Module-I

Conventional Power Generation:

Understanding Traditional Energy Sources

Definition: Conventional power generation refers to the production of electricity using non-renewable energy sources.

Importance: Backbone of global energy supply.

Examples: Thermal, hydroelectric, and nuclear power plants.

Types of Conventional Power Plants

1. Thermal Power Plants
   - Coal, oil, and natural gas-based.
2. Hydropower Plants
   - Harnessing water energy.
3. Nuclear Power Plants
   - Utilizing nuclear fission.

Thermal Power Plants

- Working Principle: Converts heat energy from fuel combustion into electricity.
- Key Components: Boiler, Turbine, Generator, Condenser.
- Advantages:
  - High reliability.
  - Readily available fuels.
- Disadvantages:
  - High pollution.
  - Depleting fossil fuel reserves.

Hydropower Plants

- Working Principle: Converts potential energy of stored water into electricity.
- Key Components: Dam, Reservoir, Turbine, Generator.
- Advantages:
  - Minimal emissions.
- Disadvantages:
  - High initial costs.
  - Environmental disruption.

Nuclear Power Plants

- **Working Principle:**

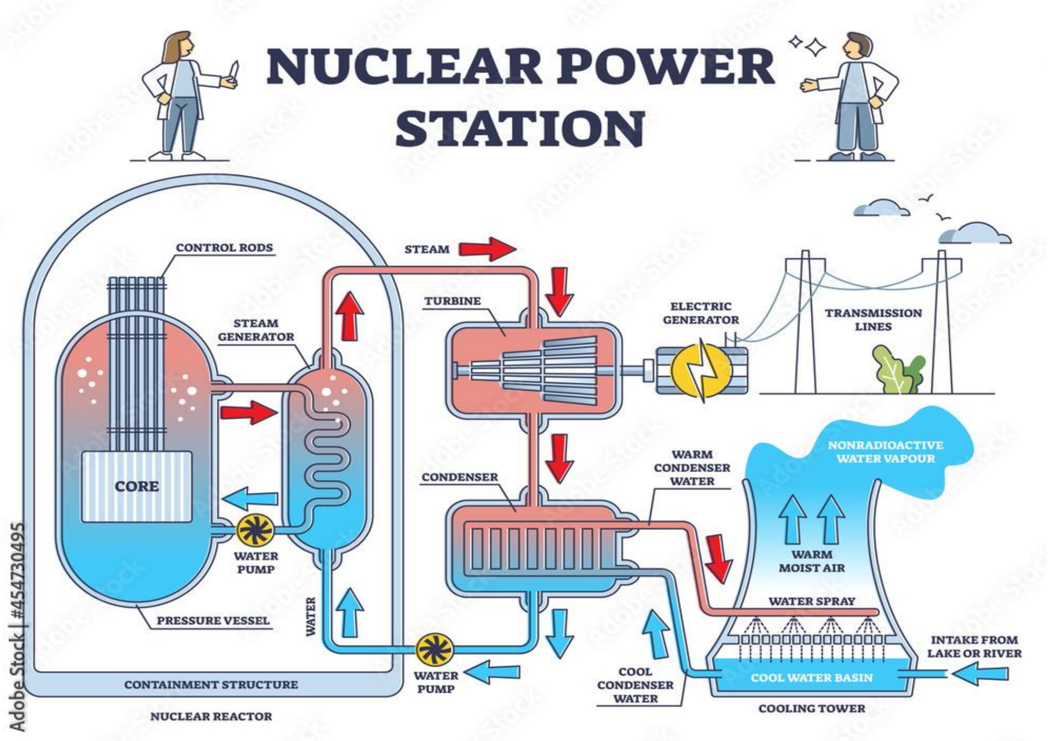
  Uses nuclear fission to produce heat, which drives turbines to generate electricity.

- **Key Components:**

  Reactor, Steam Generator, Turbine, Cooling Tower.

- **Advantages:**
  - High energy density.
  - Low greenhouse gas emissions.

- **Disadvantages:**
  - Radioactive waste management.
  - High safety risks.



Comparison of Conventional Power Plants

Aspect	Thermal	Hydropower	Nuclear
Fuel Source	Fossil Fuels	Water	Uranium
Environmental Impact	High (Pollution)	Low (Renewable)	Moderate (Waste)
Efficiency	Medium	High	High
Cost	Low (Operational)	High (Initial)	High

Challenges of Conventional Power Generation

- Environmental Impact:
  - Greenhouse gas emissions.
  - Climate change.
- Resource Depletion:
  - Fossil fuels are finite.
- Safety Concerns:
  - Accidents in nuclear plants.
  - Dam failures in hydropower.

Conventional Power Generation:

What is Hydropower Plant?

- A hydropower plant generates electricity by utilizing the hydraulic energy of water.
- The power generated by this plant is known as hydroelectric power.
- Hydropower accounts for around 16% of total global power consumption.

