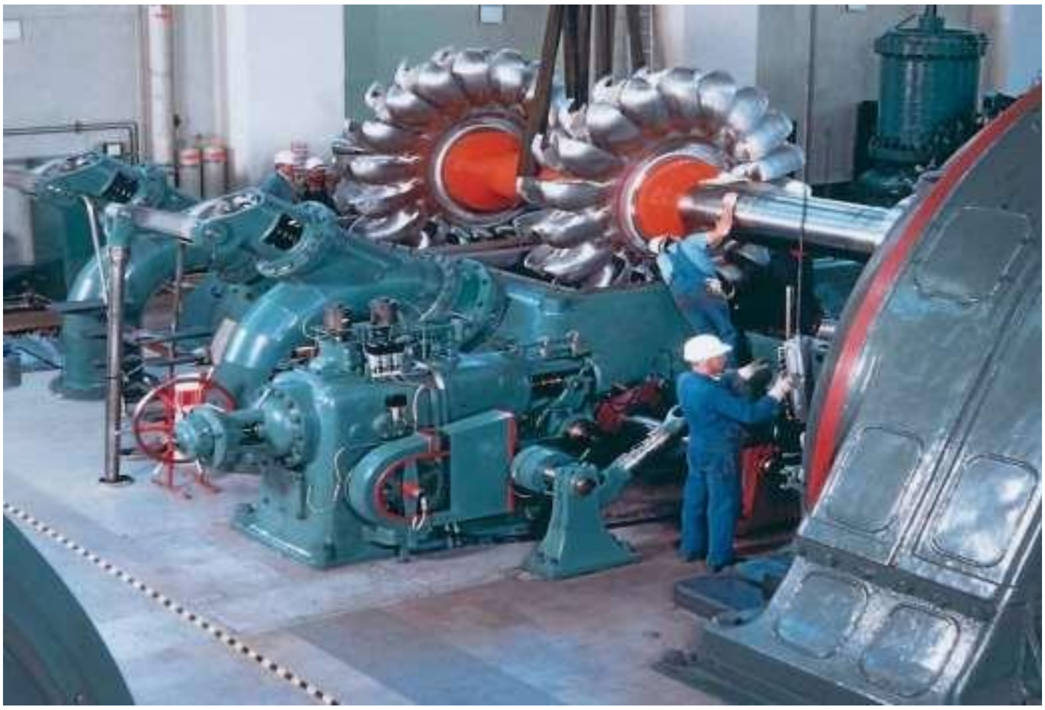


Figure 21: Pelton Turbine

Specific Speed (N_s)

- It is defined as the speed of a geometrically similar turbine to produce 1 kW of power under 1 m head. Its units are ‘rpm in (m-kW)’ or ‘rpm in (m-mhp)’.

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

Where N = rotational speed of the turbine in rpm

P = Power output of the turbine in kW or mhp

H = Head of the turbine in meters

- Specific speed is the basis of comparison of the characteristics of hydraulic turbines.
- Higher the specific speed for a given head and power output, the lower the cost of installation as a whole.

Example:

Find out the specific speed of a turbine of 10 MW capacity working under a head of 500m and having the normal working speed of 300 RPM.

Solution:

N_s = 300x sqrt (10000) / 500^(1.25) = 12 rpm in (m-kW)

Runaway Speed

It is the maximum speed at which a turbine would run under the worst conditions of operation i.e. with all gates open so as to allow all possible water inflow under maximum head and corresponding to the condition of the load being suddenly thrown off from the generator.

Turbine Setting

- Height of the turbine from the tailwater level is known as turbine setting.
- Turbine setting must ensure a cavitation free operation.

- Air bubbles are formed on the turbine, if there is no proper turbine setting leading to air cavity and can damage turbine blades.

Governing of Hydraulic Turbines

- N = 120f/P implies speed of the generator can be maintained at a constant level only when the speed of the turbine is constant.
- Load is increased => speed tends to decrease and vice versa.
- The function of the governor is to regulate the quantity of water flowing through the runner in proportion to the load. Thus the governing mechanism maintains the speed of the runner at a constant level at all loads.
- For reaction turbines, the governor controls the guide vanes and wicket gates. For impulse turbines, the governor controls the spear and nozzle.

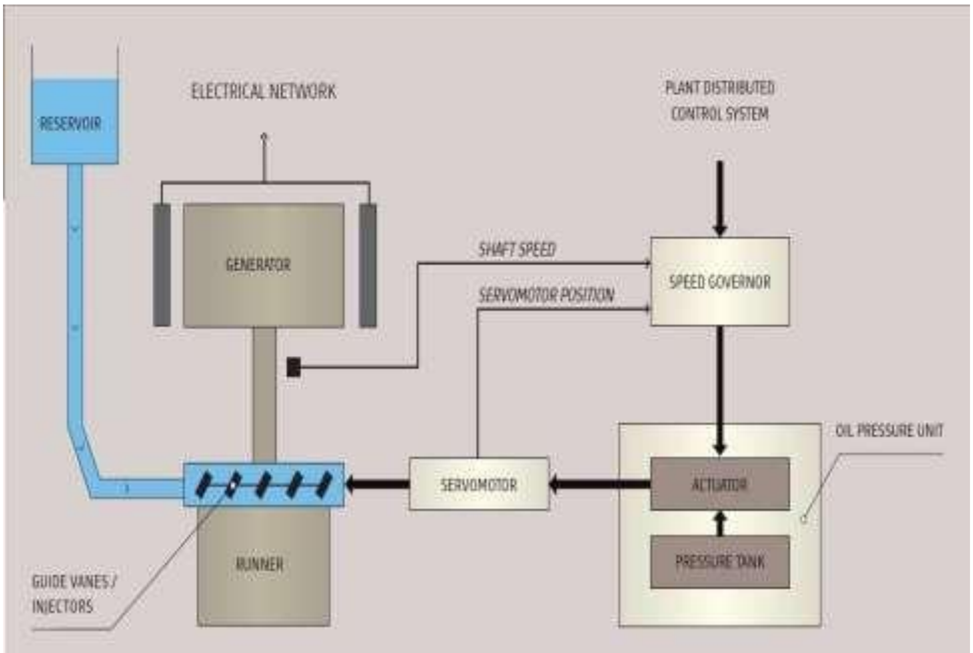


Figure 22: Governing Mechanism

Hydro Power Plant Auxiliaries

1. Governing oils systems
2. Lubricating oil pumps
3. Coolant oil pumps
4. Drainage pumps
5. Pipes, fans, ventilation
6. Air compressor
7. Cooling oil pumps for transformers
8. Head gates
9. Drain valves
10. Gantry cranes
11. Station batteries
12. Instrumentation system

Hydro Power Plant Layout

The major aspects to be considered for deciding the power plant layout are:

- Size of various units
- Size required for spiral casing
- Distance between various units
- Width of erection bay
- Position of gantry crane
- Position of control room

Figure 23: Power House Layout

Numerical Problems on Hydro Power Plants

1. A hydro plant operates under an effective head of 100 m and a discharge of 200 m^3/s. If the efficiency of the turbine alternator set is 0.9, find the power developed.
   (Ans. 176.52 MW)
2. A hydro-electric station has an average available head of 100 meters and reservoir capacity of 50 million cubic meters. Calculate the total energy in kWh that can be generated, assuming hydraulic efficiency of 85 % and electrical efficiency of 90%.
   (Ans. 10.423 x 10^6 kWh)
3. One million cubic meters of water is stored in a reservoir feeding a water turbine. The density of water is 993 kg/m^3. If the centre of mass of water is 50m above the turbine and the losses are negligible, what will be the energy in MWh produced by that volume of water? (ESE-2011)
   (Ans. 135.3/130/120/140)
4. The utilizable water from a catchment is 60x10^6 cu m annually and the hydro station has a head of 40 m. Assuming ideal generator and turbine, find power that can be theoretically generated?
   (Ans. 250/300/500/750 kW)
5. A hydroelectric station is designed to operate at a mean head of 205 m and fed by a reservoir having a catchment area of 1000 km^2 with an annual rainfall of 125 m of which 80% is available for power generation. The expected load factor is 75%. Allowing a head loss of 5 m and assuming efficiency of turbine and generator to be 0.9 and 0.95 calculate suitable MW rating of the power station. Comment on the type of turbine to be used. (BRG P-156)
   (Ans. 70.9 MW, Pelton turbine)

6. Draw the hydrograph and flow duration curve for the following data. Also find average power developed if the head is 100 m and efficiency is 90%.

Week	Discharge	Week	Discharge
1	100	7	800
2	200	8	600
3	300	9	1000
4	1200	10	600
5	600	11	400
6	900	12	200

7. For the data of weekly flow in Q-6, find the following.
    a. Draw the mass curve
    b. Calculate the size of the reservoir to permit average discharge.
    c. Calculate the possible rate at which flow will be available after the reservoir has been built.

Module-2

Laws of Thermodynamics

Zeroth Law:

- Temperature measurement
- thermal equilibrium

First Law:

- $\sum W_{cycle} = J (\sum Q_{cycle})$ for a cyclic process
- Equivalence of heat and work
- Principle of conservation of energy

Second Law:

- Gives condition of heat and work transfer
- Work is high grade energy and heat is low grade energy.
- All heat cannot be converted to work.
- Second law can be implemented by heat engine.

Third Law:

A system cannot be reduced to absolute zero (-273 ^{0}C by a finite number of operations)

Heat Engine Cycle

It is a thermodynamic cycle in which there is net heat transfer to the system and a net work transfer from the system.

Principle of Operation of Thermal Power Plants

- Thermal power plant operate on the principle of Rankine thermodynamic cycle.

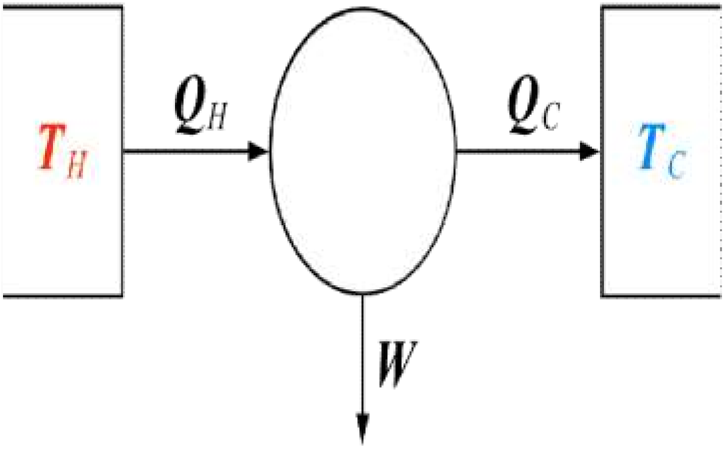


Figure 24: Carnot Heat Engine

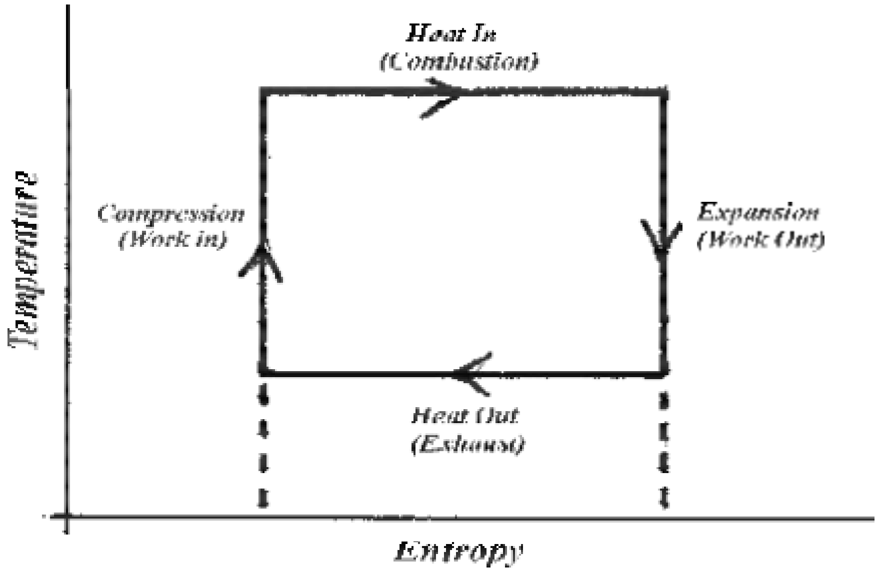


Figure 25: Carnot Cycle

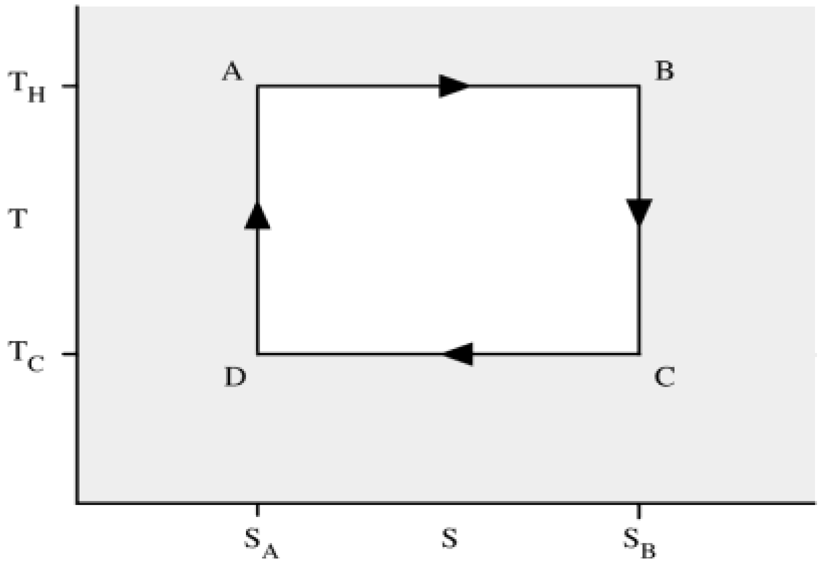


Figure 26: Carnot Cycle

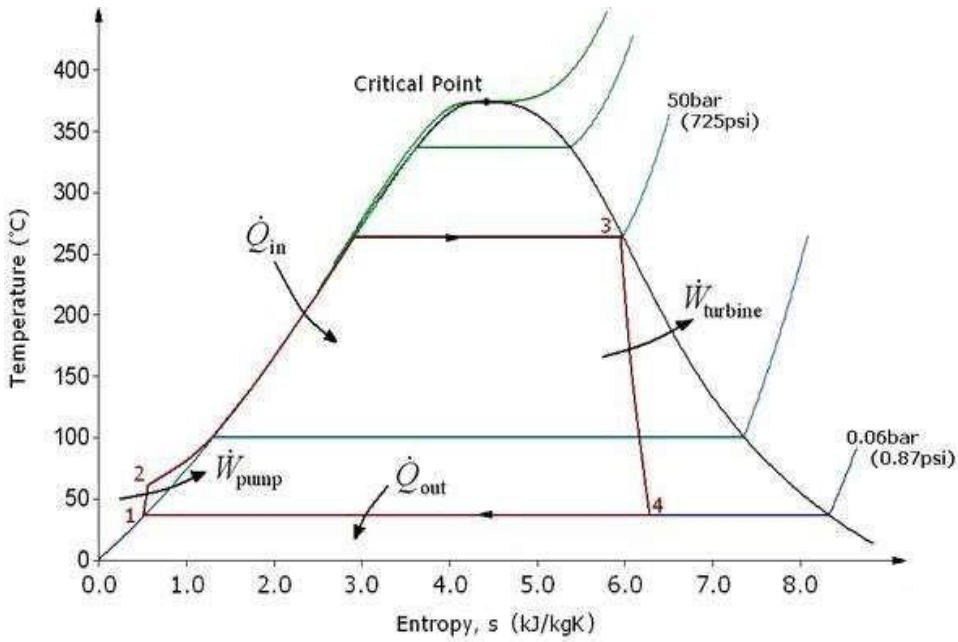


Figure 27: Rankine Cycle

Thermal Power Plant Resource

- India has large deposit of coal (about 170 billion tonnes), 5^{th} largest in world.
- Indian coals are classified as A-G grade coals.
- Power generation from coal can be estimated by means of its calorific value kCal/kg or kJ/kg.
- The calorific values of major types of coals are given below.

Table 4: Coal Classification

Coal Type	kJ/kg	kWh/kg	kCal/kg
Peat	8000	28800000	1912
Lignite	20000	72000000	4780
Bituminous	27000	97200000	6453
Anthracite	30000	108000000	7170

Selection of site for thermal power plant

Transportation network: Easy and enough access to transportation network is required in both power plant construction and operation periods.

Gas pipe network: Vicinity to the gas pipes reduces the required expenses.

Power transmission network: To transfer the generated electricity to the consumers, the plant should be connected to electrical transmission system. Therefore the nearness to the electric network can play a roll.

Geology and soil type: The power plant should be built in an area with soil and rock layers that could stand the weight and vibrations of the power plant.

Earthquake and geological faults: Even weak and small earthquakes can damage many parts of a power plant intensively. Therefore the site should be away enough from the faultsand previous earthquake areas.

Topography: It is proved that high elevation has a negative effect on production efficiency of gas turbines. In addition, changing of a sloping area into a flat site for the construction of the power plant needs extra budget. Therefore, the parameters of elevation and slope should be considered.

Rivers and floodways: obviously, the power plant should have a reasonable distance from permanent and seasonal rivers and floodways.

Water resources: For the construction and operating of power plant different volumes of water are required. This could be supplied from either rivers or underground water resources. Therefore having enough water supplies in defined vicinity can be a factor in the selection of the site.

Environmental resources: Operation of a power plant has important impacts on environment. Therefore, priority will be given to the locations that are far enough fromnational parks, wildlife, protected areas, etc.

Population centers: For the same reasons as above, the site should have an enough distance from population centers.

Need for power: In general, the site should be near the areas that there is more need for generation capacity, to decrease the amount of power loss and transmission expenses.

Climate: Parameters such as temperature, humidity, wind direction and speed affect theproductivity of a power plant and always should be taken into account.

Land cover: Some land cover types such as forests, orchard, agricultural land, pasture are sensitive to the pollutions caused by a power plant. The effect of the power plant on such land cover types surrounding it should be counted for.

Area size: Before any other consideration, the minimum area size required for theconstruction of power plant should be defined.

Distance from airports: Usually, a power plant has high towers and chimneys and large volumes of gas. Consequently for security reasons, they should be away from airports.

Archeological and historical sites: Usually historical building …are fragile and at same time very valuable. Therefore the vibration caused by power plant can damage them, and a defined distance should be considered.