$$P = wQH\eta \times 9.81 \times 10^{-3} kw$$

w=specific weight of water kg/m3=density ≈ 1000kg/m^3

Q=rate of flow of water in m^3/sec

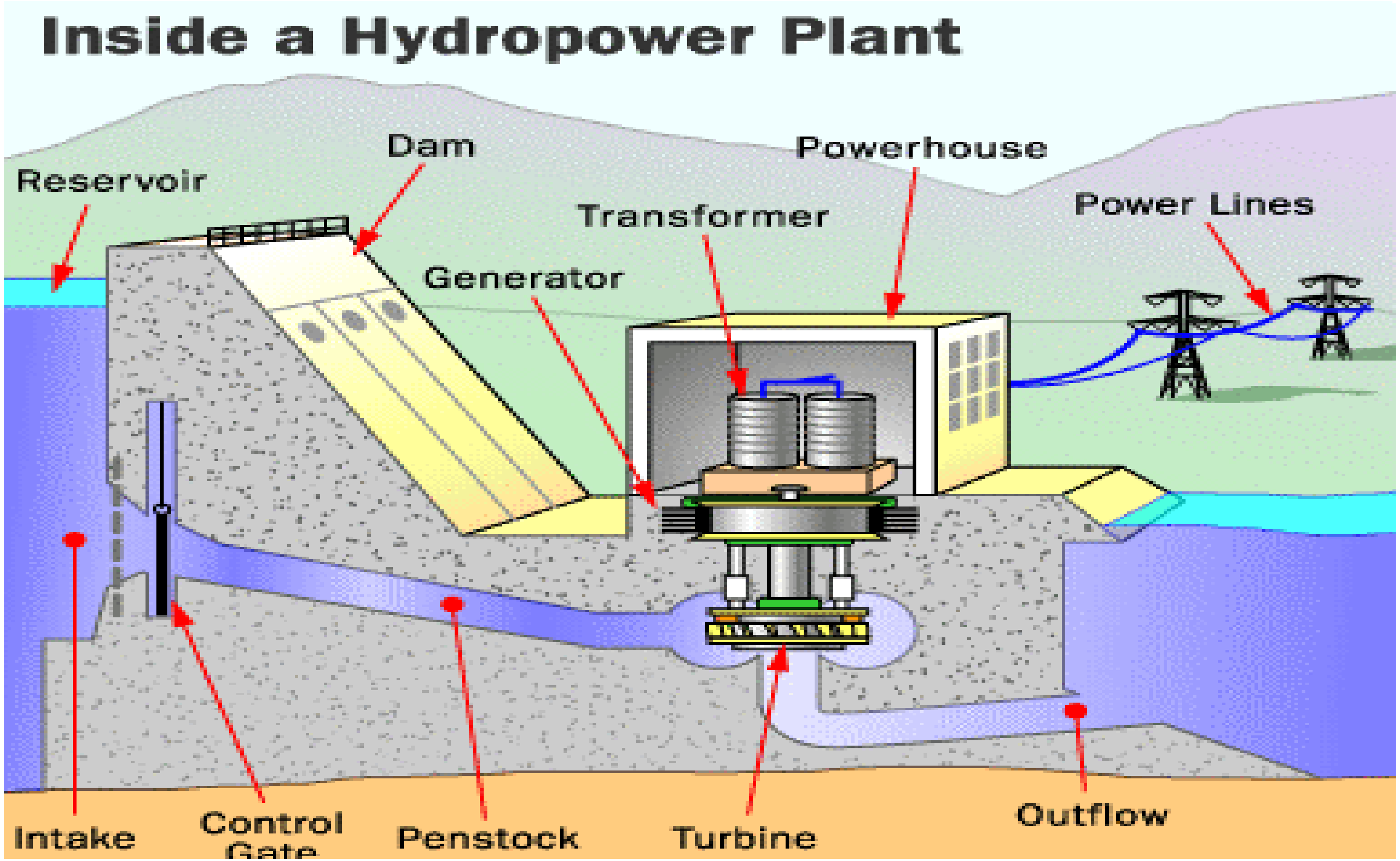
H=height of fall and head in m

$$\eta = overall\ efficiency\ of\ operation$$

Components of Hydro power plant

The major components of a hydroelectric plant are as follows.

1. Storage Reservoir
2. Dam
3. Forebay
4. Intake structure
5. Penstock
6. Surge chamber
7. Hydraulic turbines
8. Draft tube
9. Tailrace
10. Power house


Inside a Hydropower Plant
Dam
Powerhouse
Reservoir
Transformer
Power Lines
Generator
Intake
Control Gate
Penstock
Turbine
Outflow

1.Storage Reservoir

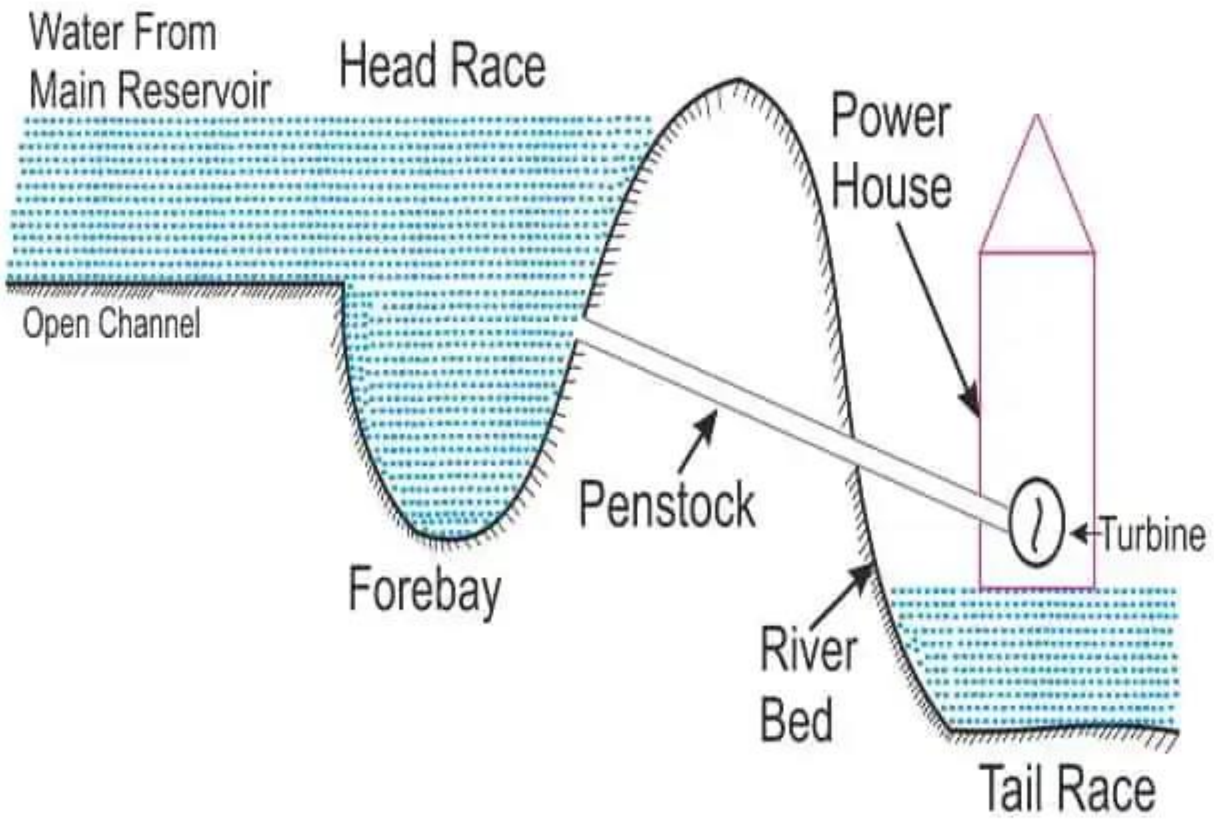
- It is a fundamental requirement of a hydropower plant.
- Its function is to store water during the monsoon season and deliver it during the dry season, thereby assisting in supplying water to the power plant.
- A reservoir can be either natural or man-made.
- A natural reservoir is a lake in the mountains, but an artificial reservoir is created by building a dam across a river.
- Low-head hydropower plants necessitate a large storage reservoir. The reservoir’s capacity is determined by the differential in runoff during high and low flows.

Dam

- A dam’s function is to provide storage as well as to elevate the water surface of a stream to form an artificial head.
- A dam is the most expensive and important component of a hydroelectric project.
- Dams are built with concrete, stone, and earth or rock fill.
- The geography of the location dictates the type and configuration.
- In a narrow canyon, a brick dam could be constructed.
- A vast valley might benefit from an earth dam.

Forebay

- A forebay is a basin area of hydropower plant where water is temporarily stored before going into intake chamber.
- The storage of water in forebay is decided based on required water demand in that area.
- This is also used when the load requirement in intake is less.
- We know that reservoirs are built across the rivers to store the water, the water stored on upstream side of dam can be carried by penstocks to the power house.
- In this case, the reservoir itself acts as forebay.



Intake Structure

- Intake structure is a structure which collects the water from the forebay and directs it into the penstocks.
- There are different types of intake structures are available and selection of type of intake structure depends on various local conditions.
- Intake structure contain some important components of which trash racks plays vital role.
- Trash racks are provided at the entrance of penstock to trap the debris in the water.
- If debris along with water flows into the penstock it will cause severe damage to the wicket gates, turbine runners, nozzles of turbines etc. these trash racks are made of steel in rod shape. These rods are arranged with a gap of 10 to 30 cm apart and these racks will separate the debris form the flowing water whose permissible velocity is limited 0.6 m/sec to 1.6 m/sec.
- In cold weather regions, there is chance of formation of ice in water, to prevent the entrance of ice into the penstocks trash racks heated with electricity and hence ice melts when it touches the trash racks.
- Other than trash racks, rakes and trolley arrangement which is used to clean the trash racks and penstock closing gates are also provided in intake structure.

Penstock

- Penstocks are like large pipes laid with some slope which carries water from intake structure or reservoir to the turbines. (Air tight)
- They run with some pressure so, sudden closing or opening of penstock gates can cause water hammer effect to the penstocks.
- So, these are designed to resist the water hammer effect apart from this penstock is similar to normal pipe.
- To overcome this pressure, heavy wall is provided for short length penstock and surge tank is provided in case of long length penstocks.
- Steel or Reinforced concrete is used for making penstocks. If the length is small, separate penstock is used for each turbine similarly if the length is big single large penstock is used and at the end it is separated into branches.

Surge Chamber

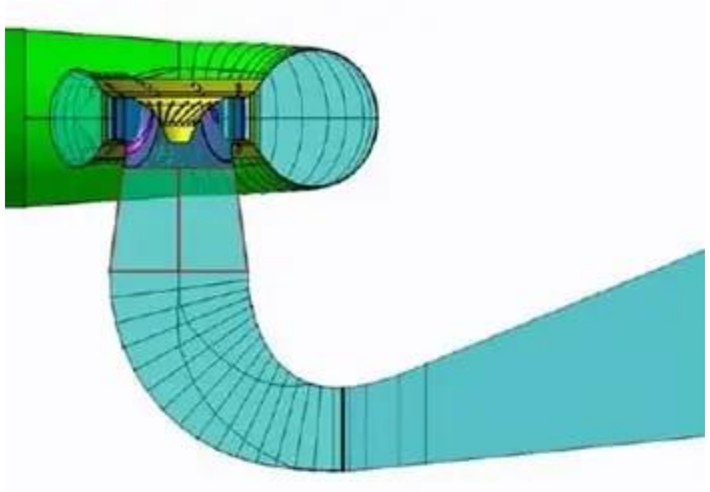
- A surge chamber or surge tank is a cylindrical tank which is open at the top to control the pressure in penstock.
- It is connected to the penstock and as close as possible to the power house.
- Whenever the power house rejected the water load coming from penstock the water level in the surge tank rises and control the pressure in penstock.
- Similarly, when the huge demand is needed in power house surge tank accelerates the water flow into the power house and then water level reduces. When the discharge is steady in the power house, water level in the surge tank becomes constant.
- There are different types of surge tanks available and they are selected based on the requirement of plant, length of penstock etc.

Hydraulic Turbines

- Hydraulic turbine, a device which can convert the hydraulic energy into the mechanical energy which again converted into the electrical energy by coupling the shaft of turbine to the generator.
- The mechanism in this case is, whenever the water coming from penstock strike the circular blades or runner with high pressure it will rotate the shaft provided at the center and it causes generator to produce electrical power.
- Generally hydraulic turbines are of two types namely
  - ✓ Impulse turbine
  - ✓ Reaction turbine
- Impulse turbine is also called as velocity turbine. Pelton wheel turbine is example for impulse turbine.
- Reaction turbine is also called as pressure turbine. Kaplan turbine and Francis turbine come under this category.

Draft Tube

- If reaction turbines are used, then draft tube is a necessary component which connects turbine outlet to the tailrace.
- The draft tube contains gradually increasing diameter so that the water discharged into the tailrace with safe velocity.
- At the end of draft tube, outlet gates are provided which can be closed during repair works.