Schematic of a Thermal Power Plant

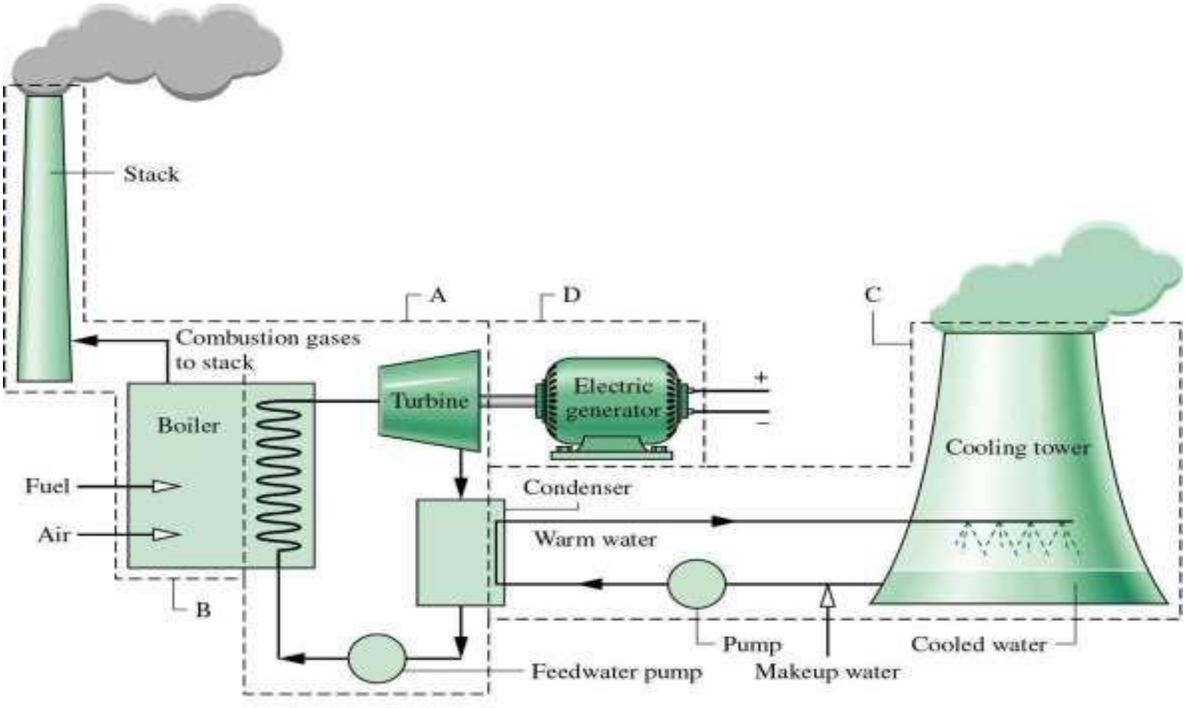


Figure 28: Rankine Cycle and Thermal Power Plants

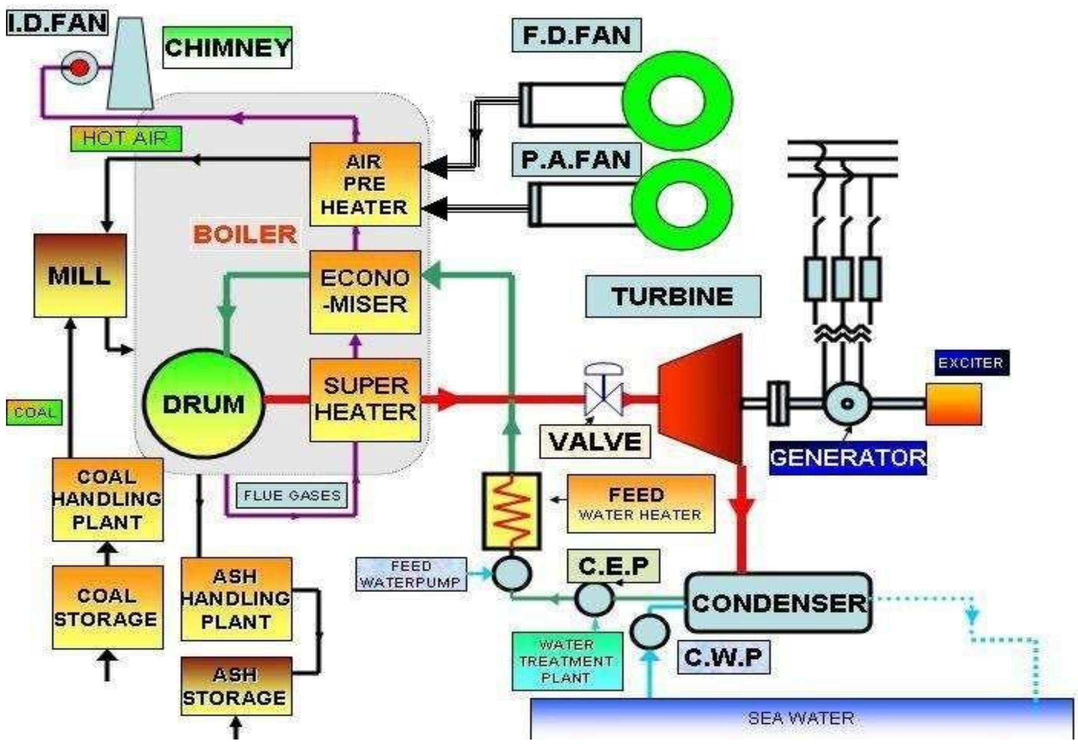


Figure 29: Schematic of a Thermal Power Plant-2

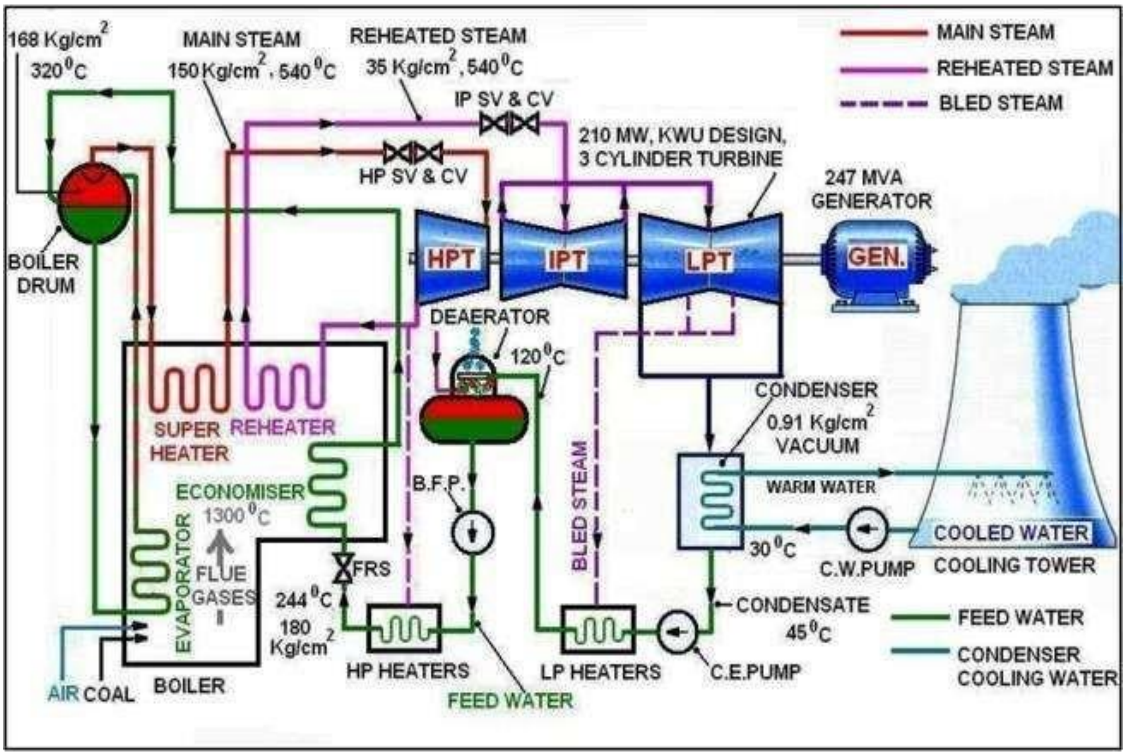


Figure 30: Schematic of a Thermal Power Plant-3

Major Components of a Thermal Power Plant

Coal Handling Plant

Pulverizing Plant

Draft or Draught fan

Boiler

Ash Handling Plant

Turbine and Generator

Condenser

Cooling Tower And Ponds

Feed Water Heater

Economiser

Super heater and Reheater

Air pre heater

Alternator with Exciter

Protection and control equipment

Instrumentation

Coal Handling Plant

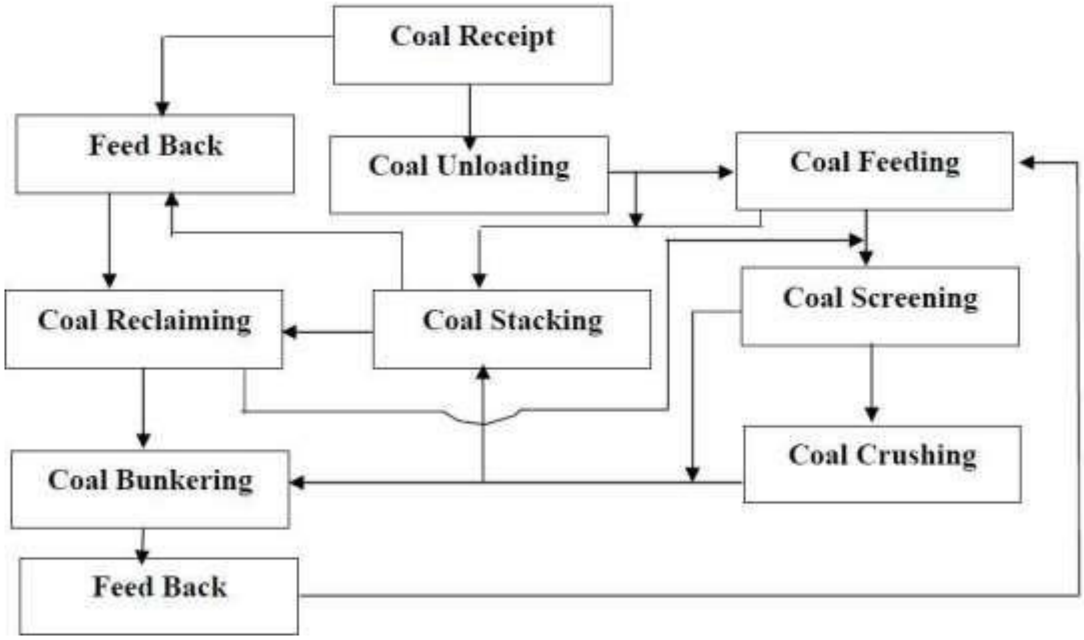


Figure 31: Block diagram of coal handling plant

Figure 32: Coal Storage

Figure 33: Crushing Plant

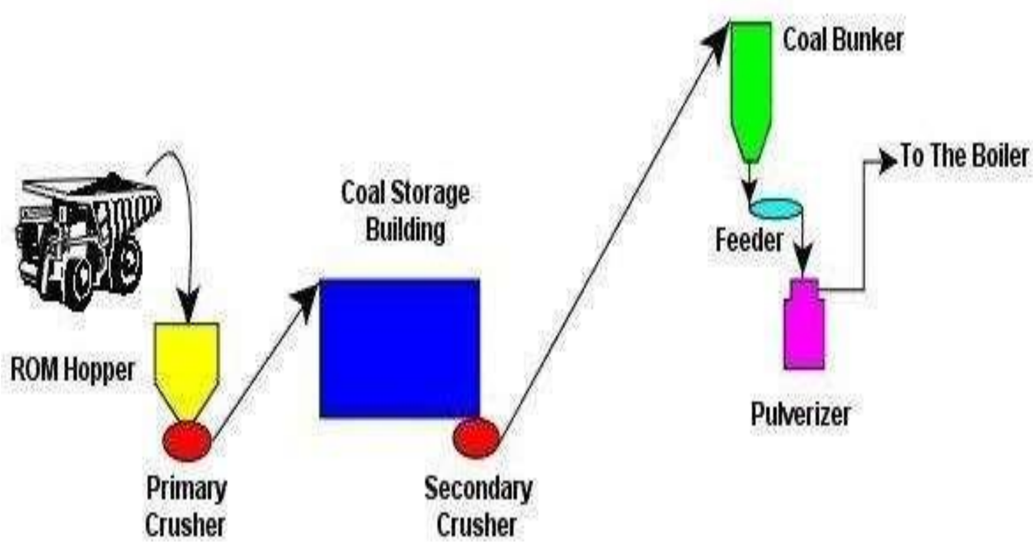


Figure 34: Processes in Coal Handling Plant

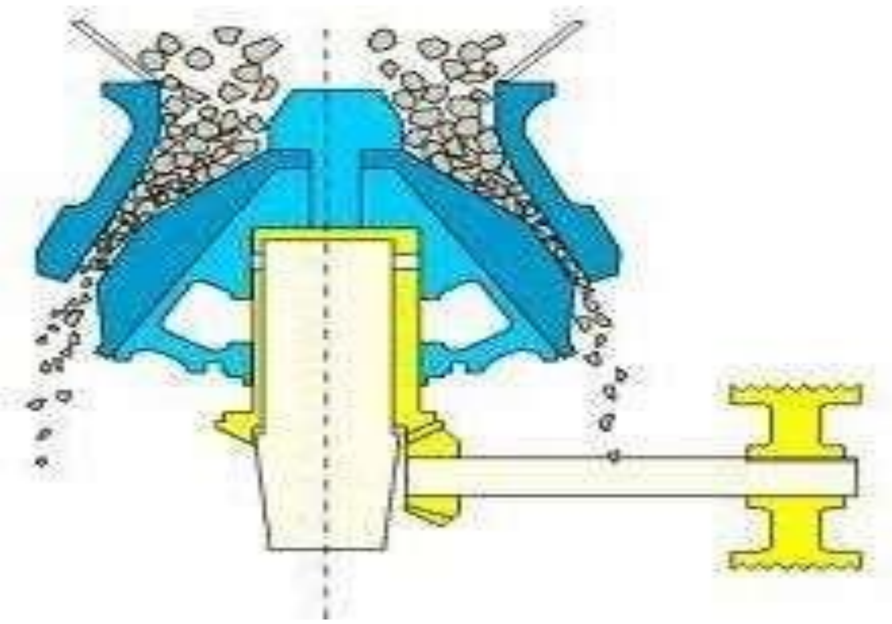


Figure 35: Impact Crushers

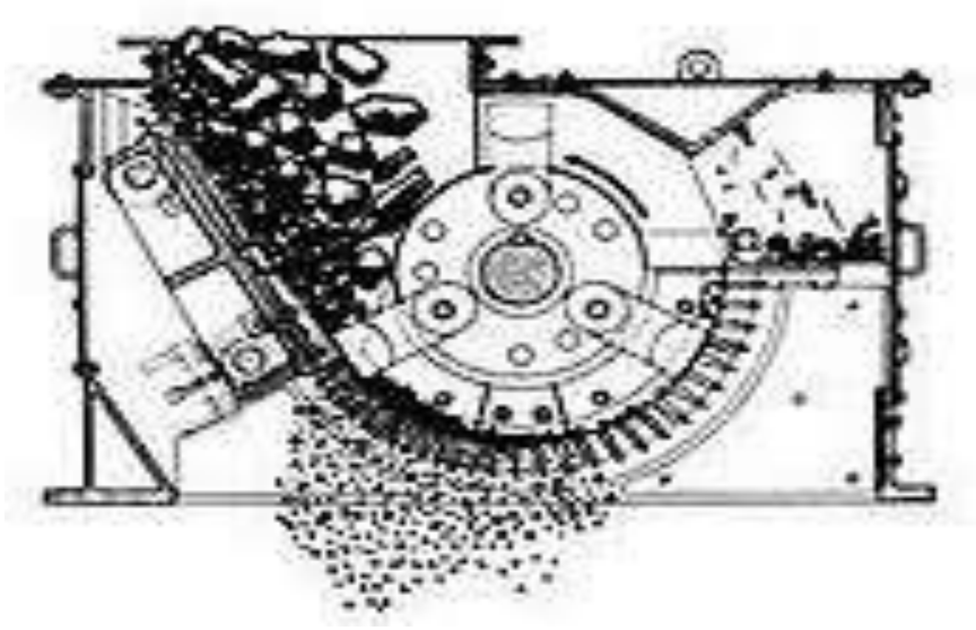


Figure 36: Attrition Crusher

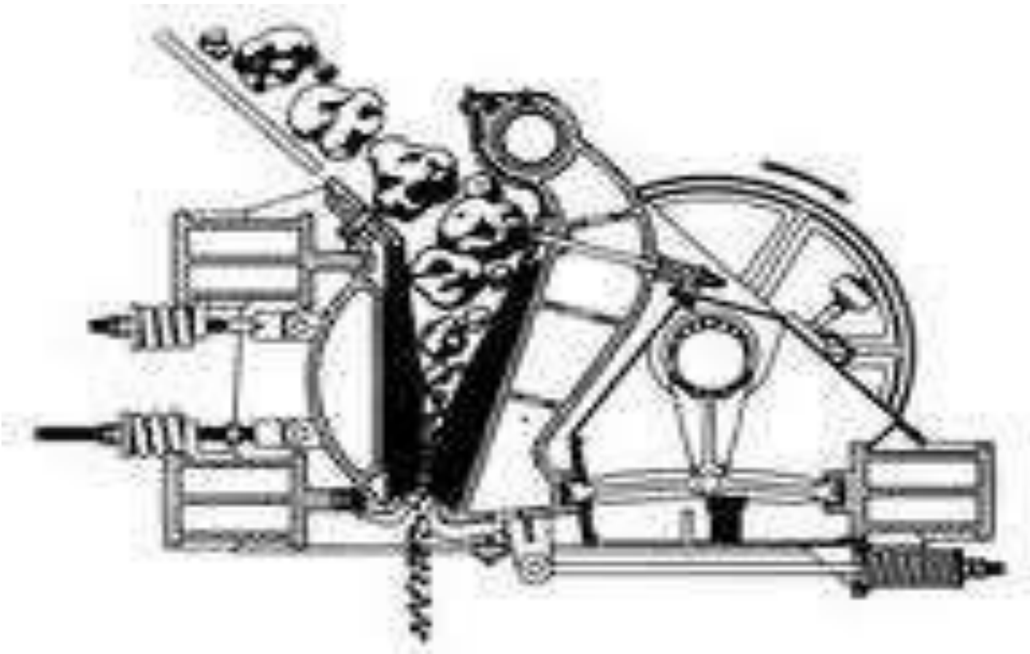


Figure 37: Compressor Crusher

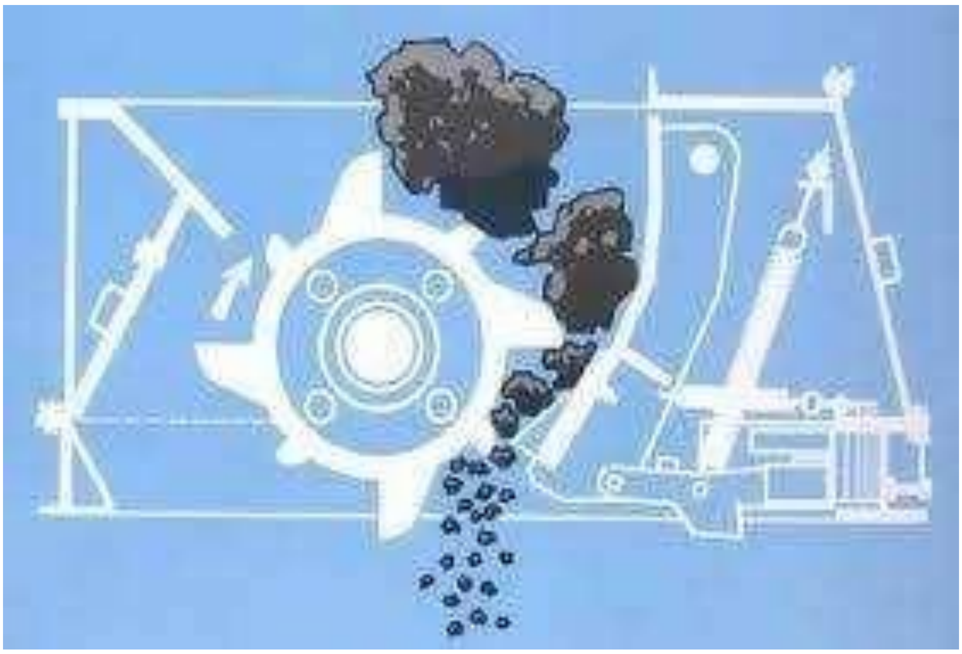


Figure 38: Shear Crusher

Screening Process: There are three basic type of screening process

- Scalping
- Fine removals
- Grading

Crushing Process: There are four basic process to reduce the size

- Impact
- attrition
- Shear
- compression

Stacking Process:

This process involves in dead storage in the form of piles laid directly in the ground. In caseof road transport and aerial transport coal are unloaded in stack yard and the coal is stacked properly using dozers.

When coal supply by railway is excess it would be stacked through a separate conveyor. For these purpose stacker or telescopic chutes are used.

Reclaiming Process:

The stored coal is required to bunkered in case of emergency or improper coal supply. The reclaiming process involves the lifting of coal from stack yard by means of dozer or reclaimer like bucket wheel.

The dozer feed this coal in hopper. This process is simple process. This process is simple. The main object of this process to bunker crush coal or non-crush coal as per requirement of bunker to support the other process feeding.

Bunkering Process:

This process involves feeding of bins and maintaining the level of these bins. From theconveyor belt the coal is discharged into bunker or bins with the help of trippers.

Draught System

The combustion in the boiler requires supply of sufficient quality of air and removal ofexhaust gases

The Circulation of air is caused by difference of pressure is known as draught. Thus draughtis the differential in pressure between the two points.

A draught tube may be

1. Natural Draught
2. Mechanical Draught

Natural Draught

A natural Draught is provided by the chimney or stack.

Natural draught has its limitation . Modern plants has high rate of heat transfer and Draught losses are very high. in view of this Natural draught is used only for small boilers.

Mechanical Draught

Modern large size plants use very large size of boilers of capacity above 1000,000 kg perhour. such boiler needs tremendous volume of air (around 200000 m3) Per minute. A chimney providethis.Therefore mechanical draught is used.

In a mechanical draught the system the movement air is due to the action of fan. A mechanical Draught consist of forced Draught or induced draught or both.

In forced draught system the fan is installed near the boiler .the fan force the air through the furnace , economizer, air preheater and chimney. The pressure of air, throughout the system, is above atmospheric and air is forced to flow through the system

In an induced draught system the , the fan is installed near the base of the chimney .The burnt gases are sucked out from the boiler , thus reducing the pressure inside the boiler. to less than atmosphere. this induces fresh air to enter the furnace.

A mechanical Draught need additional capital investment and maintenance .But it required for proper operation of modern power plant. In super thermal power plant , each boiler may used two forced fans and two induced fan.

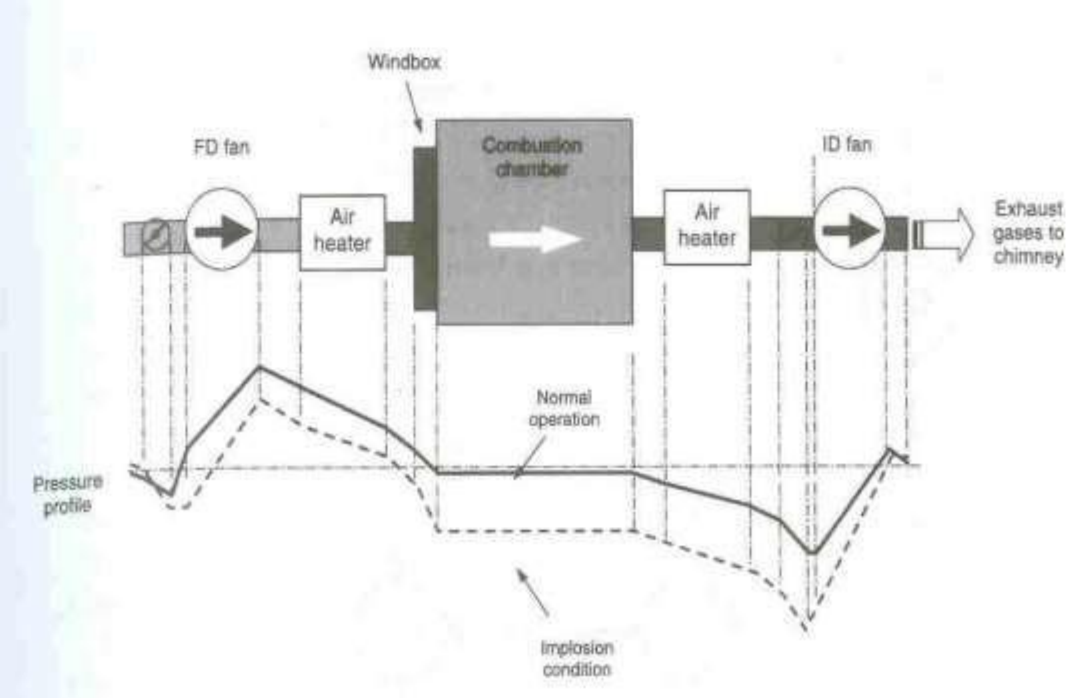


Figure 39: Draught System

Boiler

A boiler (or steam generator) is a closed vessel in which water, under pressure , is converted into steam. The heat is transferred to the boiler by all three modes of heat transfer i.e. conduction ,convection and radiation.

Major types of boilers are: (i) fire tube boiler and (ii) water tube boiler

Fire Tube Boiler

The boiler is named so because the production of combustion pass through the tubes whichare surrounded by water.

Depending on whether the tube is vertical or horizontal the fire tube boiler is divided intotwo types

Vertical tube boiler

Horizontal tube boiler

A fire tube boiler is simple ,compact and rugged in construction. Its initial cost is low.

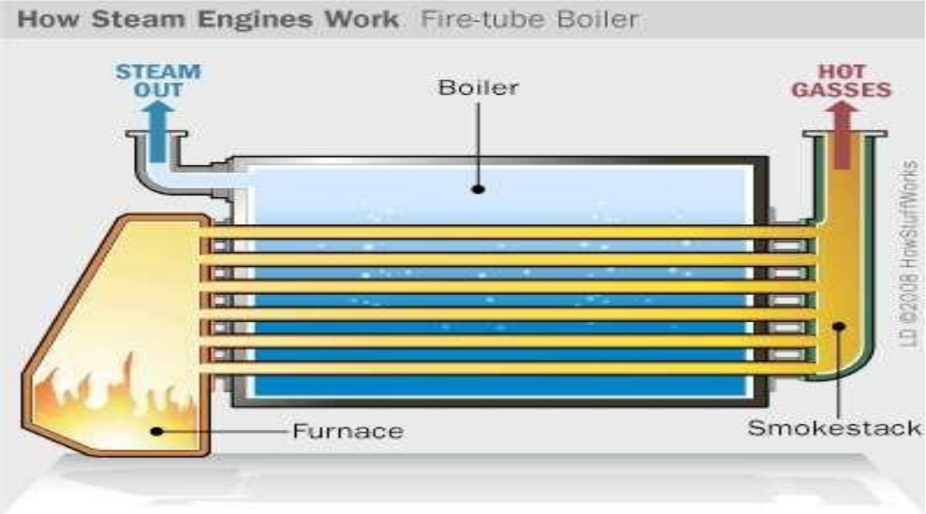


Figure 40: Fire Tube Boiler

Water Tube boilers

In this boiler, the water flows inside the tubes and hot gases flow outside the tube .