Tailrace

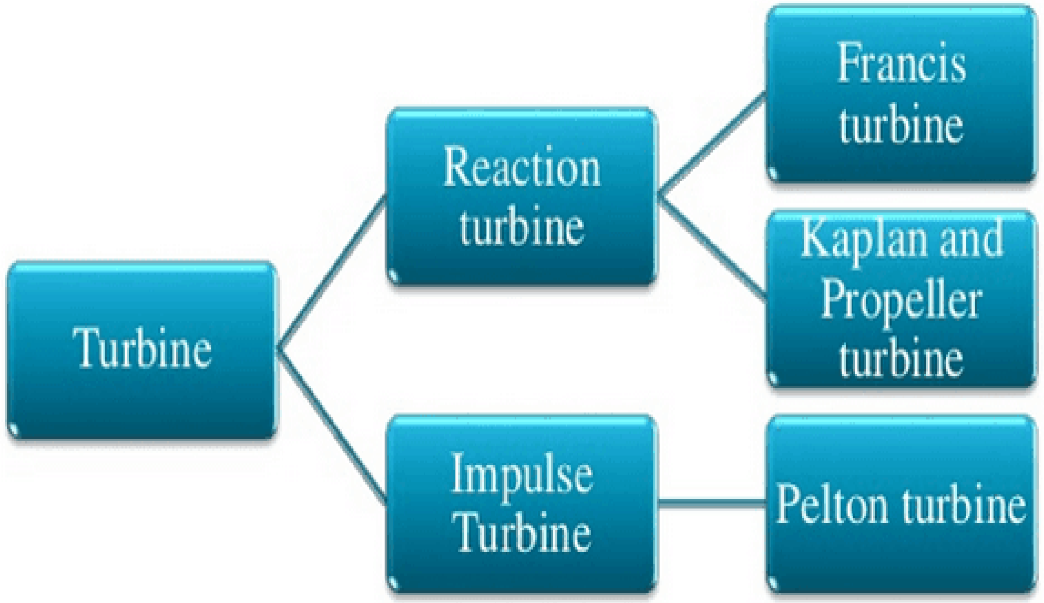
- Tailrace is the flow of water from turbines to the stream. It is good if the power house is located nearer to the stream.
- But, if it is located far away from the stream then it is necessary to build a channel for carrying water into the stream.
- Otherwise the water flow may damage the plant in many ways like lowering turbine efficiency, cavitation, damage to turbine blades etc.
- This is because of silting or scouring caused by unnecessary flow of water from power house.
- Hence, proper design of tailrace should be more important

Power House

- Power house is a building provided to protect the hydraulic and electrical equipment.
- Generally, the whole equipment is supported by the foundation or substructure laid for the power house.
- In case of reaction turbines some machines like draft tubes, scroll casing etc. are fixed with in the foundation while laying it.
- So, the foundation is laid in big dimensions.
- When it comes to super structure, generators are provided on the ground floor under which vertical turbines are provided.
- Besides generator horizontal turbines are provided. Control room is provided at first floor or mezzanine floor.

Hydraulic turbines

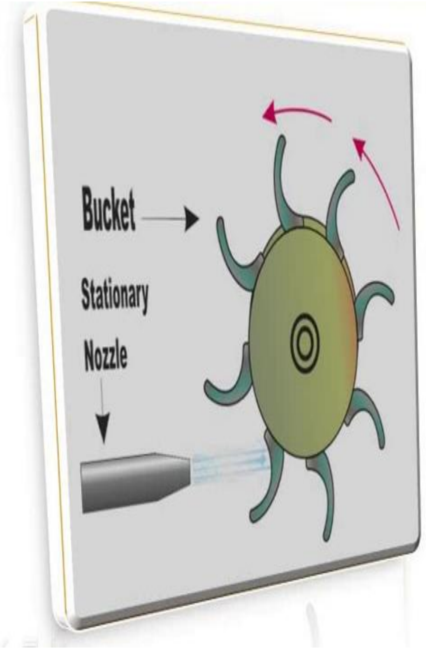
- The hydraulic turbine is a prime mover that uses the energy of flowing water and converts is into the mechanical energy in the form of rotation of the runner. (A prime mover is a machine which uses the raw energy of a substance and converts it into the mechanical energy.)
- Since the fluid medium is water, these turbines are also known as the ‘ water turbines’ .
- Hydraulic turbines coupled with hydro — generators form the so —called ‘ hydrounits’ which are widely used now a days for generating electrical power.

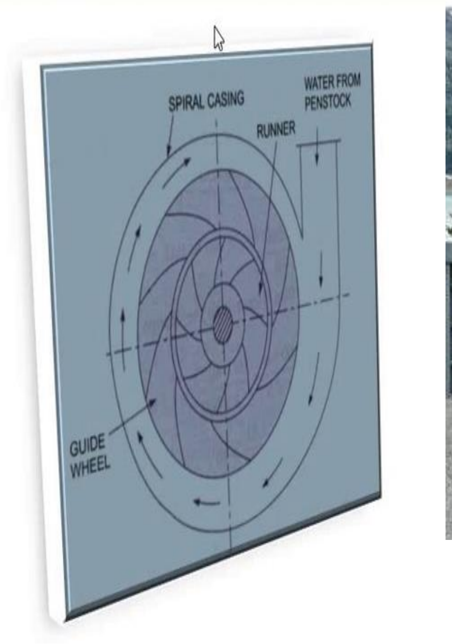


Classification of Hydraulic turbines:

Based on type of energy at inlet to the turbine:

- Impulse Turbine : The energy is in the form of kinetic form. e.g: Pelton wheel, Turbo wheel.
- Reaction Turbine: The energy is in both Kinetic and Pressure form. e.g:Tubular, Bulb, Propellar, Francis turbine.





Example Of Turbine Pelton Wheel

Based on direction of flow of water through the runner:

- Tangential flow: water flows in a direction tangential to path of rotational, i.e. Perpendicular to both axial and radial directions.
- Radial outward flow : e.g : Forneyron turbine.
- Axial flow : Water flows parallel to the axis of the turbine. e.g: Girard, Jonval, Kalpan turbine.
- Mixed flow : Water enters radially at outer periphery and leaves axially. e.g : Modern Francis turbine.

Based on the head under which turbine works:

High head, impulse turbine: e.g : Pelton turbine.
Medium head,reaction turbine: e.g : Francis turbine.
Low head, reaction turbine : e.g : Kaplan turbine, propeller turbine.

Type of turbine	Type of runner	Specific speed
Pelton	Slow Normal Fast	10 to 20 20 to 28 28 to 35
Francis	Slow Normal Fast	60 to 120 120 to 180 180 to 300
Kaplan	-	300 to 1000

Based on the specific speed of the turbine:

Low specific speed, impulse turbine. e.g : Pelton wheel.
Medium specific speed, reaction turbine.: e.g : Francis wheel.
High specific speed, reaction turbine. : e.g : Kaplan and Propeller turbine.

Based on the name of the originator

Impulse turbine : Pelton wheel, Girard, Banki turbine
Reaction turbine : orneyron, Jonval, Francis, Dubs, Deriaze, Thomson kalpan, Barker, Moody, Nagler, Bell.

Water turbines. Water turbines are used to convert the energy of falling water into mechanical
energy. The principal types of water turbines are :
(*i*) Impulse turbines **(*ii*)** Reaction turbines

(*i*) *Impulse turbines.* Such turbines are used for high heads. In an impulse turbine, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel. The example of this type of turbine is the Pelton wheel. It consists of a wheel fitted with elliptical buckets along its periphery. The force of water jet striking the buckets on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of a *needle* or *spear* (not shown in the figure) placed in the tip of the nozzle. The movement of the needle is controlled by the governor. If the load on the turbine decreases, the governor pushes the needle into the nozzle, thereby reducing the quantity of water striking the buckets. Reverse action takes place if the load on the turbine increases

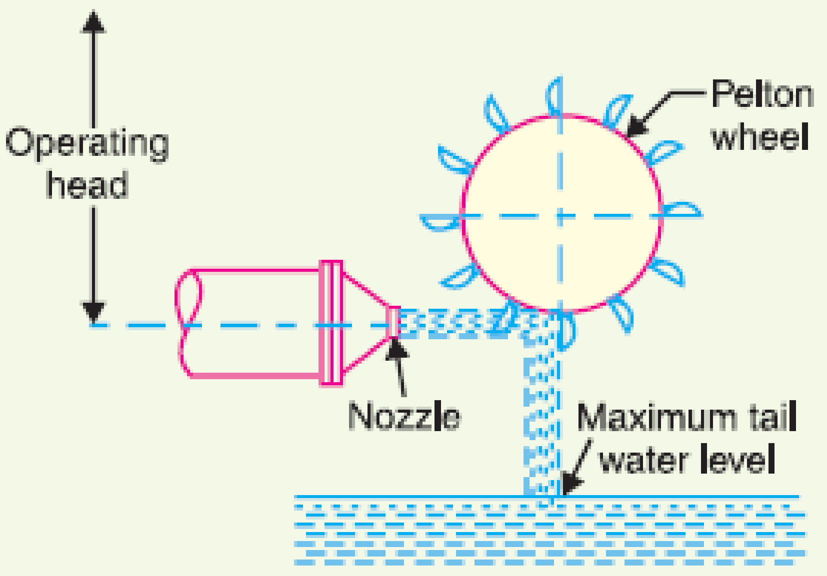


Fig. 2.4 Pelton Wheel

Reaction turbines. Reaction turbines are used for low and medium heads. In a reaction turbine, water enters the runner partly with pressure energy and partly with velocity head. The important types of reaction turbines are :

(*a*) Francis turbines **(*b*)** Kaplan turbines

A Francis turbine is used for low to medium heads. It consists of an outer ring of stationary guideblades fixed to the turbine casing and an inner ring of rotating blades forming the runner. The guide blades control the flow of water to the turbine. Water flows radially inwards and changes to a downward direction while passing through the runner. As the water passes over the "rotating blades" of the runner, both pressure and velocity of water are reduced. This causes a reaction force which drives the turbine.

A Kaplan turbine is used for low heads and large quantities of water. It is similar to Francis turbine except that the runner of Kaplan turbine receives water axially. Water flows radially inwards through regulating gates all around the sides, changing direction in the runner to axial flow. This causes a reaction force which drives the turbine.

Example: The weekly discharge of a typical hydroelectric plant is as under :

Day	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
Discharge(m_3/sec)	500	520	850	800	875	900	546

The plant has an effective head of 15 m and an overall efficiency of 85%. If the plant operates on 40% load factor, estimate (i) the average daily discharge (ii) pondage required and (iii) installed capacity of proposed plant.

Solution.

Fig. 2.5 shows the plot of weekly discharge. In this graph, discharge is taken along *Y*-axis and days along *X*-axis.

i. Average daily discharge$= \frac{500+520+850+800+875+900+546}{7}$

$$= \frac{4991}{7} = 713\, m^3 / \text{sec}$$

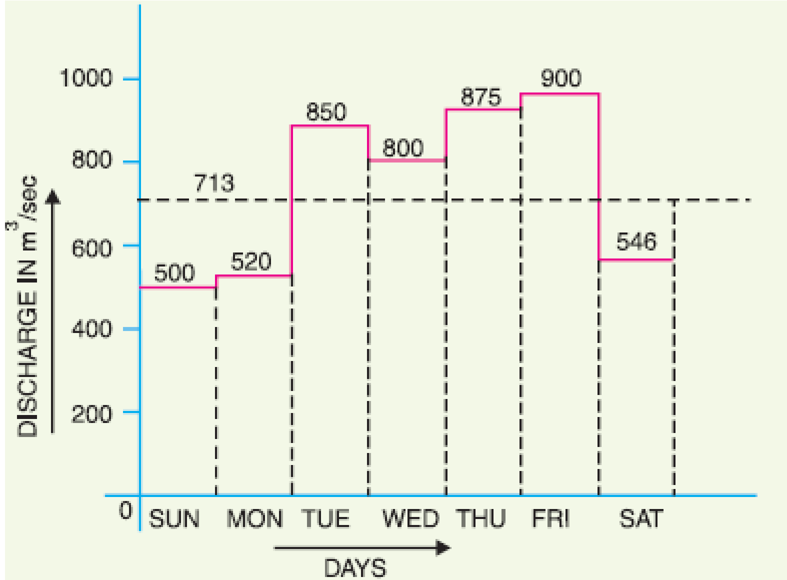


Fig. 2.5

(ii) It is clear from graph that on three dyas (*viz.*, Sun, Mon. and Sat.), the discharge is less than the average discharge. Volume of water actually available on these three days

= (500 + 520 + 546) ∗24 ∗3600 m^3 = 1566 ∗ 24 ∗3600 m^3

Volume of water required on these three days = 3 ∗713 ∗24 ∗ 3600 m^3 = 2139 ∗24 ∗ 3600 m^3