Water tube boiler are classified as

- Vertical tube boiler
- Horizontal tube boiler
- Inclined tube boiler

The circulation of water in the boiler is may be natural or forced.

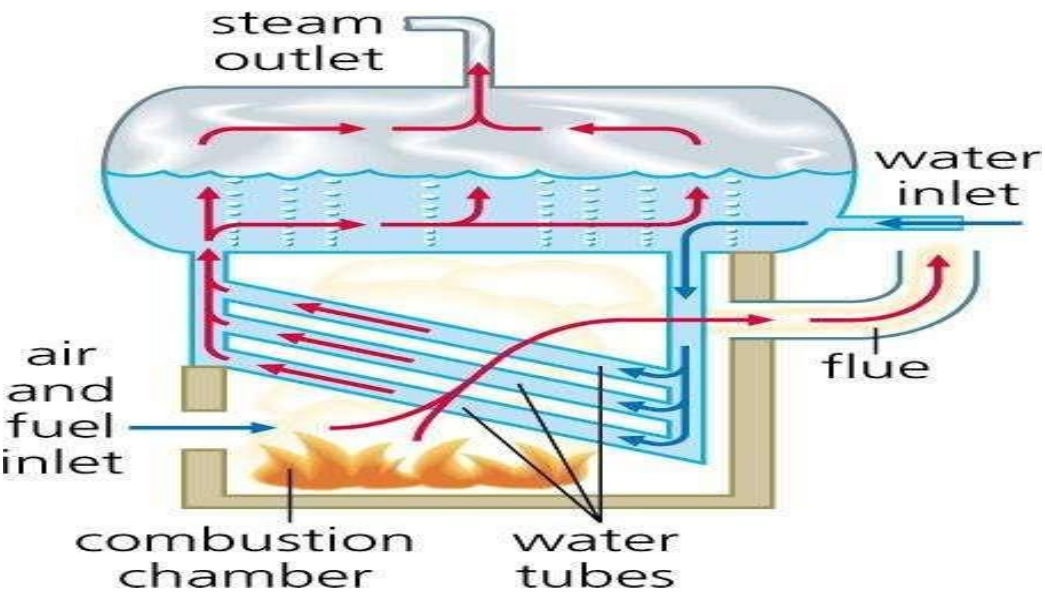


Figure 41: Water tube boiler

Superheater and Reheaters

Super heated steam is that steam which contains more heat than the saturated steam at the same pressure. The additional heat provide more energy to the turbine hence power out put is more.

Superheated steam causes lesser erosion of the turbine blades and can be transmitted for longer distance with little heat loss

The function of the super heater is to remove the last trash of moisture from the saturated steam.

A superheater may be convention type, radiant type or combination

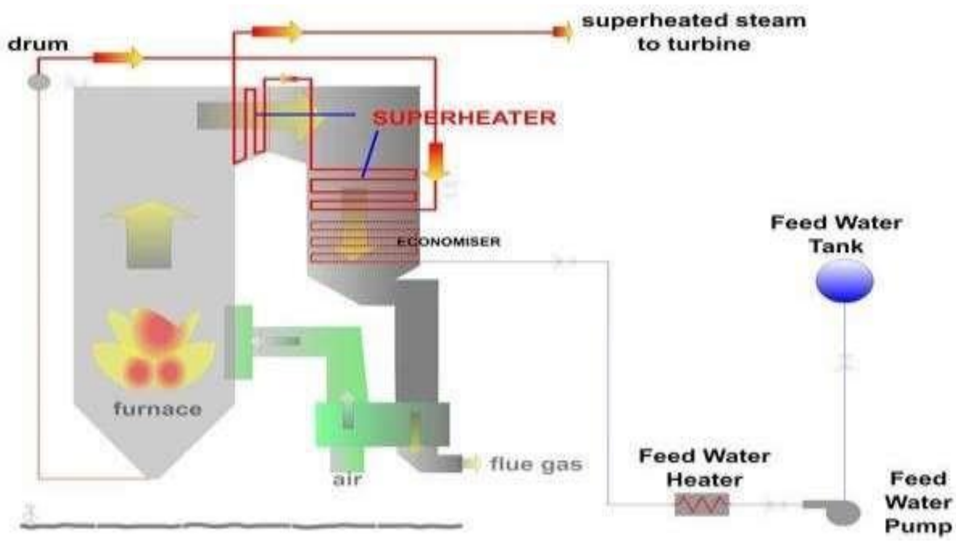


Figure 42: Functions of superheater

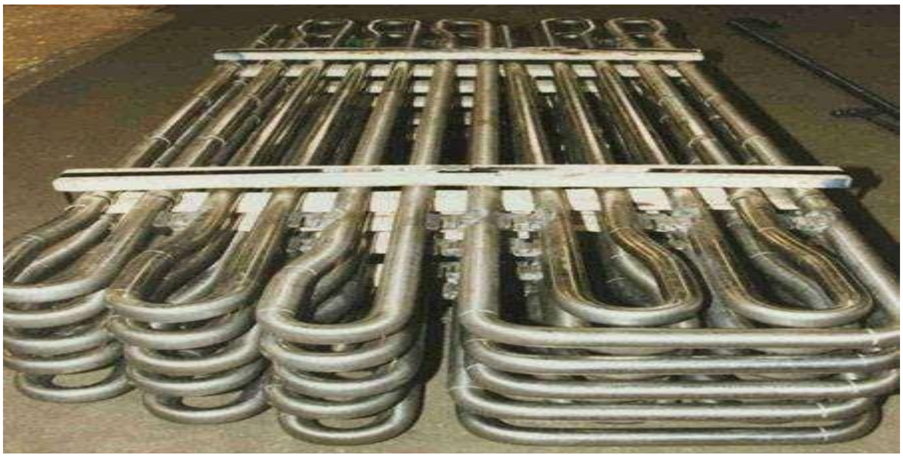


Figure 43: Superheaters

Reheater

In addition to super heater modern boiler has reheater also. The function of the reaheater is to superheat the partly expanded steam from the turbine, this ensure that The steam remain dry through the last stage of the turbine.

A reheater may be convention type, radiant type or combination.

Feed Water Heaters

Feed Water heating improve overall efficiency.

The dissolved oxygen which would otherwise cause boiler corrosion are removed in the feed water heater.

Thermal stresses due to cold water entering the boiler drum are avoided.

Quantity of steam produced by the boiler is increased.

Some other impurities carried by steam and condensate, due to corrosion in boiler andcondenser, are precipitated outside the boiler.

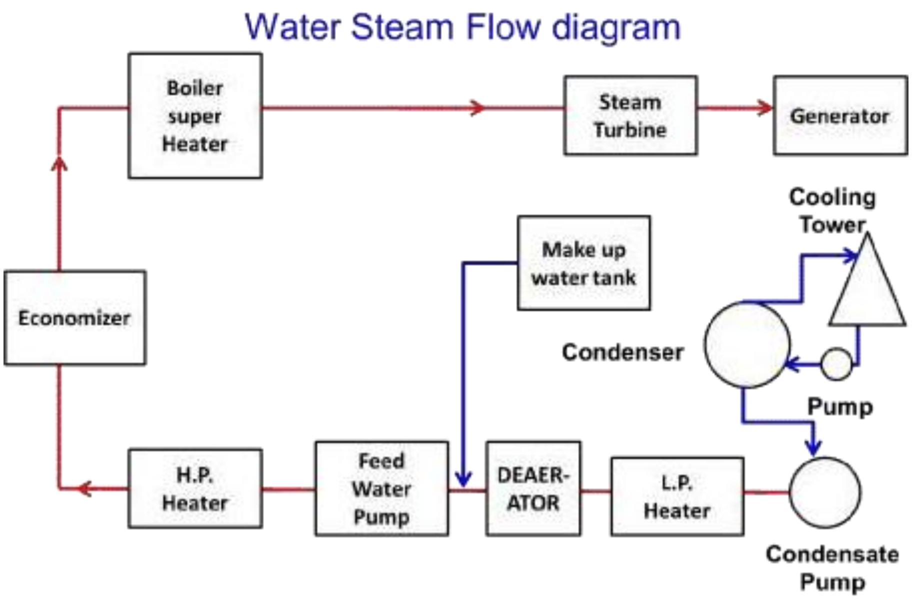


Figure 44: Water steam flow diagram

Economizer

Boilers are provided with economizer and air pre-heaters to recover heat from the flue gases. An increase of about 20% in boiler efficiency is achieved by providing both economizer and air pre-heaters.

Economizer alone gives only 8% efficiency increase. The feed water from the high pressure heaters enters the economizer and picks up heat from the flue gases after the low temperature superheater.

Economizer can be classified as an inline or staggered arrangement based on the type of tube arrangement.

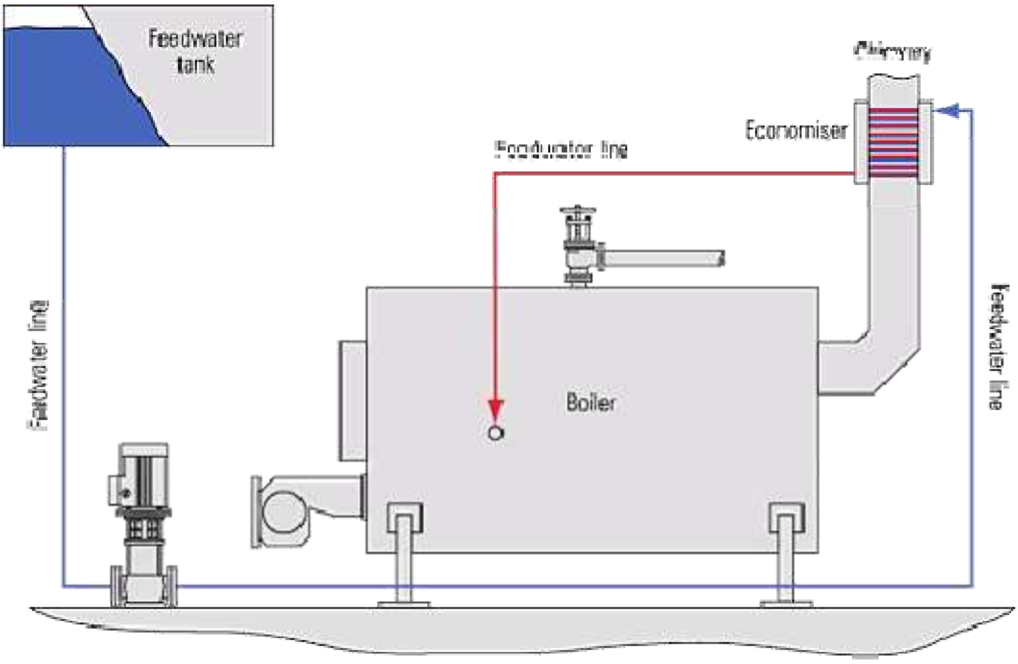


Figure 45: Economizer

Air Preheaters

After the flue gases leave economizer, some further heat can be extracted from them and isused to heat the incoming air for combustion.

Air preheaters may be of following types:

- Plate type
- Tubular type
- Regenerative type

Cooling of flue gases by 20^0increase the efficiency of the plant by 1%.

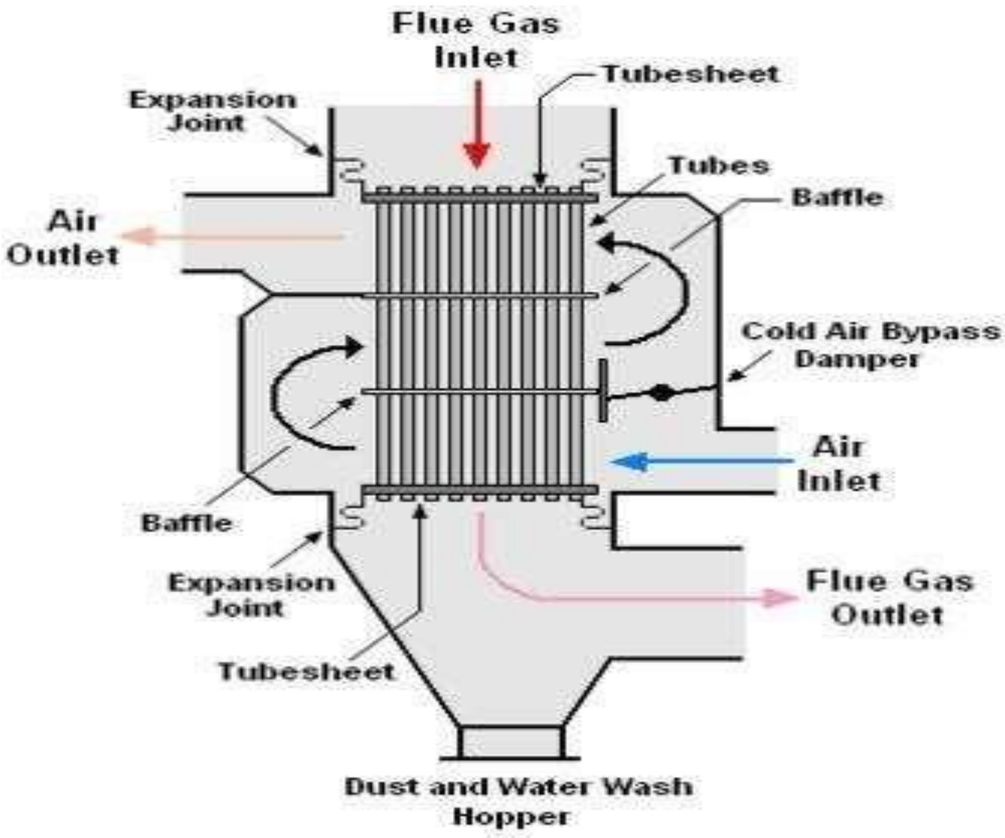


Figure 46: Air Preheater

Steam Turbines

- Steam entering from a small opening attains a very high velocity. The velocity attained during expansion depends on the initial and final content of the steam.
- The difference in initial and final heat content represent the heat energy to be converted to kinetic energy.
- There are two types of steam turbines:

Impulse	**Reaction**
Expansion happens in a nozzle	Expansion happens in turbine blades
High speed	Low speed
Sufficient number of impulse stages are provided.	

Compounding of steam turbines:

- Single stage turbines are of low efficiency.
- In compounding, a number of rotors are connected or keyed to the same shaft
- Two types of compounding are used: velocity compounding and pressure compounding

Governing of steam turbines:

Governing signifies the process of controlling the volume of steam to meet the load fluctuation.

Figure 47: Steam Turbines

Figure 48: Steam Turbines

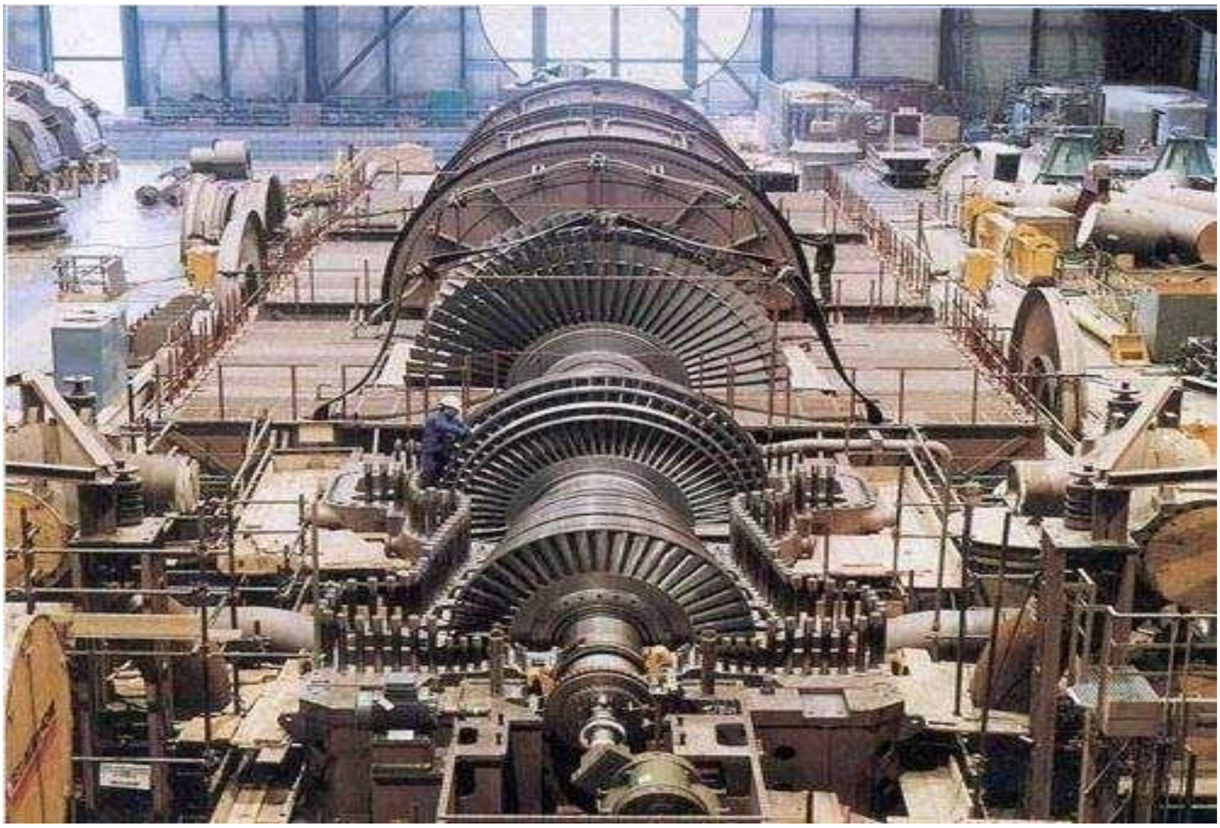


Figure 49: Steam Turbines

Condensers

- The function of the condenser is to condense the steam exiting the turbine.
- The condenser helps maintain low pressure at the exhaust.
- Two types of condensers are used.

Table 5: Jet and Surface Condensers

Jet condenser (contact type)	Surface condenser (non-contact type)
Exhaust steam mixes with cooling water.	Steam and water do not mix.
Temperature of the condensate and cooling water is same while leaving the condenser.	Condensate temperature higher than the cooling water temperature at outlet.
Condensate cannot be recovered.	Condensate recovered is fed back to the boiler.
Heat exchanged by direct conduction	Heat transfer through convection.
Low initial cost	High initial cost.
High power required for pumping water.	Condensate is not wasted so pumping power is less.

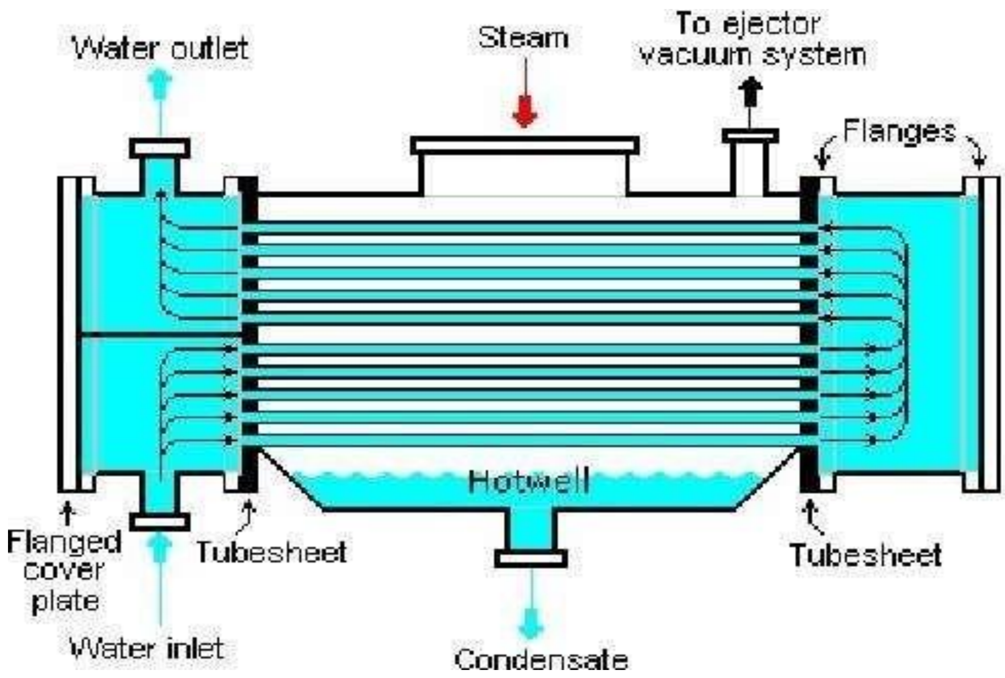


Figure 50: Surface Condenser

Figure 51: Surface Condenser

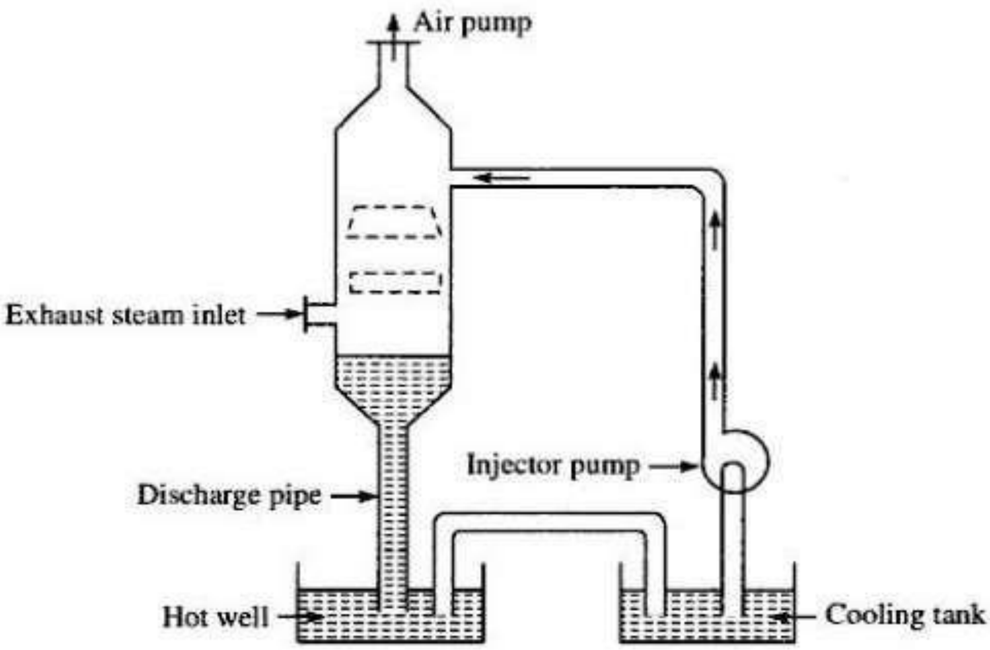


Figure 52: Jet Condenser

Figure 53: Jet condenser

Deaerators

A deaerator is a device that is widely used for the removal of oxygen and other dissolvedgases from the feedwater to steam-generating boilers.