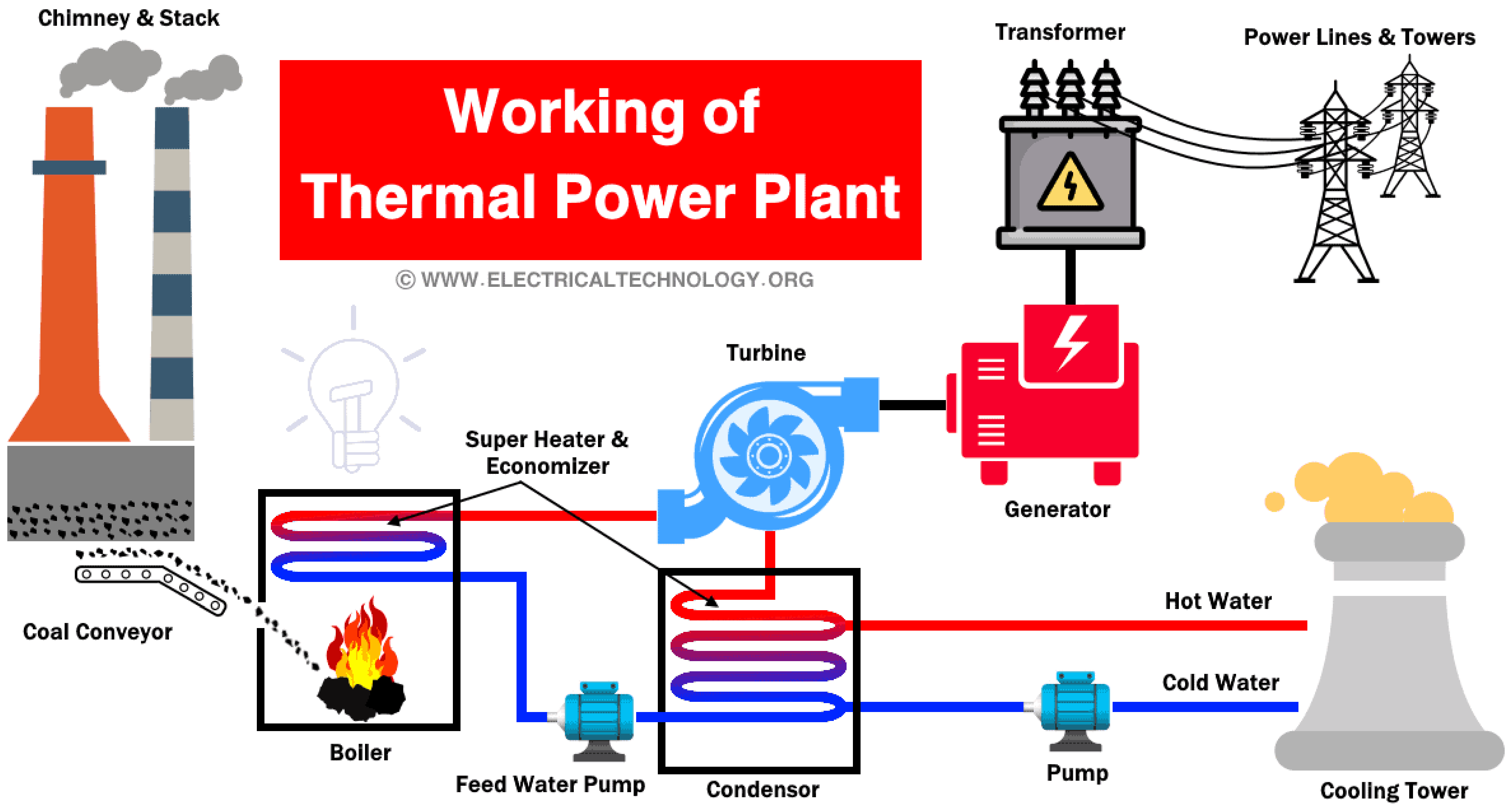
Pondage required = (2139 – 1566) ∗24 .∗ 3600 m^3 = **495 ∗10^5 m^3**

(iii) Wt. of water available/sec, *w* = 713 ∗ 1000 ∗ 9·81 N

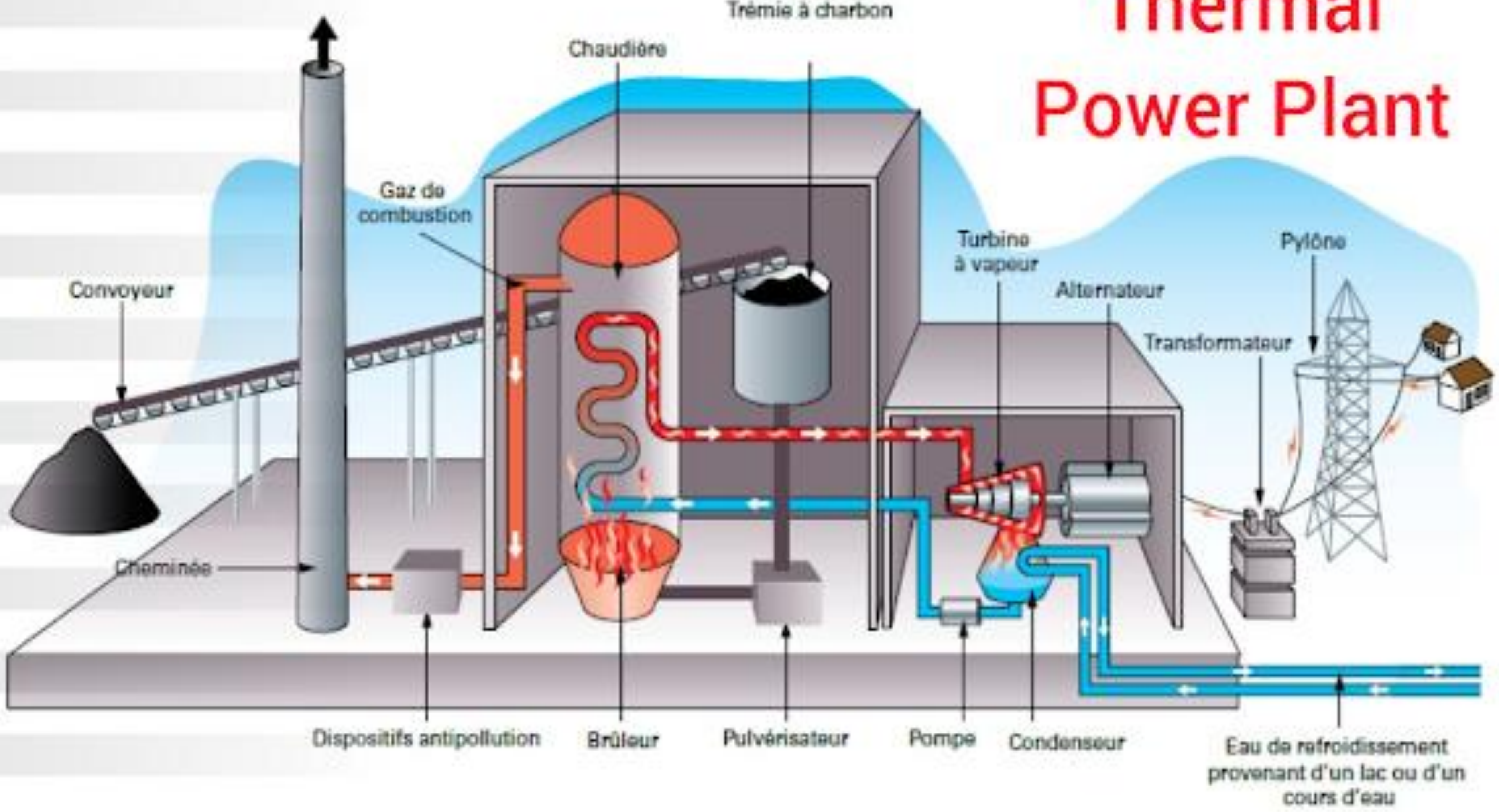
Average power produced = *w* . *H* . $\eta_{overall}$ = (713 ∗ 1000 ∗ 9·81) ∗(15) ∗ (0·85) watts