In particular, dissolved oxygen in boiler feedwaters will cause serious corrosion damage in steam systems by attaching to the walls of metal piping and other metallic equipment and forming oxides (rust).

There are two basic types of deaerators,

1. the tray-type an
2. the spray-type

The tray-type (also called the cascade-type) includes a vertical domed deaeration section mounted on top of a horizontal cylindrical vessel which serves as the deaerated boiler feedwater storage tank.

The spray-type consists only of a horizontal (or vertical) cylindrical vessel which serves asboth the deaeration section and the boiler feedwater storage tank.

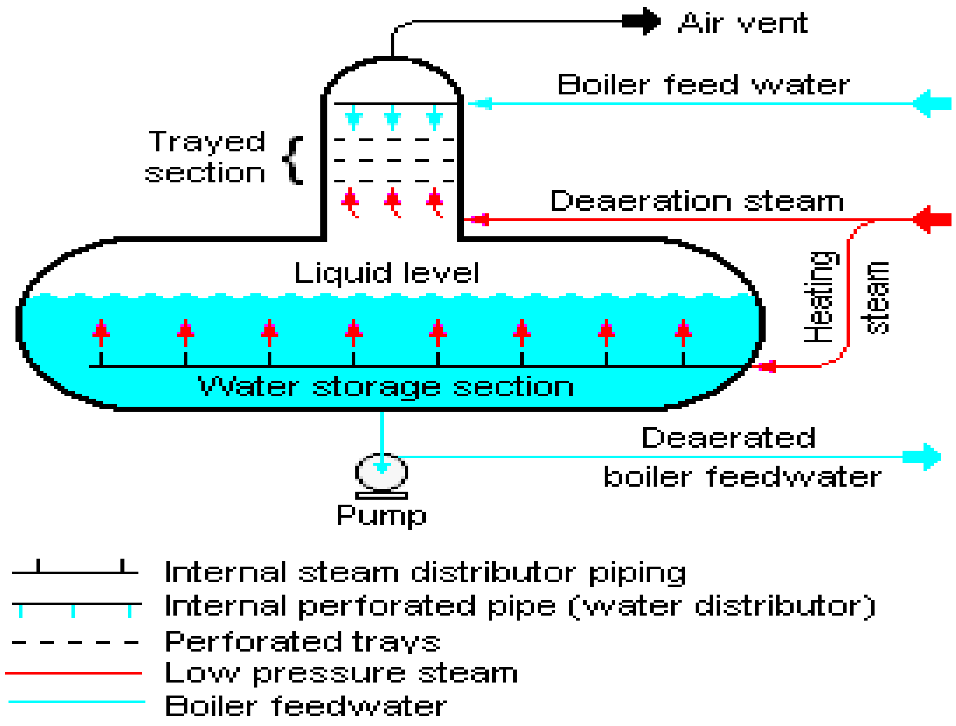


Figure 54: Deaerator

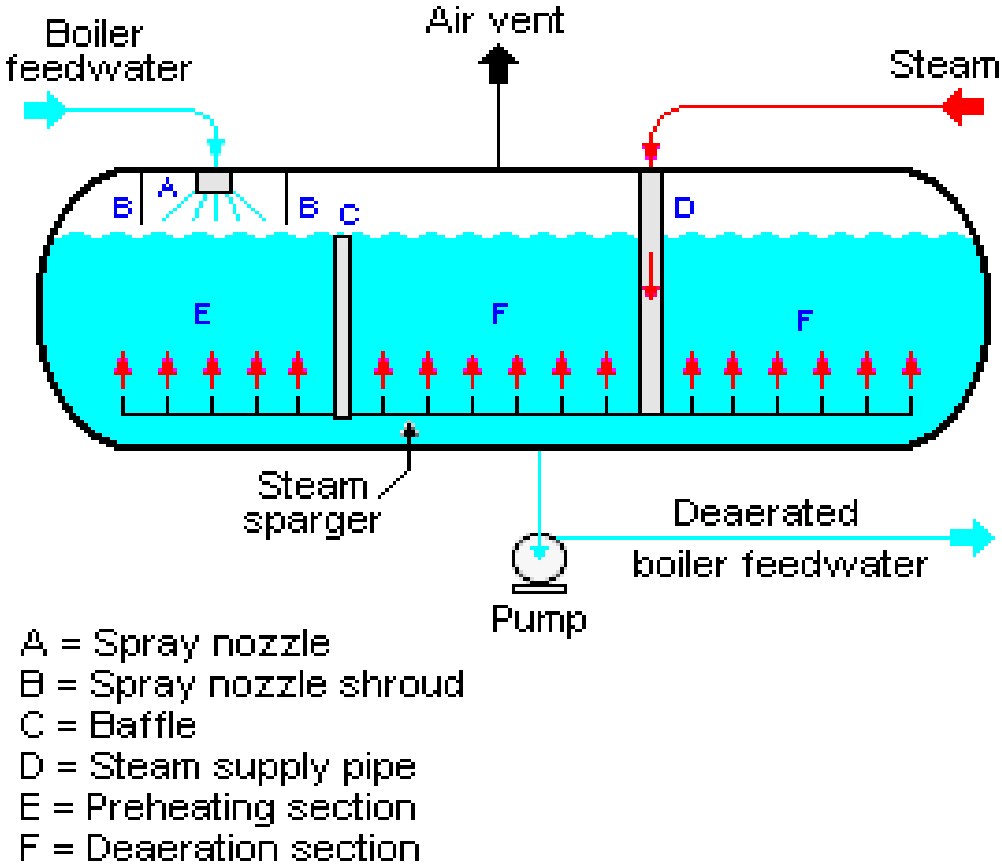


Figure 55: Deareators

Cooling Towers and Spray Ponds

- Condensers need huge quantity of water to condense the steam.
- Water is led into the plants by means of circulating water pumps and after passing through the condenser is discharged back into the river.
- If such a source is not available closed cooling water circuit is used where the warm water coming out of the condenser is cooled and reused.
- In such cases ponds and cooling towers are used where the water loses heat to the atmosphere.

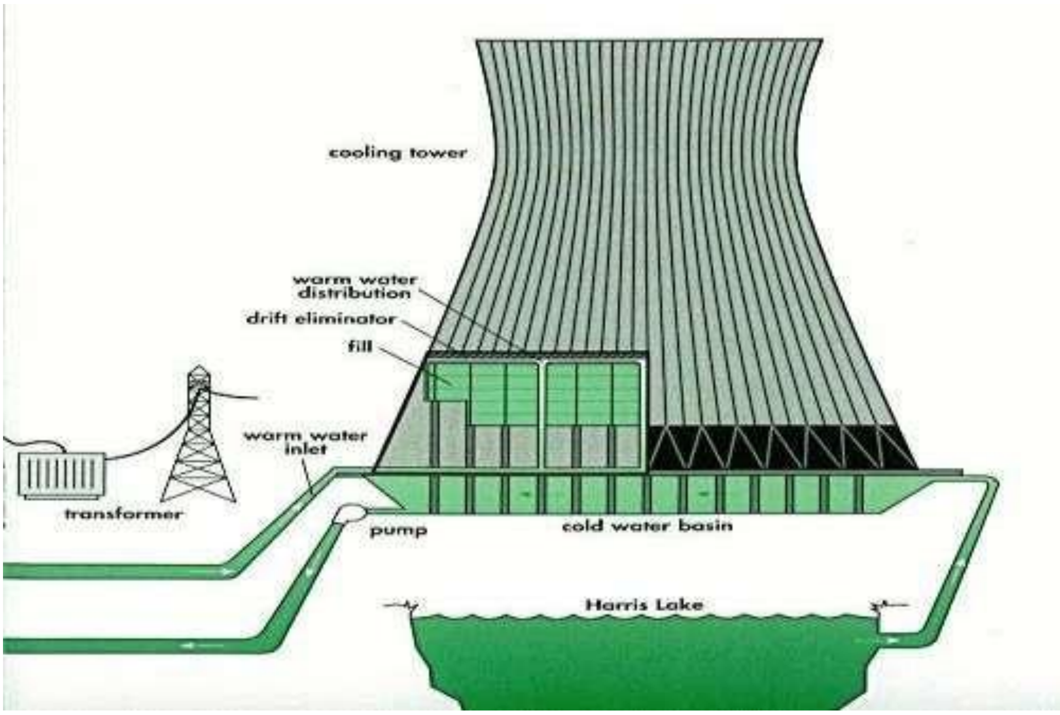


Figure 56: Cooling Tower

Figure 57: Cooling Tower

Figure 58: Cooling Towers

Ash Handling Plant

In Thermal Power Plant’s coal is generally used as fuel and hence the ash is produced as the byproduct of Combustion. Ash generated in power plant is about 30-40% of total coal consumption and hence the system is required to handle Ash for its proper utilization or disposal.

The steam power plant produces 5000 of tons ash daily (2000MW)

The ash may be-----

Fly Ash (Around 80% is the value of fly ash generated)

Bottom ash (Bottom ash is 20% of the ash generated in coal based powerstations.

Fly Ash

Ash generated in the ESP which got carried out with the flue gas isgenerally called Fly ash. It also consists of Air pre heater ash & Economizer ash (it is about 2 % of the total ash content).

Bottom ash

Ash generated below furnace of the steam generator is called the bottomash.

The operation of ash handling plants is…….

Removal of ash from the furnace ash hoppers

Transfer of the ash to a fill or storage

and disposal of stored ash

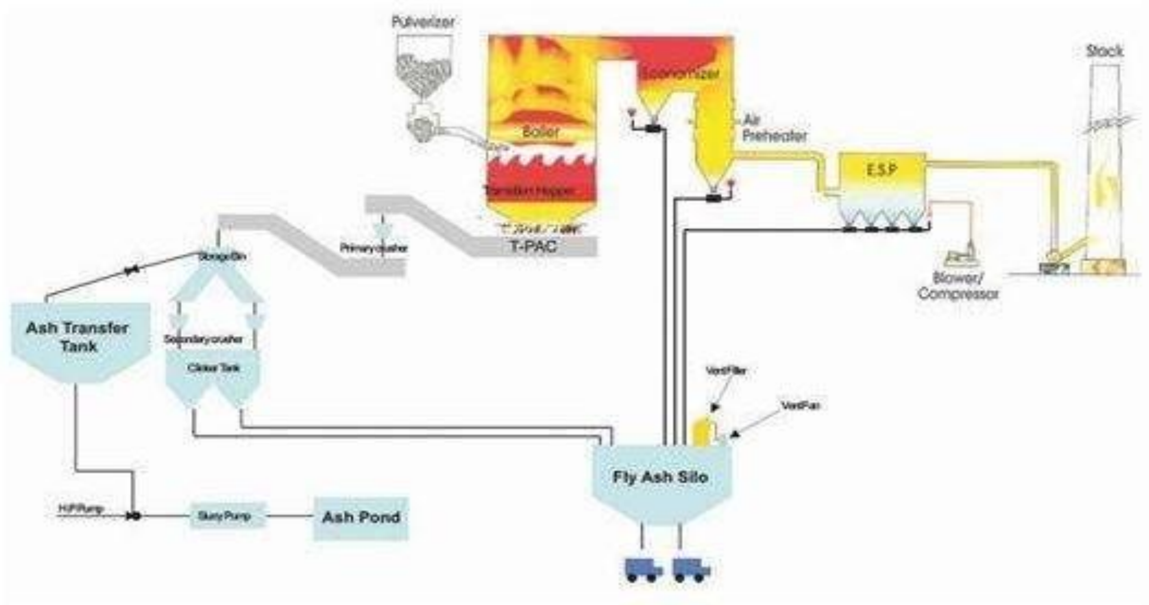
The ash may be disposed in the following way…….

Waste land site may be reserved for the disposal of ash.

Building contractor may utilize it to fill the low lying area.

Deep ponds may be made and ash can be dumped into these ponds to fillthem completely

When sea born coal is used, barrage may take the ash to sea for disposalinto water grave.



Ash Handling System Flow Diagram

Figure 59: Ash handling Plant flow diagram

The modern ash handling system usually used in large steam power plants are …….

Belt conveyor system

Pneumatic system

Hydraulic system

Steam jet system

Belt conveyor system

In this system the ash is made to flow through a water seal over the belt conveyor in order to cool it down and then carried out to a dumping site over the belt.

It can deliver 3 tonnes of ash per hour with a speed of 0.3m/minute.

The life of belt is 5 years. it is used in small power plant

Pneumatic system

In this system air is employed as a medium to driving the ash through a pipe over alongdistance.

This system can handle 5-30 tonnes of ash per hour

This is used for disposal of fly ash

Hydraulic system

In this system a stream of water carries ash along with it in a closed channel and disposed itoff to the proper site.

It is of two types high pressure system and low pressure system.

Steam jet system

This system employs jets of high pressure blowing in the direction of ash travel through aconveying pipe in which ash from the boiler ash hopper is fed.

It is employed in small and medium size plant

Steam consumption is 110 kg per tonne of material conveyed.

Figure 60: Belt Conveyor System

Figure 61: Ash Storage

Figure 62: Ash Ponds

Figure 63: Ash Usage

Electrostatic Precipitators

An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge.

the basic idea of an ESP:

- *Charging*
- *collecting.*
- *removing*

Every particle either has or can be given a charge—positive or negative.

we impart a negative charge to all the particles in a gas stream in ESP.

Then a grounded plate having a positive charge is set up.

The negatively charged particle would migrate to the grounded collection plate and becaptured.

The particles would quickly collect on the plate, creating a dust layer. The dust layer would accumulate until we removed it.

The structural design and operation of the discharge electrodes (rigid-frame, wires or plate)and collection electrodes.