= 89180 . 10^3 watts = 89180 kW

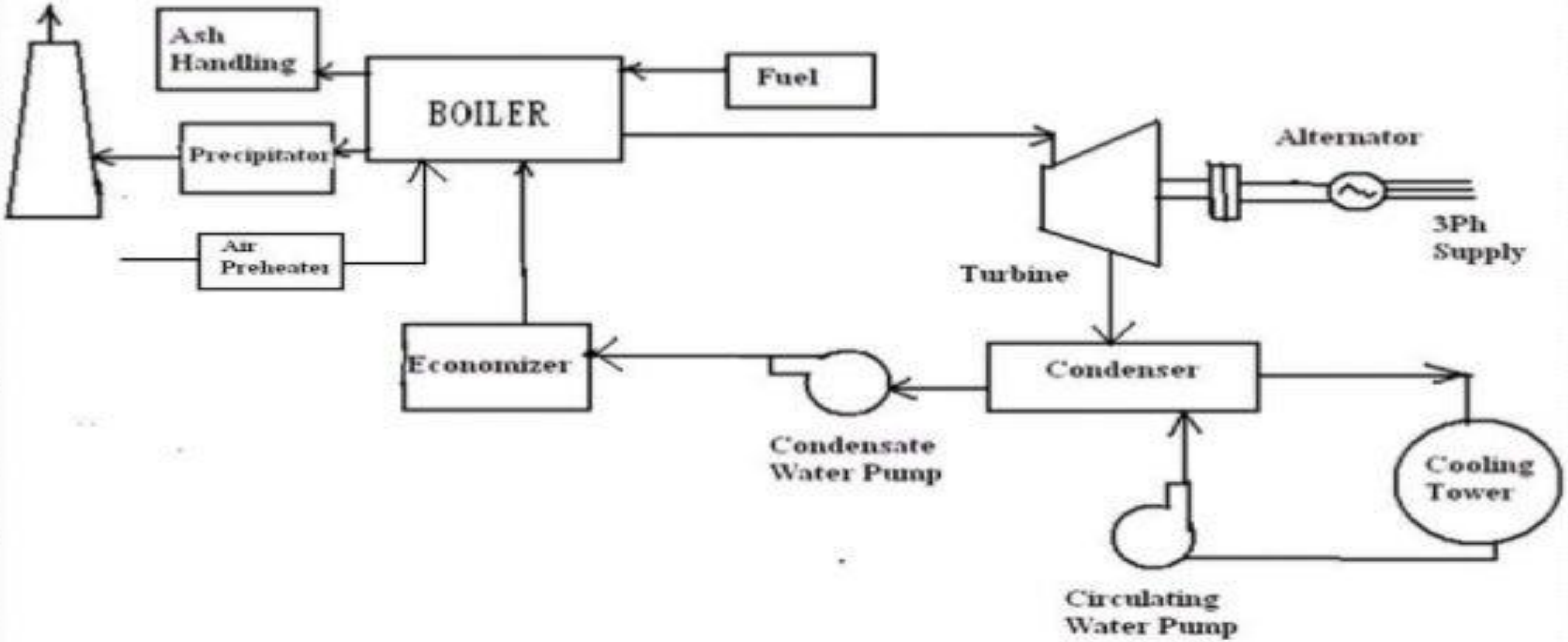
$$\text{Installed capacity of the plant} = \frac{\text{Output power}}{\text{Load factor}} = \frac{89180}{4} = 223 \times 10^3\, KW$$


Working of
Thermal Power Plant
© WWW.ELECTRICALTECHNOLOGY.ORG
Chimney & Stack
Transformer
Power Lines & Towers
Turbine
Generator
Super Heater &
Economizer
Coal Conveyor
Boiler
Feed Water Pump
Condensor
Hot Water
Cold Water
Pump
Cooling Tower

Thermal Power Plant



GENERAL LAYOUT OF THERMAL POWER PLANT



The whole arrangement of Thermal power plant can be divided into the following stages for the sake of simplicity :

1. Coal and ash handling arrangement : The coal is transported to the power station by road or rail and is stored in the coal storage plant. Storage of coal is primarily a matter of protection against coal strikes. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverised (*i.e.*, crushed into small pieces) in order to increase its surface exposure, thus promoting rapid combustion without using large quantity of excess air. The pulverised coal is fed to the boiler by belt conveyors. The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal. The removal of the ash from the boiler furnace is necessary for proper burning of coal.
2. Steam generating plant: The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilisation of flue gases.

(*i*) *Boiler*. The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure. The flue gases from the boiler make their journey through superheater, economiser, air pre-heater and are finally exhausted to atmosphere through the chimney.

(***ii***) *Superheater.* The steam produced in the boiler is wet and is passed through a superheater where it is dried and superheated (*i.e.*, steam temperature increased above that of boiling point of water) by the flue gases on their way to chimney. Superheating provides two principal benefits. Firstly, the overall efficiency is increased. Secondly, too much condensation in the last stages of turbine (which would cause blade corrosion) is avoided. The superheated steam from the superheater is fed to steam turbine through the main valve.

(***iii***) *Economiser.* An economiser is essentially a feed water heater and derives heat from the flue gases for this purpose. The feed water is fed to the economiser before supplying to the boiler. The economiser extracts a part of heat of flue gases to increase the feed water temperature.

(***iv***) *Air preheater.* An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air preheater before supplying to the boiler furnace. The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion. The principal benefits of preheating the air are : increased thermal efficiency and increased steam capacity per square metre of boiler surface.

3. Steam turbine: The dry and superheated steam from the superheater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy. After giving heat energy to the turbine, the steam is exhausted to the *condenser* which condenses the exhausted steam by means of cold water circulation.