- tubular type ESP
- plate type ESP

The method of charging

- single-stage ESP
- two-stage ESP

The temperature of operation

- cold-side ESP
- hot-side ESP

The method of particle removal from collection surfaces

- wet ESP
- Dry ESP

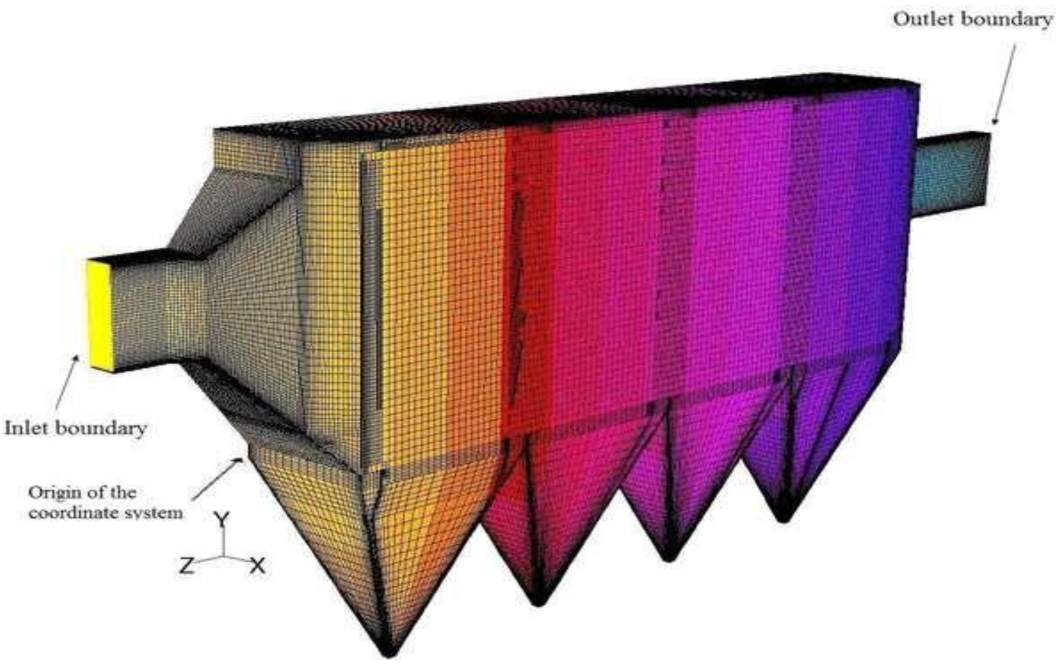


Figure 64: Electrostatic Precipitator

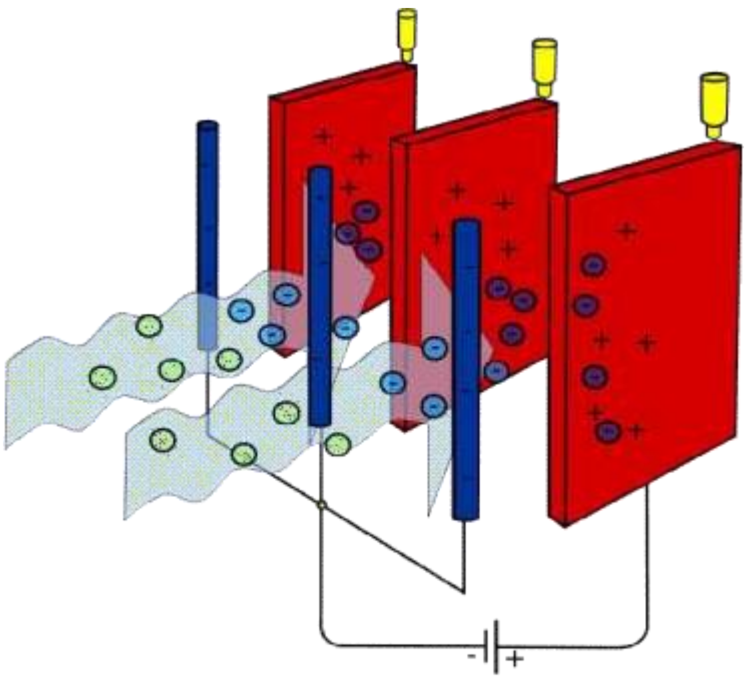


Figure 65: Electrostatic Precipitator

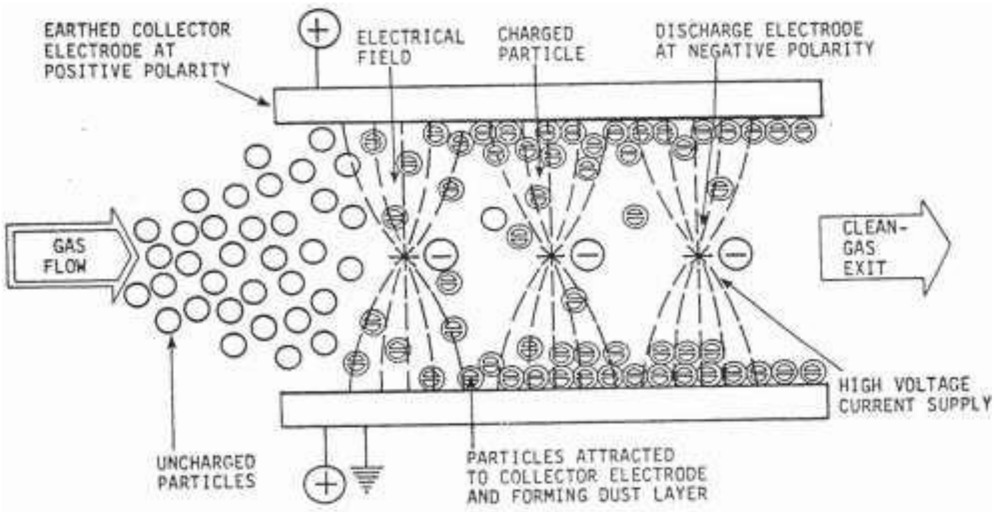


Figure 66: Electrostatic Precipitator

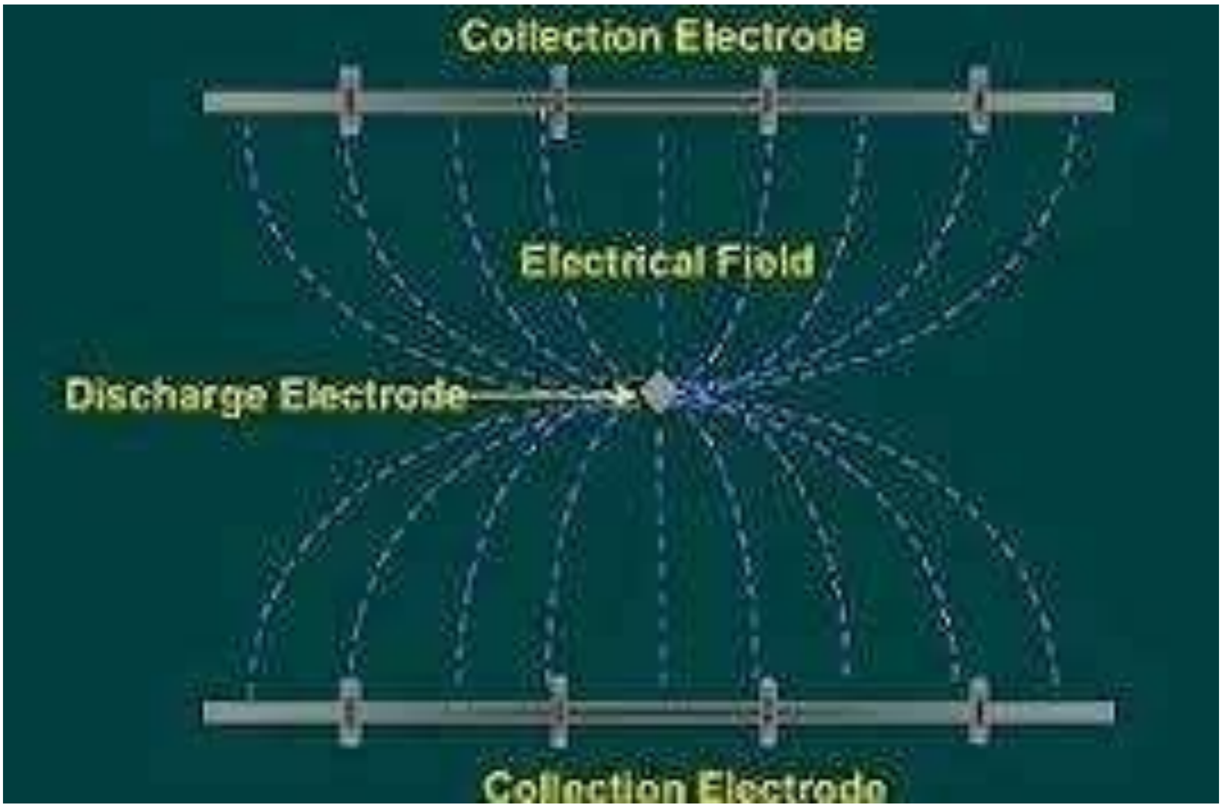


Figure 67: ESP Principle

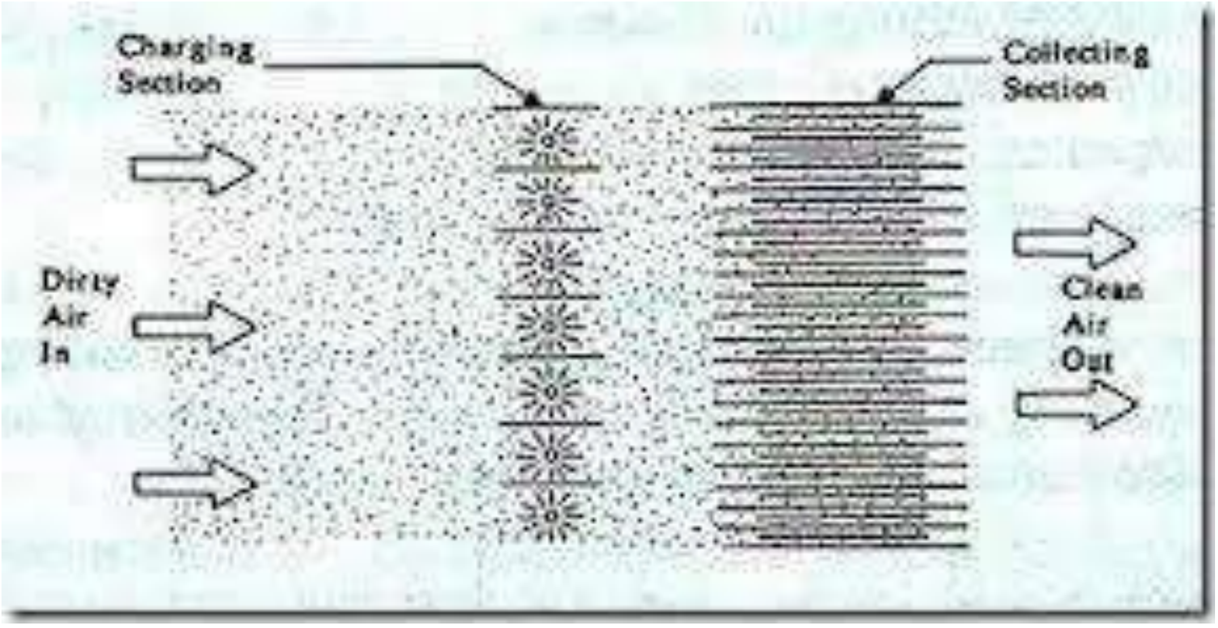


Figure 68: ESP Principle

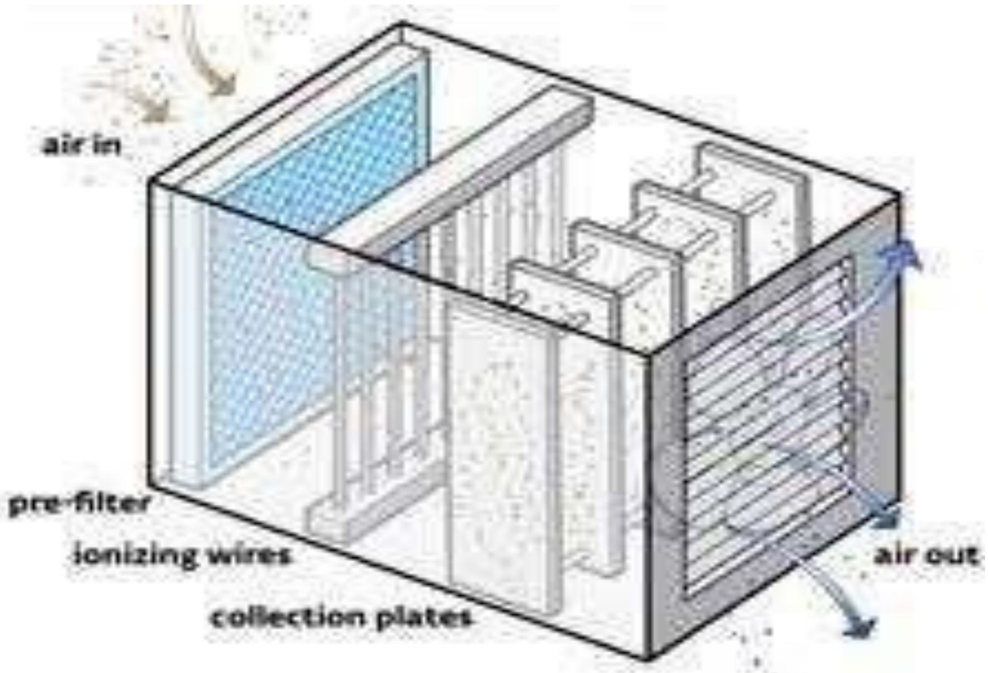


Figure 69: ESP Principle

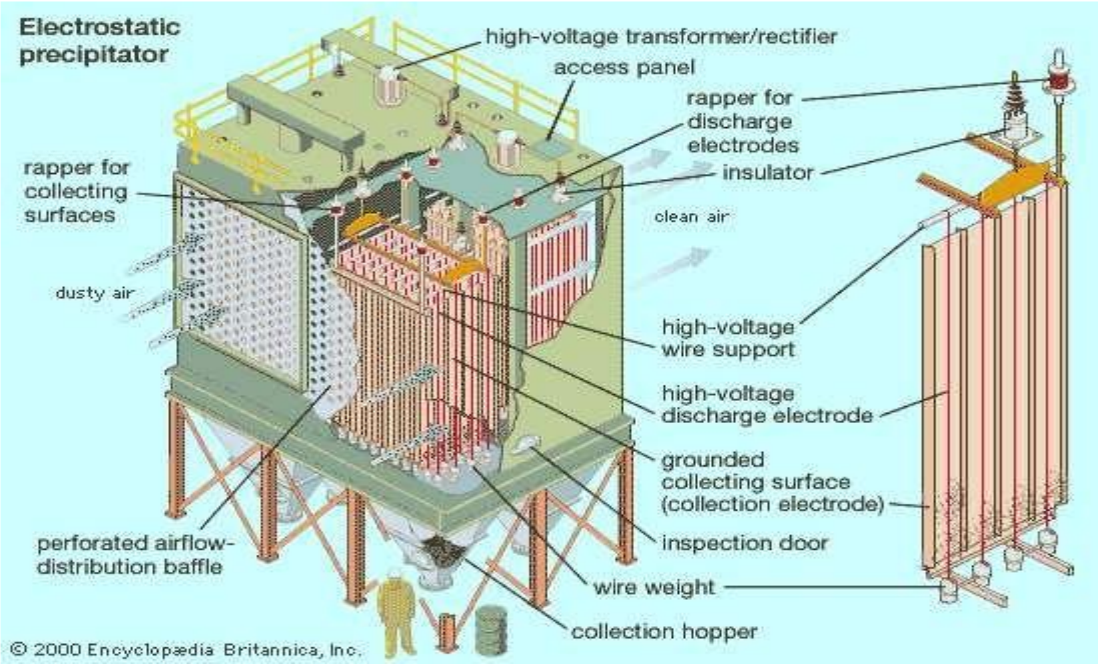


Figure 70: ESP Principle

Numerical Problems on Thermal Power Plant

1. A steam power station of 100 MW capacity uses coal of calorific value 6400 kCal/kg. The thermal efficiency of the station is 30% and electrical generation efficiency is 92%. Find the coal requirement per hour when the plant is working on full load.
2. Assuming efficiency of 33%, how much coal is needed to be burnt to supply energy for a average household in a year. Given connected load: 1 kW, load Factor: 60%.

Module-3

Nuclear Reactions

Basics

- Atoms consist of nucleus and electrons.
- The nucleus is composed of protons and neutrons.
- Protons are positively charged whereas neutrons are electrically neutral.
- Atoms with nuclei having same number of protons but difference in their masses are called isotopes. They are identical in terms of their chemical properties but differ with respect to nuclear properties.
- Natural Uranium consists of $_{92}U^{238}$ (99.282%), $_{92}U^{235}$ (0.712%) and $_{92}U^{234}$
- $_{92}U^{235}$ is used as fuel in nuclear power plants.

Energy from Nuclear Reactions

- The sum of masses of protons and neutrons exceeds the mass of the atomic nucleus and this difference is called mass defect Δm.
- In a nuclear reaction the mass defect is converted into energy known as binding energy according to Einstein's equation ($E=\Delta m\ c^2$).
- Fissioning one amu of mass results in release of 931 MeV of energy.
- It has been found that element having higher and lower mass numbers are unstable. Thus the lower mass numbers can be fused or the higher mass numbers can be fissioned to produce more stable elements.
- This results in two types of nuclear reactions known as fusion and fission.
- The total energy per fission reaction of U^{235} is about 200 MeV.
- Fuel burn-up rate is the amount of energy in MW/days produced by each metric ton of fuel.

Nuclear Fission

Nuclear fission is the reaction by which a heavy nucleus (that is one with a high value of Z) is hit with a small particle, as a result of which it splits into two (occasionally more) smaller nuclei.

Before the reaction		After the reaction	
$^{1}_{0}n$	1.008665	$^{140}_{54}Xe$	139.9216
$^{235}_{92}U$	235.0439	$^{94}_{38}Sr$	93.9154
		$2\ ^{1}_{0}n$	2.0173
Total mass	236.0526	Total mass	235.8543

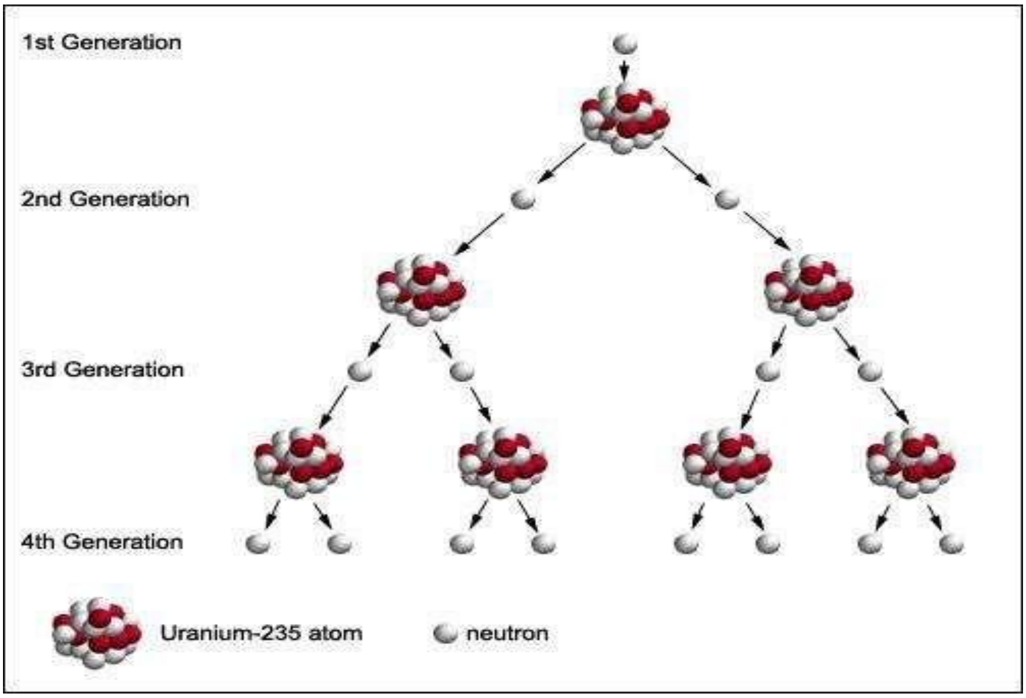


Figure 71: Nuclear Fission

Nuclear Fusion

Fusion is the opposite of fission, it is the joining together of two light nuclei to form a heavier one (plus a small fragment). For example if two 2H nuclei (two deuterons) can be made to come together they can form He and a neutron.

$$^{2}H + {}^{2}H \rightarrow {}^{3}He + n$$

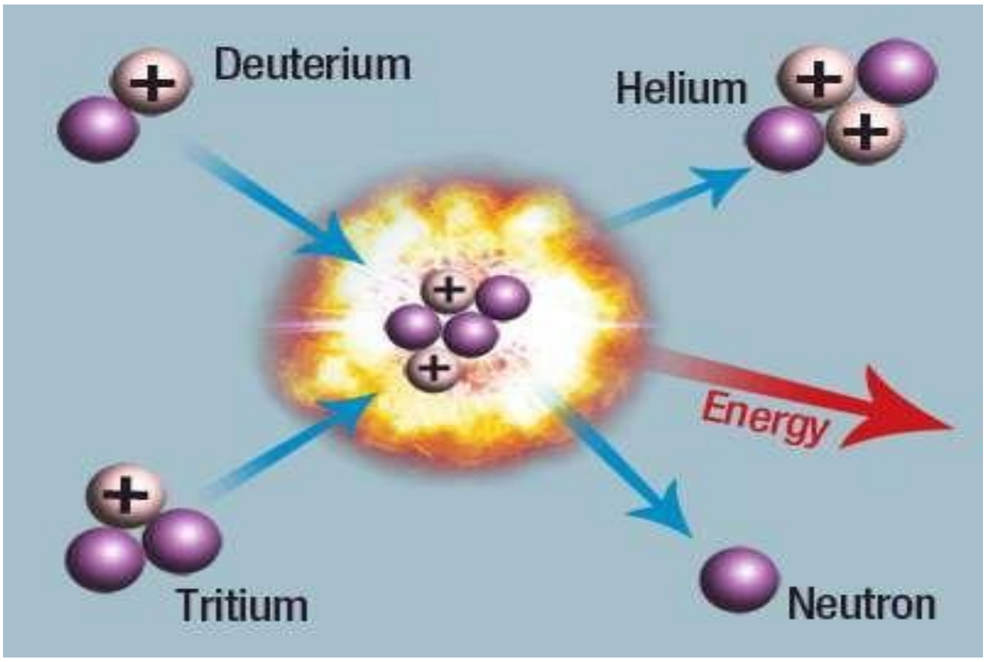


Figure 72: Nuclear Fusion

Nuclear Power Plant

A nuclear power plant is a thermal power station in which the heat source is one or more nuclear reactors. As in a conventional thermal power station the heat is used to generate steam which drives a steam turbine connected to a generator which produces electricity.

Nuclear power plants are usually considered to be base load stations, which are best suited to constant power output.

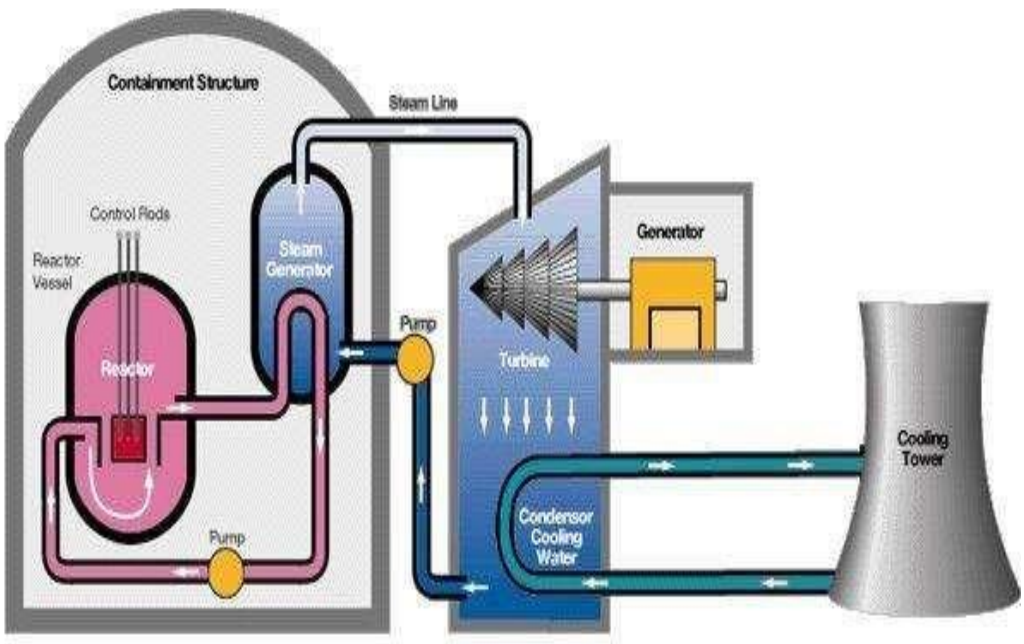


Figure 73: Schematic of a Nuclear Power Plant

Nuclear Power Reactors

Magnox Reactors

Of the six main commercial reactor types, two (Magnox and AGR) owe much to the very earliest reactor designs in that they are graphite moderated and gas cooled. Magnox reactorswere built in the UK from 1956 to 1971 but have now been superseded.

The Magnox reactor is named after the magnesium alloy used to encase the fuel, which is natural uranium metal. Fuel elements consisting of fuel rods encased in Magnox cans are loaded into vertical channels in a core constructed of graphite blocks.

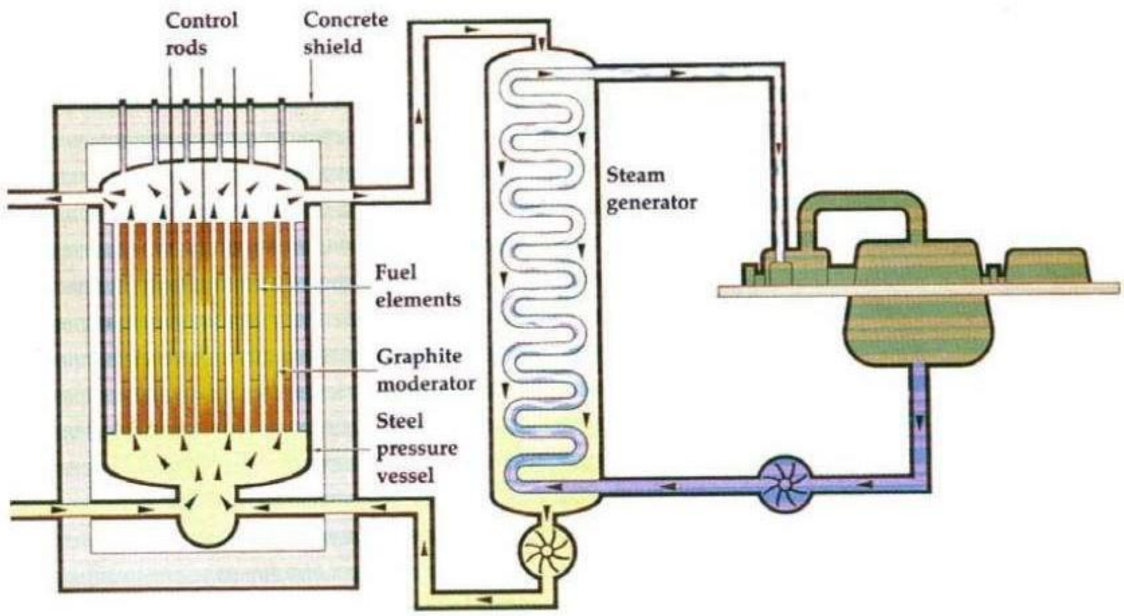


Figure 74: Magnox Reactor

Advanced Gas cooled Reactors

In order to improve the cost effectiveness of this type of reactor, it was necessary to go to higher temperatures to achieve higher thermal efficiencies and higher power densities toreduce capital costs.

This entailed increases in cooling gas pressure and changing from Magnox to stainless steel cladding and from uranium metal to uranium dioxide fuel. This in turn led to the need for an increase in the proportion of U^{235} in the fuel. The resulting design, known as the **Advanced Gas-Cooled Reactor, or AGR**

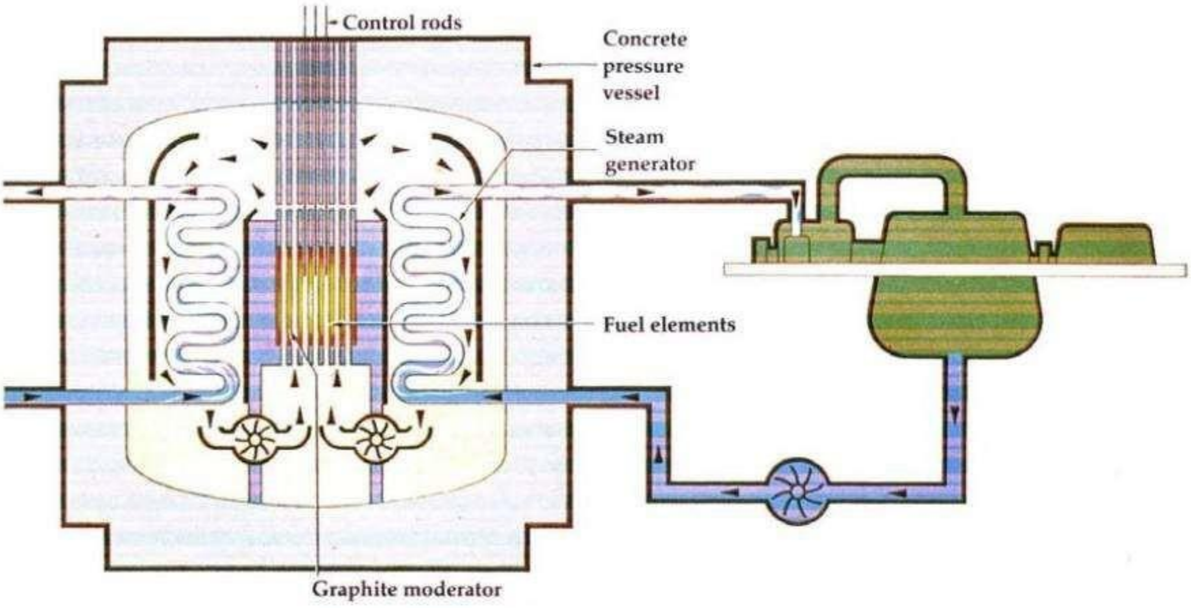


Figure 75: Advanced Gas Cooled Reactor

Pressurized Water Reactor (PWR)

The most widely used reactor type in the world is the Pressurized Water Reactor (PWR) which uses enriched (about 3.2% U235) uranium dioxide as a fuel in zirconium alloy cans.

The fuel, which is arranged in arrays of fuel "pins" and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator.

The high-pressure water is then passed through a steam generator, which raises steam in the usual way.

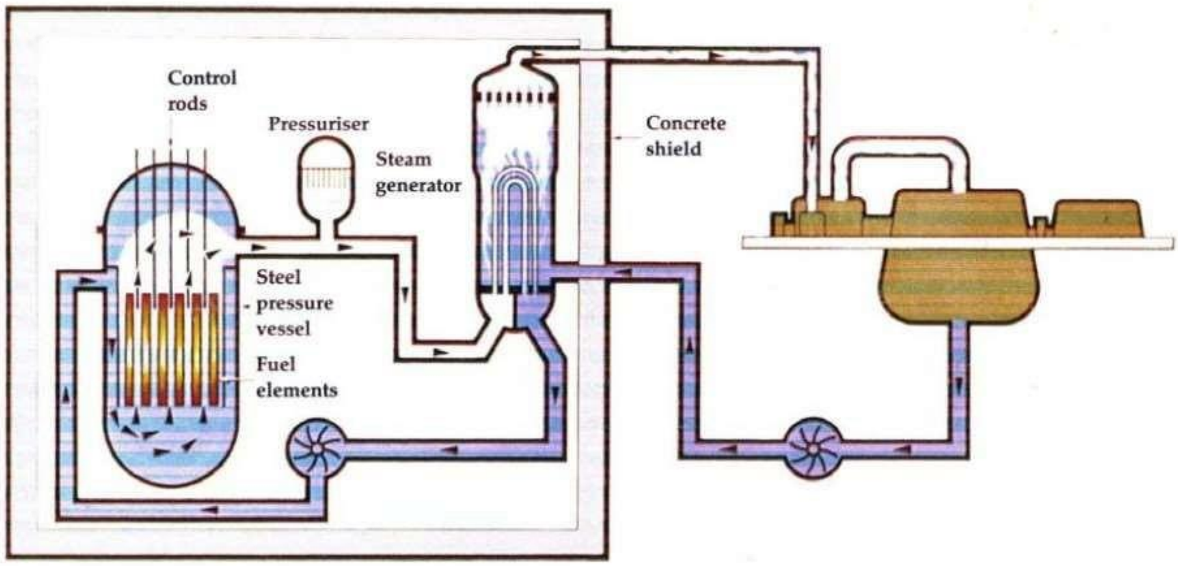


Figure 76: Pressurized Water Reactor

Boiling Water Reactors (BWR)

The second type of water cooled and moderated reactor does away with the steam generator and, by allowing the water within the reactor circuit to boil, it raises steam directly for electrical power generation. Such reactors, known as Boiling Water Reactors (BWRs), throughout the world.

This, however, leads to some radioactive contamination of the steam circuit and turbine, which then requires shielding of these components in addition to that surrounding the reactor.

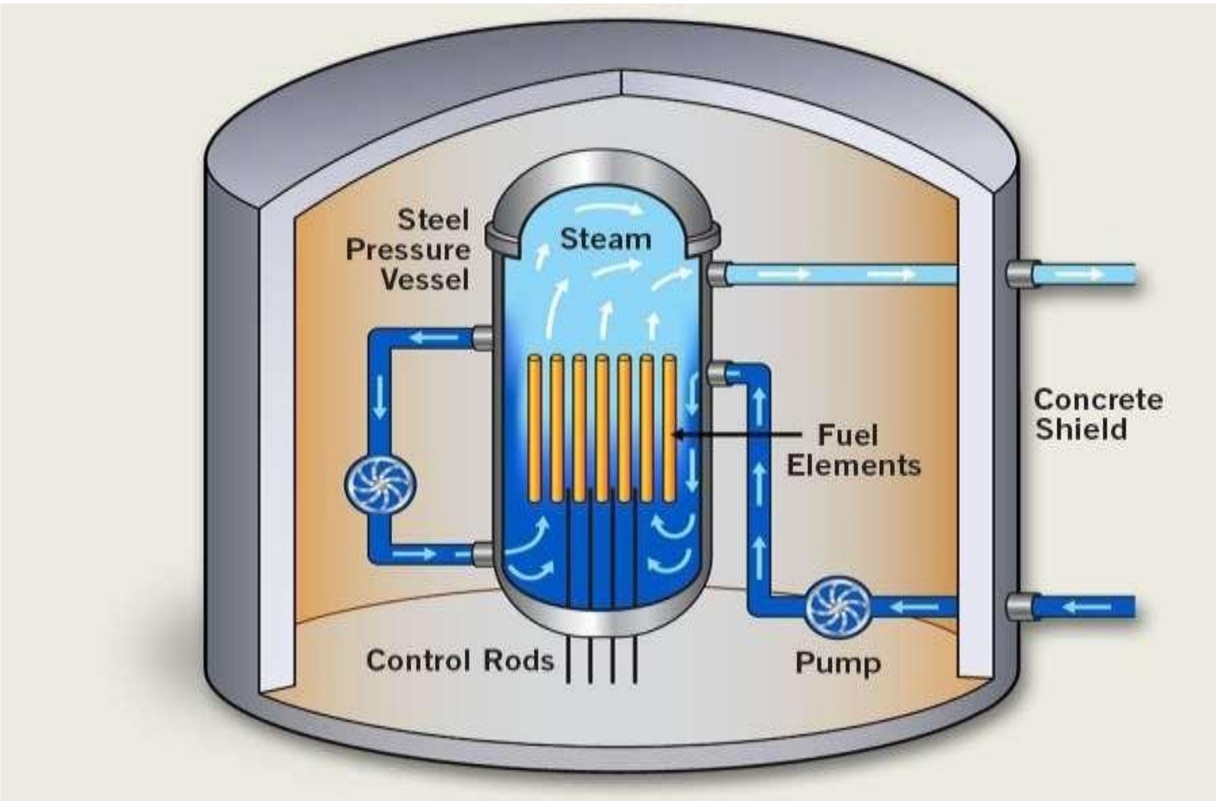


Figure 77: Boiling Water Reactor

Comparison of PWR and BWR

Table 6: Comparison of PWR and BWR

PWR	BWR
Advantages	Advantages
• Relatively compact in size • Possibility of breeding plutonium by providing a blanket of U-238 • High power density • Containment of fission products due to heat exchanger • Inexpensive 'light water' can be used as moderator, coolant and reflector • Positive power demand coefficient i.e. the reactor responds to load increase	• Elimination of heat exchanger circuit results in reduction in cost and gain in thermal efficiency (to about 30%) • Pressure inside in the reactor vessel is considerably lower resulting in lighter and less costly design • BWR cycle is more efficient than PWR as the outlet temperature of steam is much higher • Metal surface temperature is lower since boiling of water is inside the reactor • BWR is more stable than PWR and hence is commonly known as a self-controlled reactor
Disadvantages	Disadvantages
• Moderator remains under high pressure and hence a strong pressure vessel is required • Expensive cladding material is required to prevent corrosion • Heat loss occurs due to heat exchanger • Elaborate safety devices are required • Lacks flexibility i.e. the reactor needs to be shut down for recharging and there is difficulty in fuel element	• Possibility of radio-active contamination in the turbine mechanism • Wastage of steam may result in lowering of thermal efficiency on part load operation • Power density of BWR is nearly half that of PWR resulting in large size vessel • Possibility of burn-out of fuel is more as water boiling is on the surface of fuel. • BWR cannot meet a sudden increase in load

design and fabrication • Thermal efficient is very low; around 20%	

Fast Breeder Reactors

All of today's commercially successful reactor systems are "thermal" reactors, using slow or thermal neutrons to maintain the fission chain reaction in the U^{235} fuel. Even with the enrichment levels used in the fuel for such reactors, however, by far the largest numbers of atoms present are U^{238}, which are not fissile.

Consequently, when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element, Plutonium.

Plutonium is fissile and some of it is consumed *in situ, while some remains in the spent fuel together with unused* U^{235}*. These fissile components can be separated from the fission product wastes and recycled to reduce the consumption of uranium in thermal reactors by upto 40%, although clearly thermal reactors still require a substantial net feed of naturaluranium.*

It is possible, however, to design a reactor which overall produces more fissile material in the form of Plutonium than it consumes. This is the **fast reactor in which the neutrons are unmoderated, hence the term "fast".**

The physics of this type of reactor dictates a core with a high fissile concentration, typically around 20%, and made of Plutonium. In order to make it breed, the active core is surrounded by material (largely U238) left over from the thermal reactor enrichment process. This material is referred to as fertile, because it converts to fissile material **when irradiated during operation of the reactor.**

The successful development of fast reactors has considerable appeal in principle. This is because they have the potential to increase the energy available from a given quantity of uranium by a factor of fifty or more, and can utilise the existing stocks of depleted uranium, which would otherwise have no value.

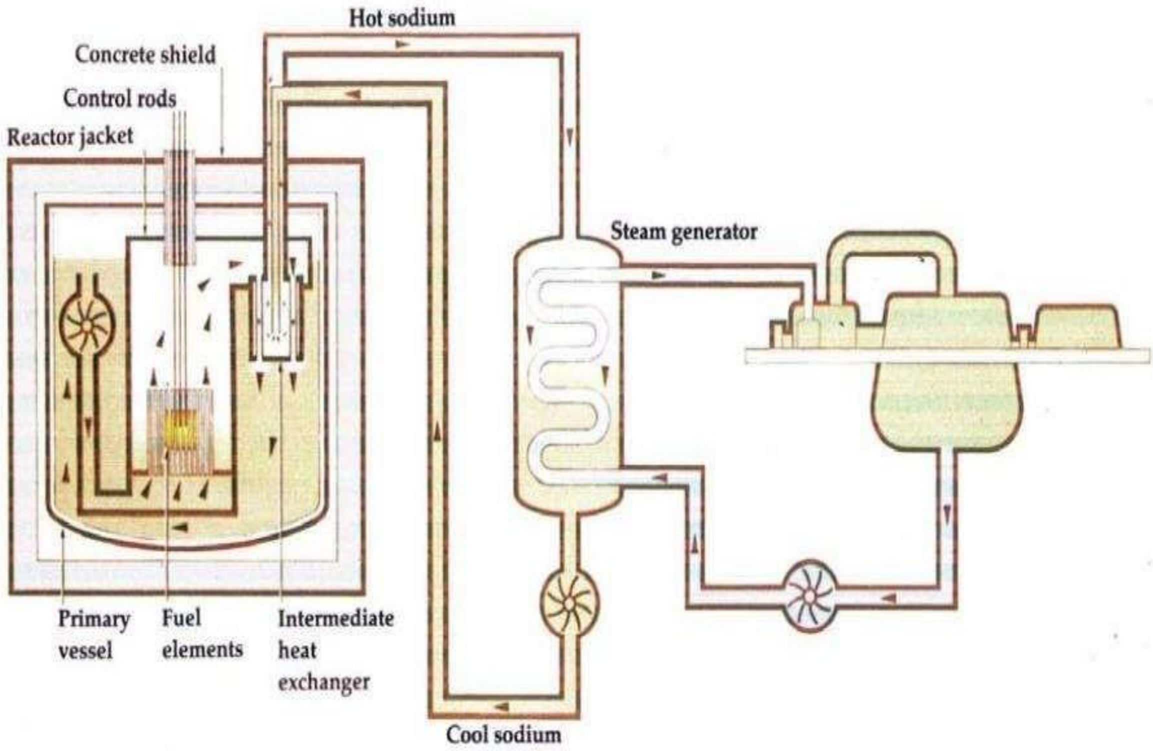


Figure 78: Fast Breeder Reactors

Factors for Site Selection of NPPs

1. **Availability of Water:** working fluid
2. **Distance from Populated Area:** danger of radioactivity
3. **Nearness to the load centre:** reduction in transmission cost
4. **Disposal of Waste:** radioactive waste
5. **Accessibility by Rail and Road:** transport of heavy equipment

Advantages of NPPs

1. **Reduces demand for fossil fuels**
2. **Quantity of nuclear fuel is much less:** thus reducing transport and resulting costs
3. **Area of land required is less:** compared to a conventional plant of similar capacity
4. **Production of fissile material**
5. **Location independent of geographical factors:** except water requirement

Disadvantages of NPPs

1. **Not available for variable loads (load factor-0.8):** as the reactors cannot be controlled to respond quickly
2. **Economical reason should be substantial**
3. **Risk of leakage of radioactive material**
4. **Further investigation on life cycle assessment and reliability needs to be done**
5. **Perception problems**

Nuclear Power in India

Plant	Units	Capacity	Established
Tarapur, Maharashtra	BWR	160x2, 540x2	1969, 2005, 2006
Rawatbhata, Rajasthan	PHWR	110x1, 200x1, 220x4	1973, 1981, 2000, 2010
Kalpakkam, Tamil Nadu	PHWR	220x2	1984, 1986
Narora, UP	PHWR	220x2	1991, 1992
Kakrapar, Gujarat	PHWR	220x2	1993, 1995
Kaiga, Karnataka	PHWR	220x4	2000, 2007, 2011
Kundankulam, Tamil Nadu	VVER-1000	1000x1	2013

Nuclear Power in World

Sl No	Country	Capacity (MW)	% Share in Electricity production
1	United States	102136	19 %
2	France	63130	75 %
3	Japan	44215	18 %
4	Russia	23643	18 %
5	South Korea	20739	30 %
6	Canada	14135	15 %
7	Ukraine	13107	46 %
8	China	12086	2 %
9	Germany	12068	16 %
10	U K	9938	18 %

Numerical Problems on Nuclear Power Plant

1. Calculate the amount of coal containing the same energy as in 1 kg of Natural Uranium under the following assumptions. Also calculate the number of fissions per second to produce 1 watt power.
    - Energy release from one fission of U^{235} = 200 MeV
    - Atoms in one gram pure U^{235} = 25.64 x 10^{20}
    - Calorific value of coal = 6000 kcal/kg
    - U^{235} content in Natural Uranium = 0.7 %
    - Fission efficiency = 50 %
    - One Joule = 0.239 cal
2. Find the power produced by fissioning 5 grams of U235 per day. Number of atoms in one gram of U235 =2.563 x 1021
3. Find the U235 fuel used in one year in a 235 MW pressurized water reactor. Assume overall plant efficiency of 33 % and 100% load factor throughout the year. Number of fissions required for 1 watt-sec= 3.1x1010. Number of atoms in one gram of U235 = 2.563 x 1021

Types of Alternators

Table 7: Hydro and Turbo generators

Hydrogenerator	Turbogenerator
Low speed (50-500 RPM)	High speed (1500/3000 RPM)
Arrangement: Impulse: Horizontal; Reaction: Vertical	Always horizontal
Salient pole construction	Cylindrical construction
Damper windings provided	No damper windings needed
Direct axis and quadrature axis reactances	Synchronous reactances
Air cooled	Hydrogen cooled

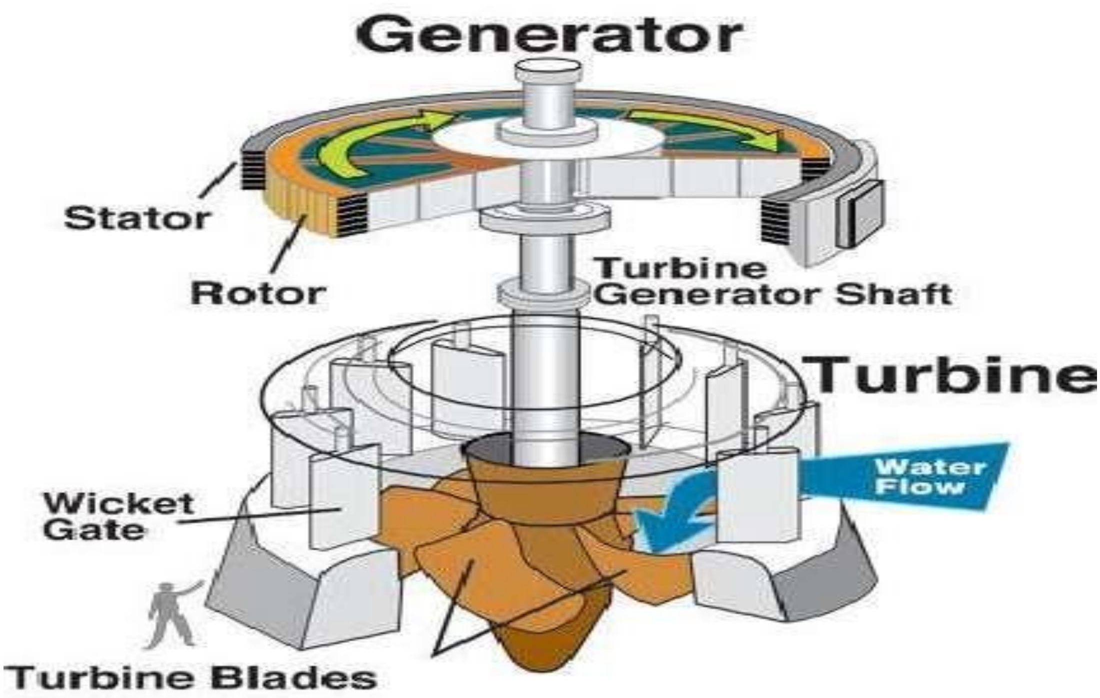


Figure 79: Hydrogenerator

Figure 80: Hydrogenerator under construction

Figure 81: Turbogenerator

Figure 82: Turbogenerator

Figure 83: Turbogenerator

Generator Cooling Arrangements

Cooling is basically of two types:

1) Open circuit cooling
2) Closed circuit cooling

Open circuit cooling

- Air is drawn into the generator by means of fans and is circulated inside.
- The air is later released into the atomosphere
- Suitable for small generators

Closed circuit cooling

- Hydrogen is used as cooling medium
- Circulated by pumps and then drawn back into a chamber
- Used for large sized generators

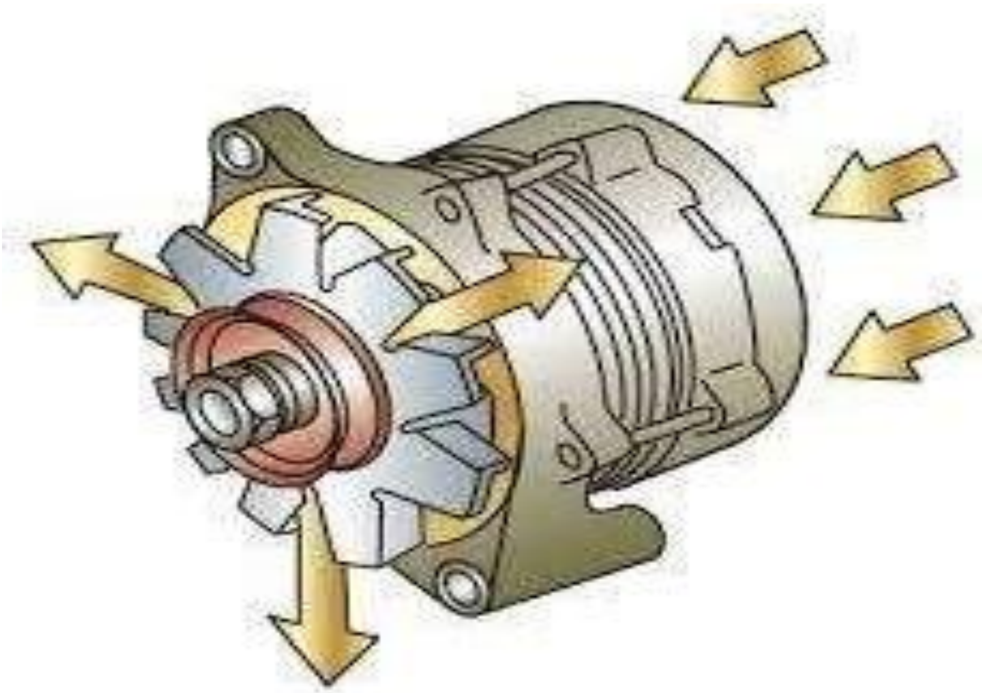


Figure 84: Air cooling of generators

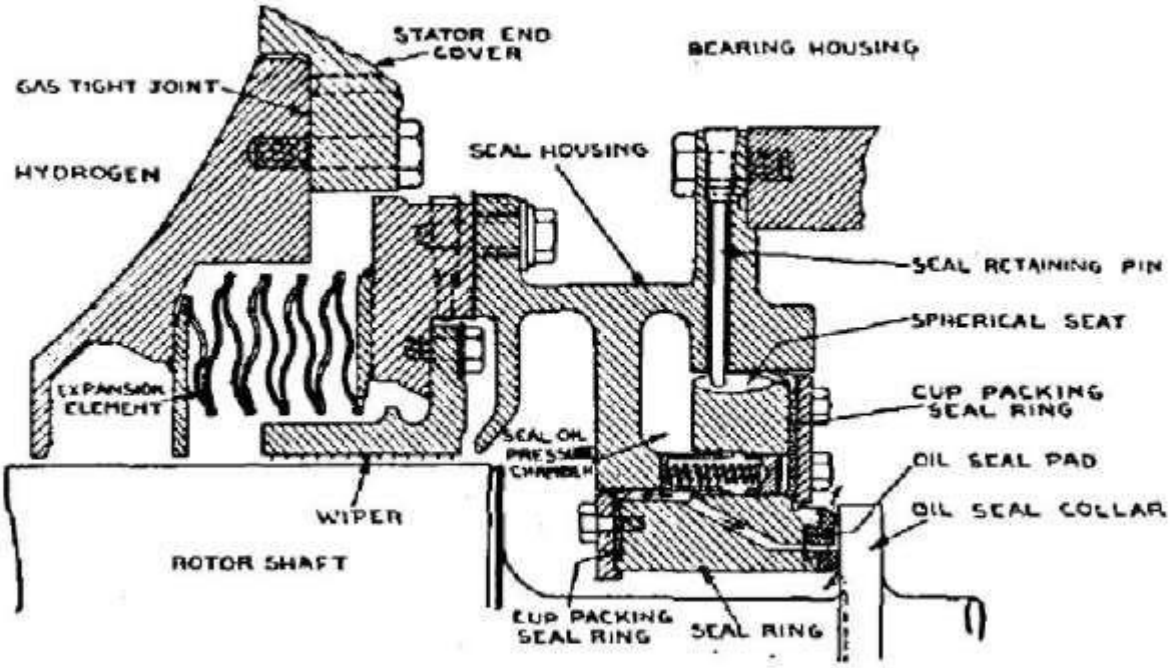


Figure 85: Hydrogen Cooling

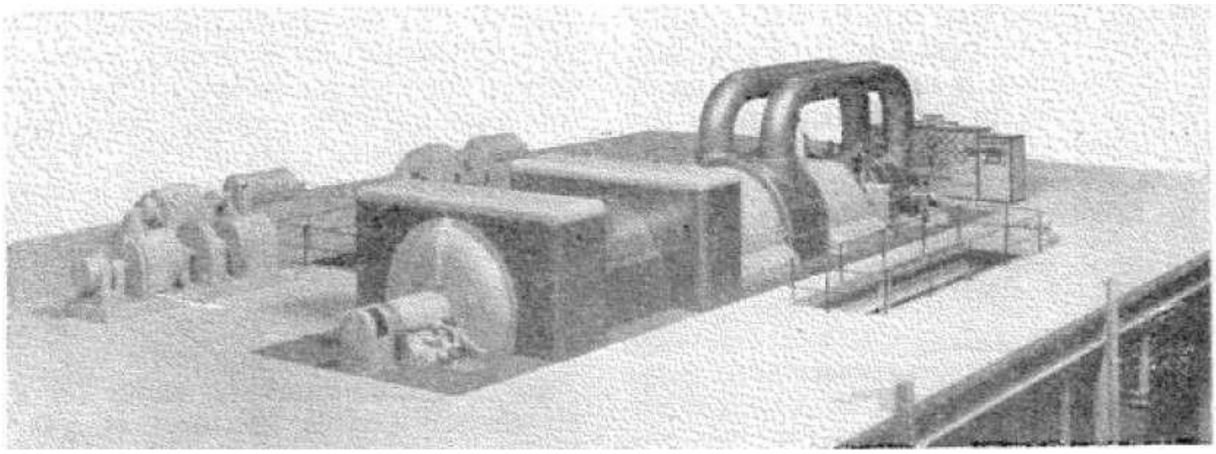


Figure 86: Hydrogen Cooled Alternator

Excitation Systems

Function

- The alternators are provided with shaft or gear mounted exciters for providing dc excitation to their field windings.
- For a large alternator the main exciter is a separately excited dc machine supplied by a pilot exciter.

Exciter Design

- Excitation power required for large turbo-generators is of the order of 0.4-0.5% of the generator rating .
- Usually main exciter separately excited from a pilot exciter.
- The advantage of using pilot exciter is to improve voltage response to changes of the field current.

Minimum Requirements for the Main Exciter

- Rated current must not be less than 110% of rotor current for rated generator output.
- Rated voltage must not be less than 110% of the slip ring voltage for rated generator output. The exciter voltage is generally 230V.
- in some cases nominal voltage of 440V is used.
- ceiling voltage must not be less than 120 percent of rated slip ring voltage .
- Nominal response must not be less than .5

Types of Excitation Systems

1) DC Excitation using DC Generators
2) AC Excitation using AC Generators along with Rectifiers
3) Static Excitation (from alternator terminals)

DC Excitation System

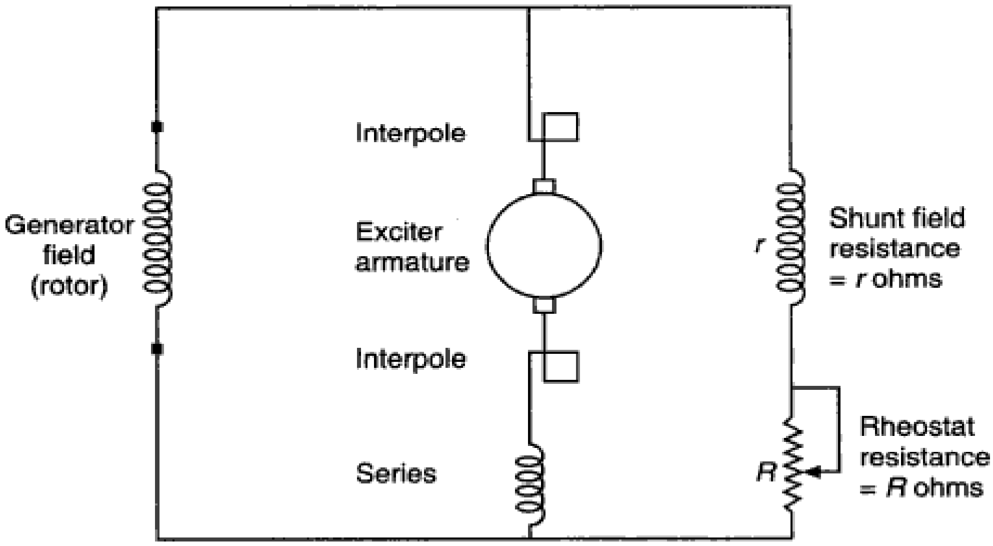


Figure 87: DC Excitation

- The pilot exciter is a d.c shunt machine. The main exciter is a d.c shunt machine with a number of control field windings .
- The main and pilot exciters are coupled to the main generator shaft.
- A d.cmotor drives an amplidyne or rotating amplifier which is cross field machine. It has a number of control windings.
- The voltage transformers secondaries supply AVR and magnetic amplifier circuits.

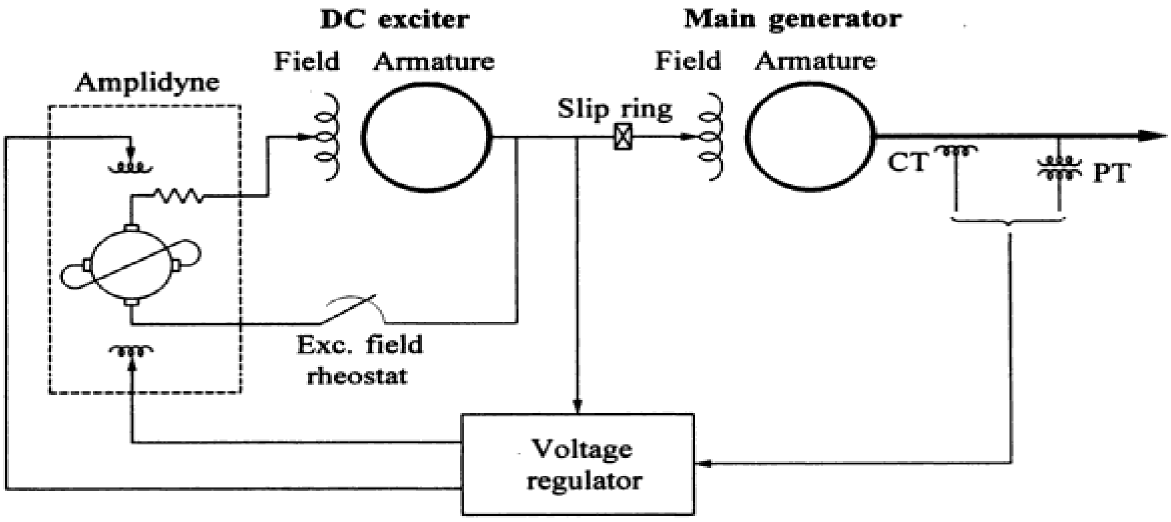


Figure 88: Excitation System with Amplidyne

AC Excitation System

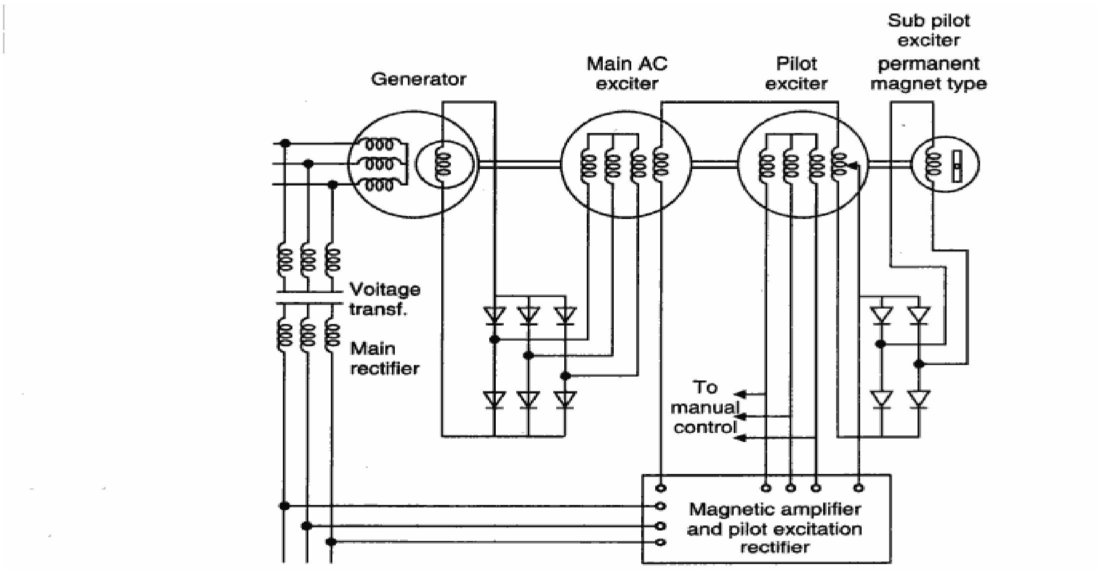


Figure 89: AC Excitation System

Table 8: AC versus brushless excitation

AC Excitation System	Brushless Excitation System
The rectifier is on the floor.	Rectifier is rotating
Cooling and maintenance problem of slip rings and brushes	No need of brushes and slip rings, however it is impossible to meter and read main generator filed quantities as it is rotating

Static Excitation Systems

- The supply of power to the rectifier is from the main generator through the station auxiliary bus, using step down transformer.
- The rectifier output is fed directly to the field of the main generator by means of slip rings.
- There can be two arrangements:
    - Power to the excitation using voltage only
    - Using voltage as well as current from main generator

Field flashing: from battery bank, initial supply is given for starting up the alternator.

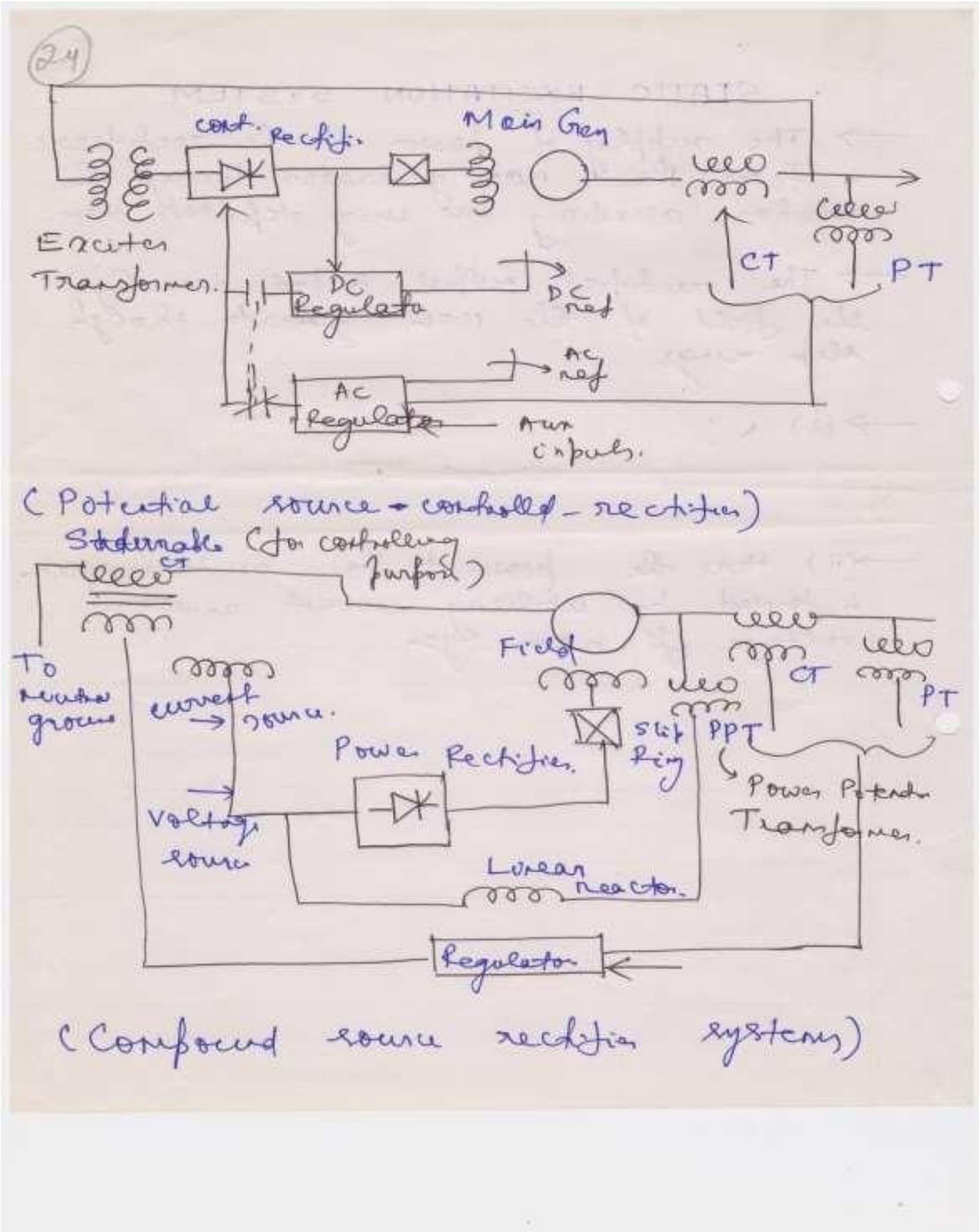


Figure 90: Static Excitation System

Module-4

Automatic Voltage Regulators

Functions

- To control system voltage within limits
- To regulate the sharing of reactive load between machines operating is parallel.
- To maintain voltage under system fault conditions to ensure rapid operation of protection systems.
- To keep the machine under synchronism.

Direct acting voltage regulator

- Adjustment of variable resistance
- Voltage transformer to the operating coil thus the torque to operate the drum
- Movement of pivot (P,P) causes sectors (S) to move
- Clockwise movement increases the resistance

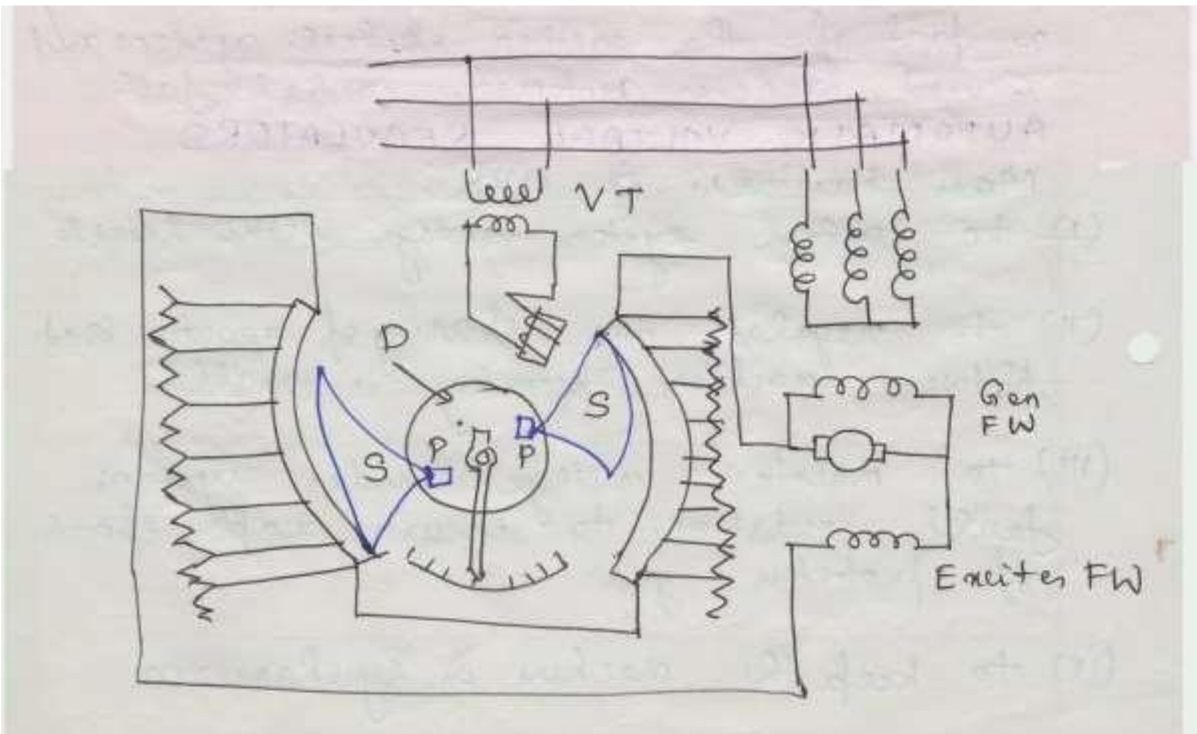


Figure 91: Direct Acting Voltage Regulator

Magnetic Amplifier Regulator

Principle

- Controls the flow of current by means of saturation of magnetic core.
- There are two windings:
    - Control/DC winding: controls the mmf o/p and
    - AC winding through which power is delivered to load
- The operation is based on reduction of impedance of the core as DC magnetization is increased.
- When the DC is so high that full saturation of the core occurs, the impedance becomes minimum and load current is maximum.

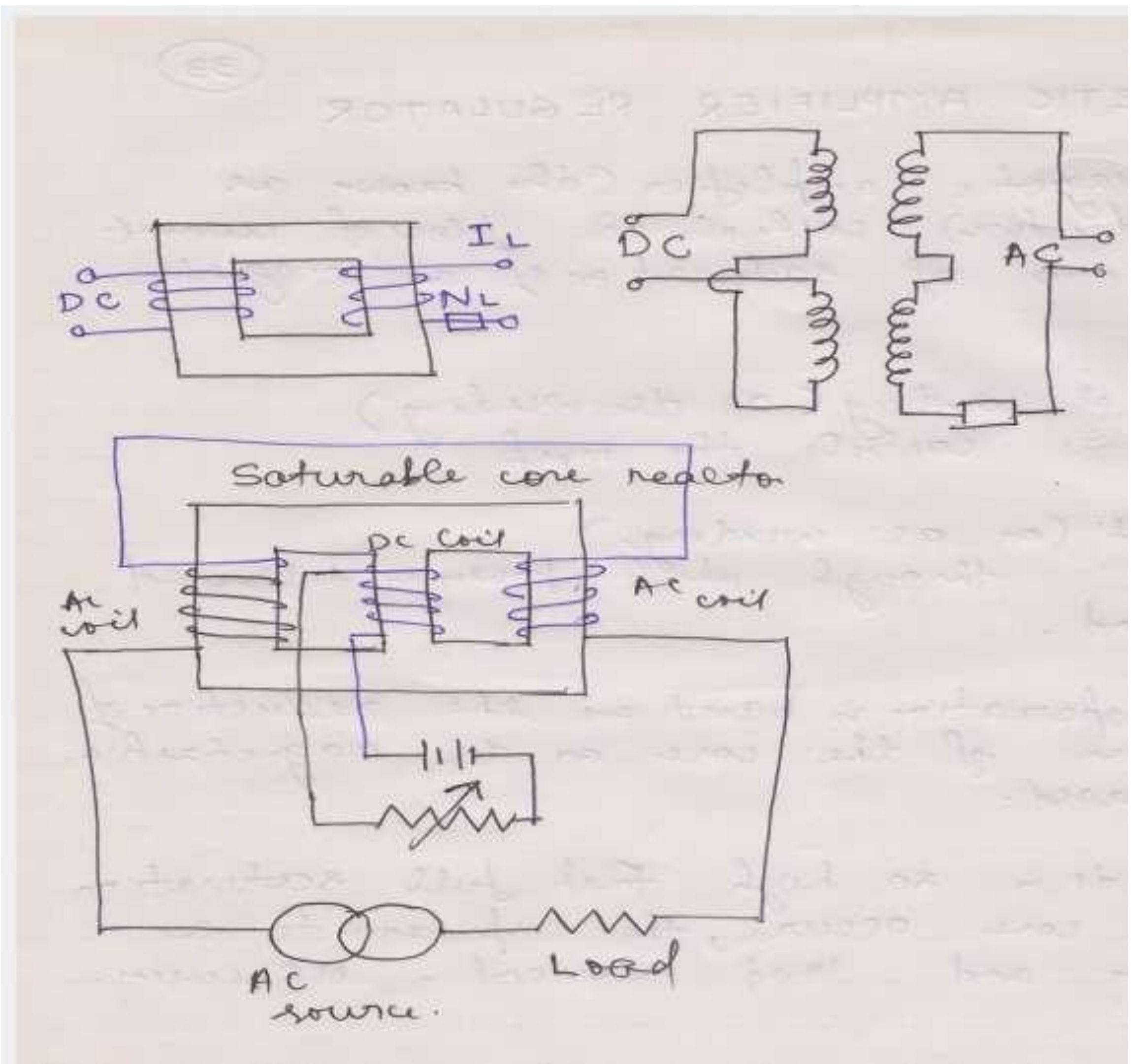


Figure 92: Magnetic Amplifier Regulator Principle

Construction

1) Self excited main exciter
2) Motor operated field rheostat
3) Boost and buck control fields
4) Static components
5) Compensation

Operation

- Deviation of the alternator terminal voltage
- Difference between reference and compensated output
- Amplified by input magnetic amplifier and power amplifier
- High frequency AC supply ensures that delay in regulating system is negligible compared to delay in exciter and alternator.

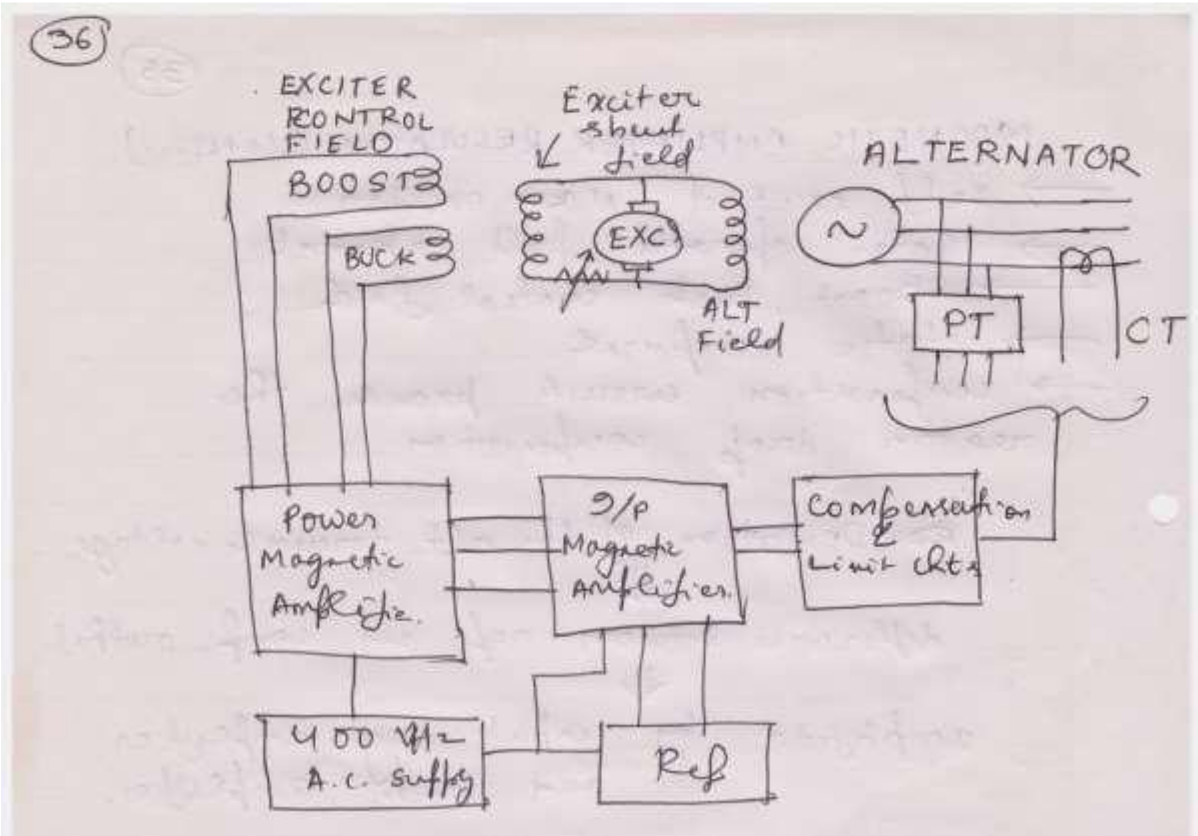


Figure 93: Magnetic Amplifier Regulator

Solid State Electronic Regulator

1) The sensing circuit responds to average 3 phase voltage output connected from PT to sensing element.
2) To regulate output, we need to sense voltage; for this we use potential transformer (step down transformer), from CT through compensate to limit sensing for current measurement.
3) Compensator works as amplifier. It stabilizes CT/PT outputs because output is always fluctuating.
4) Three phase voltage from PT is rectified, filtered and compared with a constant reference.
5) The output of the amplifier is the voltage error signal.
6) Single phase CT is used for reactive current compensations.
7) Minimum excitation limiter prevents the regulator from decreasing regulation below the set characteristics value.
8) The signal mixer amplifier output controls the firing circuit of thyristor which supplies excitation to the machine.
9) The power and control elements can be taken out for repair.
10) From voltage reference to voltage adjuster.

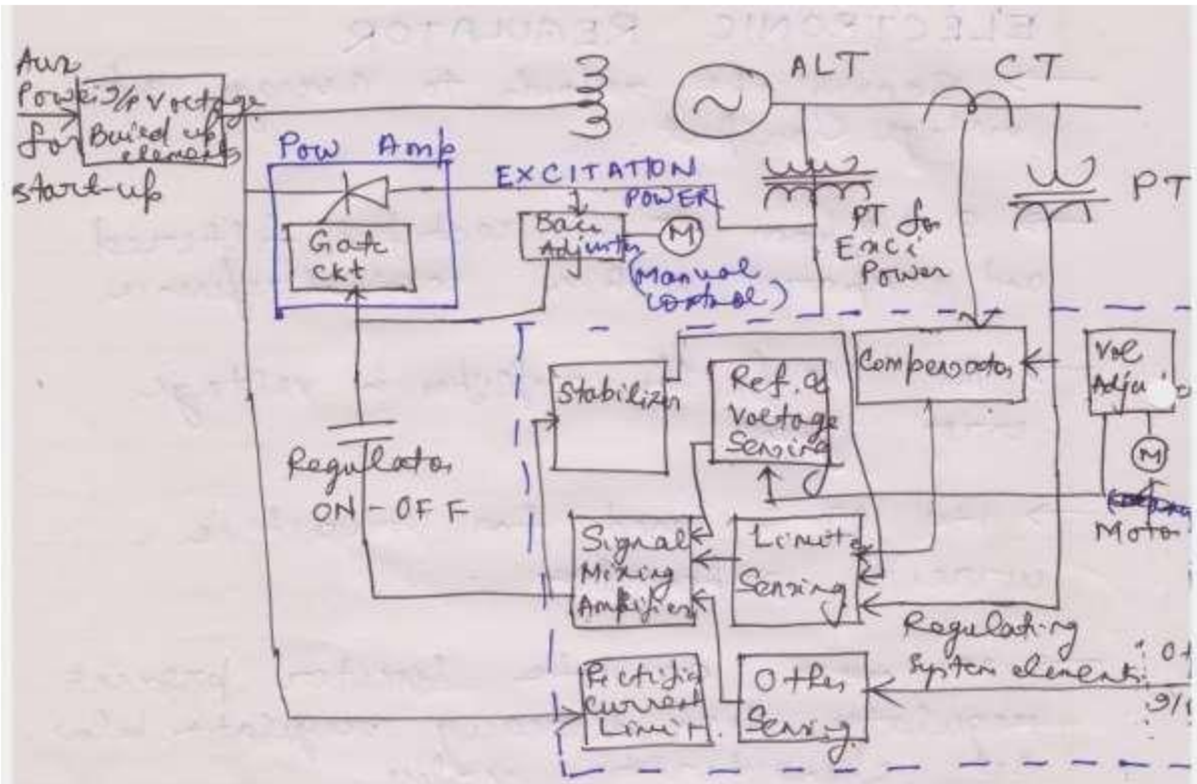
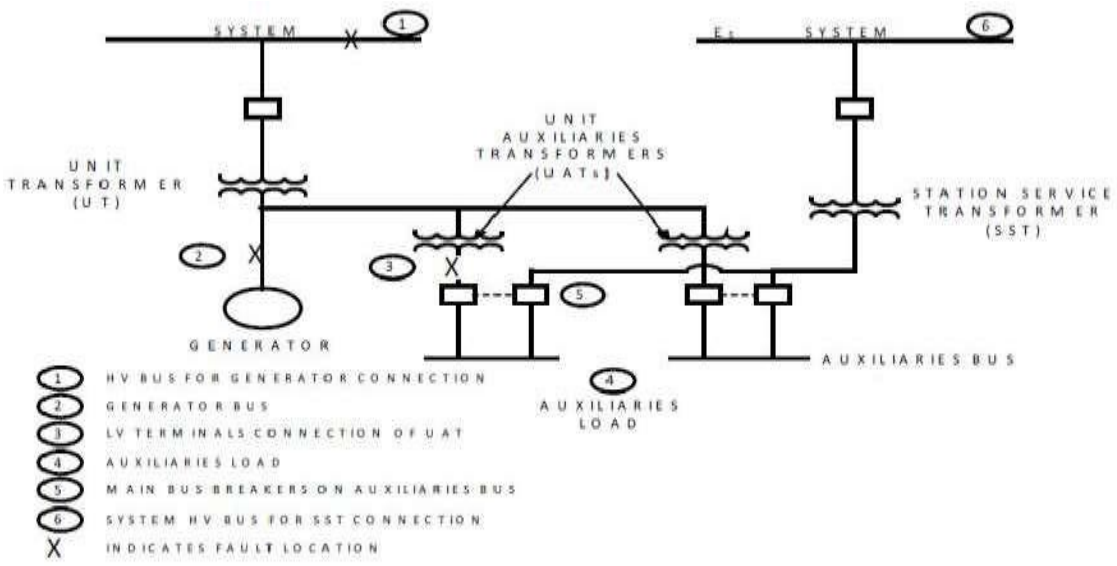


Figure 94: Solid State Electronic Regulator

Power Plant Transformers



NOTE 1—UT and UAT LV groundings are design dependent.[6]

NOTE 2—UT and UAT neutral connections are omitted for simplicity.

Figure 95: Typical Generation Station Auxiliaries [7]

1) **Unit:** The generator or source of electrical power
2) **Unit Transformer (UT):** transforms all or a portion of unit power from unit voltage to power system voltage
3) **Unit Auxiliary Transformer (UAT):** transformer intended primarily to supply all or a portion of unit auxiliaries.
4) **Station Service Transformer (SST):** transformer that supplies power from a station HV bus to the station auxiliaries and unit auxiliaries during unit startup.
5) **Back feed:** operation of unit transformer with generator disconnected to supply start up auxiliaries power or testing power where low magnitude current in the opposite direction from normal operation of transformer.

Pre-commissioning Tests on Alternators

1) **Inspection:** visual inspection to correct air gap, that bearings are free, that lubricating system is free or dirt
2) **Drying out:** to release trapped moisture, measure insulation resistance
3) **Short circuit curve:** to compare rated current in each phase
4) **Stator high voltage tests:**
5) **Phase sequence tests:** between bus bar and alternator
6) **Testing protection system of alternators:**
    a. **Primary injection test**
    b. **Trip test**
    c. **Fault test**
    d. **Field fault**

Pre-commissioning Tests on Transformers

1) Insulation Test
2) Drying out
3) Estimation of most suitable tap
4) Cooling equipment (pumps, fans etc)
5) Measurement of voltage ratio and checking of voltage phasor relationship
6) Measurement of no load current and no load loss
7) Testing of protection systems:
    a. Differential
    b. Restricted earth fault
    c. Overload
    d. Buchholz
    e. Temperature

Choice of size and number of Generating Units

1. Economy: large size units have
    a. low capital cost/kW,
    b. need less land area
    c. requires less operating labor
    d. have better efficiency
    e. system strength
2. Power plant capacity: neither small nor large number of units
3. Transmission facility
4. Reserve requirements
5. Status of technology
6. For hydro stations unit size depends on nature of flow, availability of head and water to generate maximum power possible.

Type of Load

Domestic Load

Industrial Load

Commercial Load

Municipal Load

Traction Load

Irrigation Load

Important Terms

Demand Factor
= Maximum Demand / Connected Load

Connected Load: sum of continuous ratings of all outlets in a distribution circuit

Maximum Demand: maximum power that the distribution circuit is likely to draw at any time

Group Diversity Factor
= Sum of individual maximum demands / Maximum demand of the group

GDF is always greater than unity

Peak Diversity Factor
=sum of maximum demand of a consumer group / demand of the consumer group at the time of maximum demand

Load Factor
=Average Load / Peak Load

Capacity Factor
= Average Demand / Installed Capacity

Utilization Factor
= Maximum Load / Rated Plant Capacity

Load Curve:
It is the curve between load (MW) versus time.

Load Duration Curve:

It is the rearrangement of all the load elements of a load curve in a descending order plotted as a function of time.

Energy Load Curve:

It plots the cumulative integration of area under the load curve.

Mass Curve

It gives the total energy used by the load up to each hour of the day.

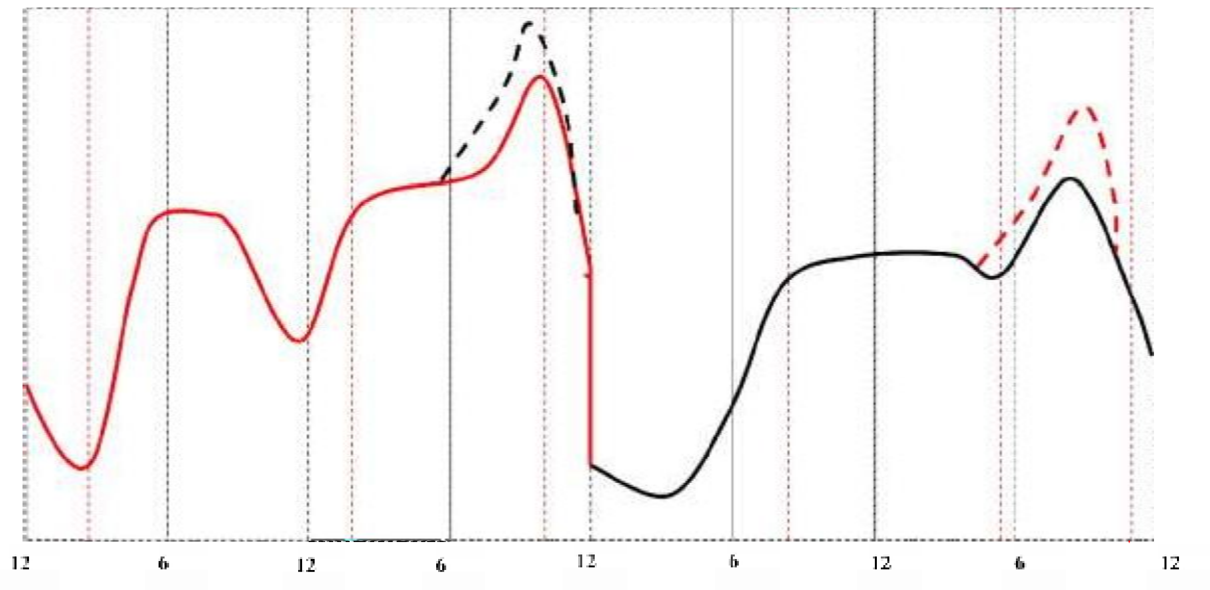


Figure 96: Load Curve

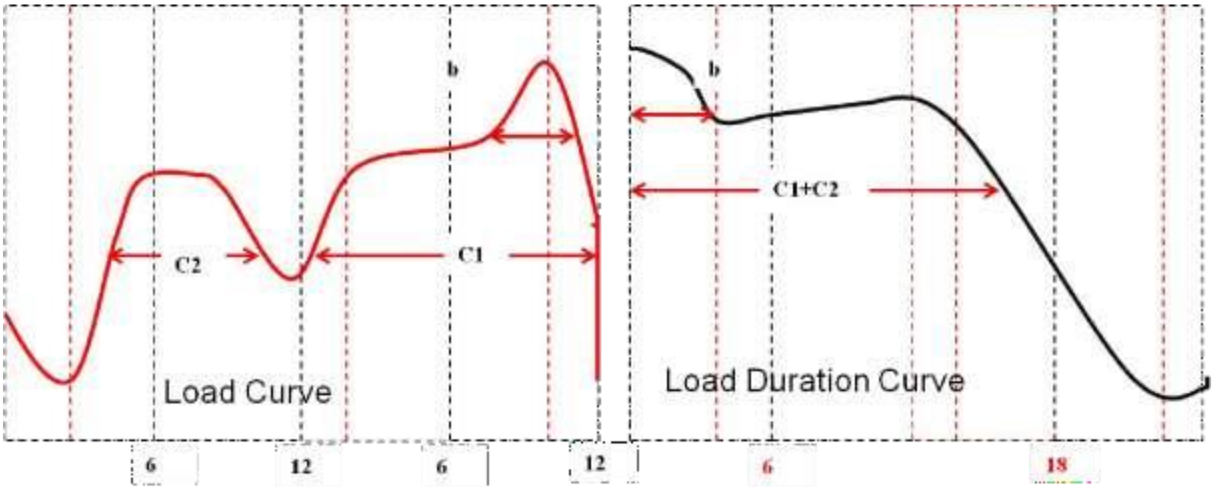


Figure 97: Load Duration Curve

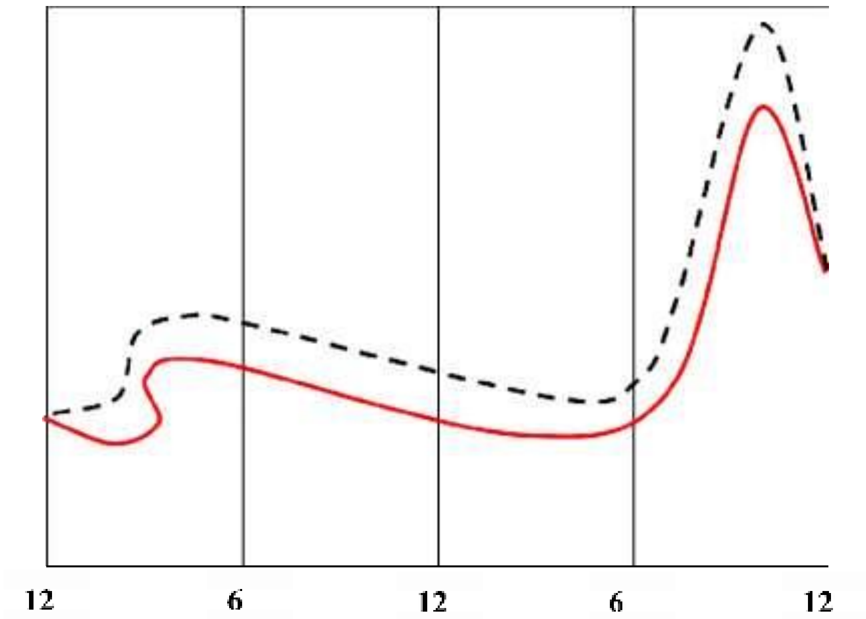


Figure 98: Domestic Load (DF=0.5)

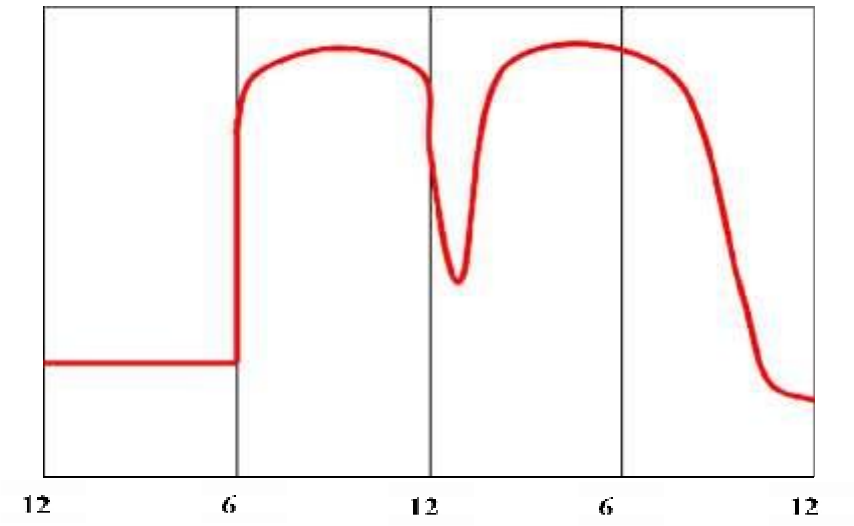


Figure 99: Industrial Load (DF=0.8)

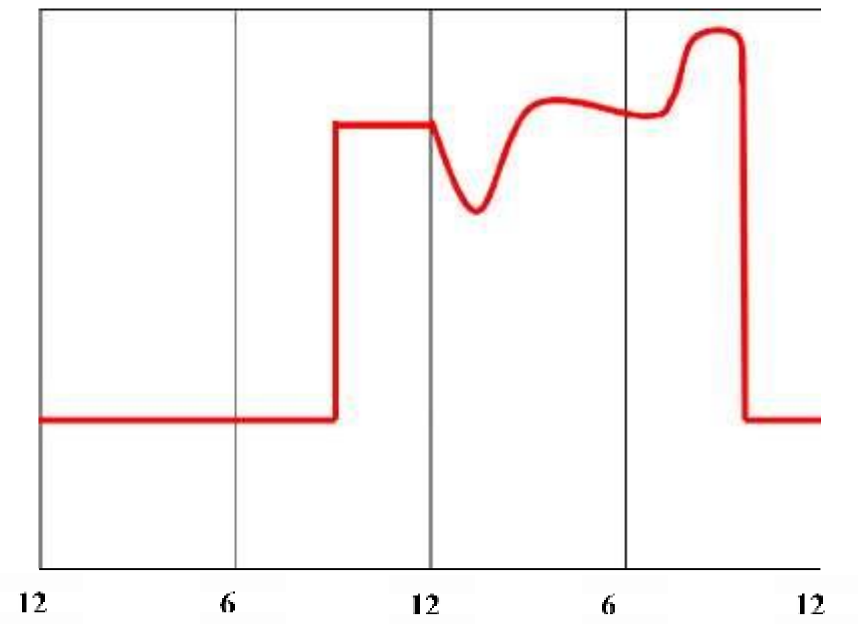


Figure 100: Commercial Load

Operating Reserves

- How much generating capacity should be committed and how much should be left for future expansion?
- In electricity networks, the "operating reserve" is the generating capacity available to system operator within a short interval of time to meet the changing demand or in case a generator is out of service.

Table 9: Operating Reserves

Spinning Reserve (Hot Reserves)	**Non-spinning Reserve (Cold Reserves)**
It is the extra generating capacity that is available by increasing the power output of the generator that are already connected to power system.	It is the reserve which can be brought ONLINE after a short delay. It also includes imported power.
In other words, it is the unloaded generation i.e. synchronized and ready to serve the additional demand.	In other words, cold reserve is the reserve generating capacity that is available for service but not in operation.

Tariffs

Objectives

- Capital recovery
- Operational cost of distribution utility
- Cost of metering, billing and collection
- Simple and comprehensible to general public
- Uniform for a large population
- Should provide incentives for using power in off-peak hours
- Should have a provision of penalty for low power factor.

General Tariff Form

A = c*x + d*y + f

Where

A= total amount of bill for a certain period

x=maximum demand during a period (kW or kVA)

y= total energy consumed during the period in kWh

c=unit charge for maximum demand (Rs/kWh or Rs/kVA)

d=unit cost of energy (Rs/kWh)

f= constant charge

Flat Demand Rate

A = c*x

Straight Meter Rate

A = d*y

Block Meter Rate

A=d1*y1 +d2*y2 + …

Spot Pricing

- It is the half hour price of whole sale electricity market.
- The spot price is published by the pricing manager for each point of connection on the national grid.
- The electricity market uses spot electricity prices for each trading period to schedule available generation so that the lowest cost generation is dispatched first.

Availability based Tariff

It is a frequency based pricing mechanism for electric power. The ABT falls under electricity market mechanisms to charge and regulate power to achieve short term and long term network stability as well as incentives and disincentives to grid participants against interruption in committed supplies.

National Grid

Table 10: Grids in India

NEWNE Grid				Southern Grid
Northern	**Eastern**	**Western**	**North-Eastern**	**Southern**
Chandigarh	Bihar	Chhattisgarh	Arunachal Pradesh	Andhra Pradesh
Delhi	Jharkhand	Gujarat	Assam	Karnataka
Haryana	Orissa	Daman & Diu	Manipur	Kerala
Himachal Pradesh	West Bengal	Dadar & Nagar Haveli	Meghalaya	Tamil Nadu
Jammu & Kashmir	Sikkim	Madhya Pradesh	Mizoram	Pondicherry
Punjab	Andaman-Nicobar	Maharashtra	Nagaland	Lakshadweep
Rajasthan		Goa	Tripura	
Uttar Pradesh				
Uttarakhand				

- From 2006, all the northern grids connected to form central grid
- Since 2013, the southern and central grid unified, but not fully.

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[6] Power Plant Engineering by R. K. Rajput, Laxmi Publications Pvt. Ltd

[7] IEEE Guide for Transformers directly connected to Generators, IEEE Std C57.116™-2014 (Revision of IEEE Std C57.116-1989)