4. Alternator: The steam turbine is coupled to an alternator. The alternator converts mechanical energy of turbine into electrical energy. The electrical output from the alternator is delivered to the bus bars through transformer, circuit breakers and isolators

5. Feed water : The condensate from the condenser is used as feed water to the boiler. Some water may be lost in the cycle which is suitably made up from external source. The feed water on its way to the boiler is heated by water heaters and economiser. This helps in raising the overall efficiency of the plant.

6. Cooling arrangement: In order to improve the efficiency of the plant, the steam exhausted from the turbine is condensed* by means of a condenser. Water is drawn from a natural source of supply such as a river, canal or lake and is circulated through the condenser. The circulating water takes up the heat of the exhausted steam and itself becomes hot. This hot water coming out from the condenser is discharged at a suitable location down the river. In case the availability of water from the source of supply is not assured throughout the year, *cooling towers* are used. During the scarcity of water in the river, hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser.

Efficiency of Steam Power Station

i. Thermal efficiency. The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of combustion of coal is known as **thermal efficiency** of steam power station.

$$\textit{Thermal efficiency}, \eta_{thermal} = \frac{\text{Heat equivalent of mech. energy transmitted to turbine shaft}}{\text{Heat of coal combustion}}$$

(ii) Overall efficiency. The ratio of heat equivalent of electrical output to the heat of combustion of coal is known as **overall efficiency** of steam power station i.e.

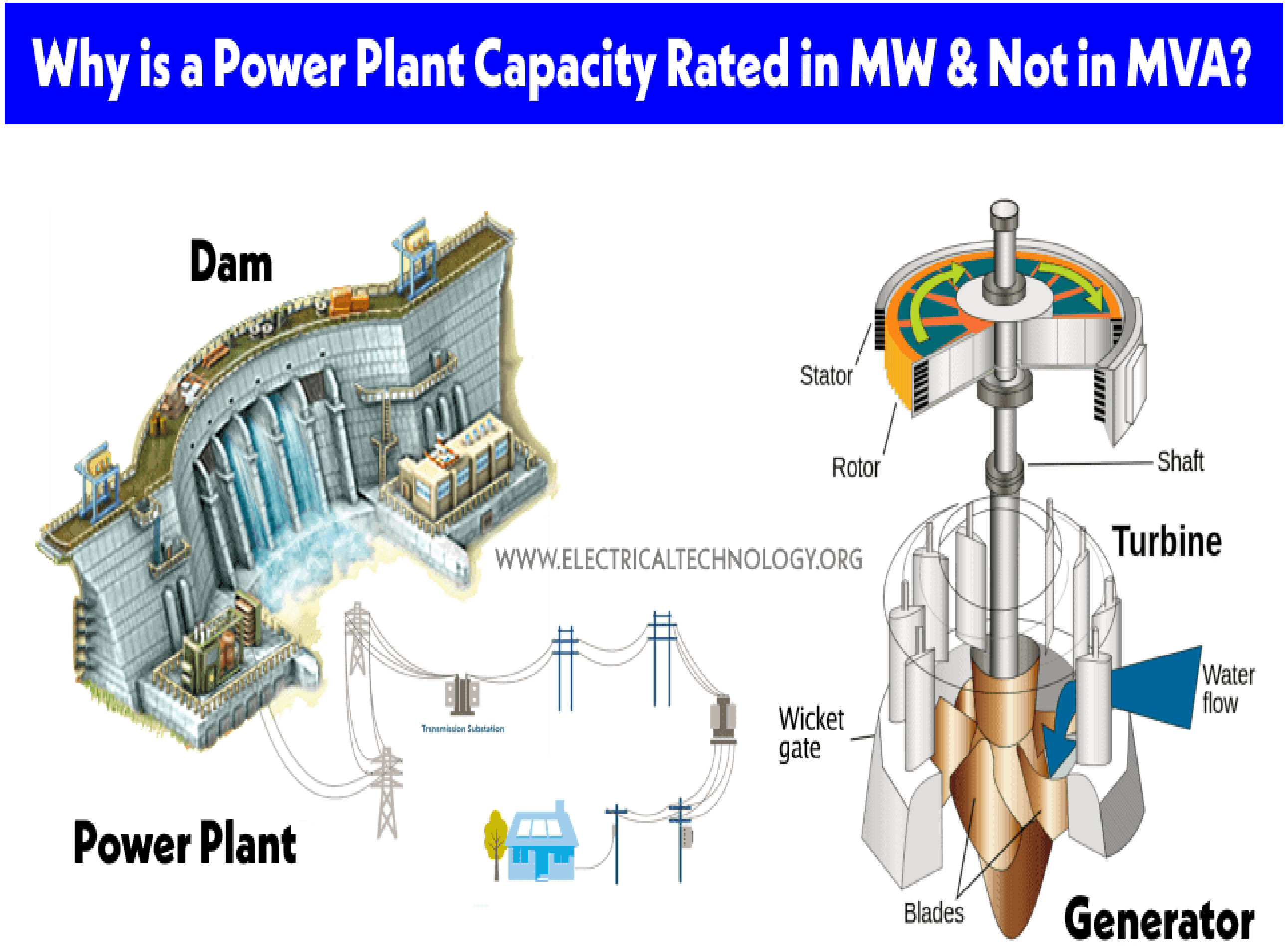
$$\text{Overall efficiency}, \eta_{\text{Overall efficiency}} = \frac{\text{Heat equivalent of electrical ouput}}{\text{Heat of combustion of coal}}$$

It may be seen that overall efficiency is less than the thermal efficiency. This is expected since some losses (about 1%) occur in the alternator. The following relation exists among the various efficiencies.

Overall efficiency = Thermal efficiency –Electrical efficiency

Relationship between MW capacity and fuel consumption

- In a generating station, the prime mover (turbine) generates only and only active power in Watts.
- A generator then converts the mechanical power into electrical energy i.e. Volt x Amps x Power factor which is further transmit and distribute in a typical power system scheme.
- That's why we express the rating of a a power plant capacity in MW instead of MVA.
- It means no matter how large your generator is, but it depends on the capacity of the engine (prime mover / turbine) i.e. a 50 MW turbine connected to a 90MVA alternator (which generates both active and reactive power) in a power plant will generate only 50MW at full load.



- Another thing is that, electric power companies charge their consumer for kVA (electricity bill) while they generate kW (or MW) at the power station (power plant).
- They penalize their consumer for low power factor because they are not responsible for low power factor and kVA but we responsible.
- Moreover, in a power plant, power factor is 1 therefore MW is equal to MVA …… (MW = MVA x P.F).

Steam Turbine

Definition:

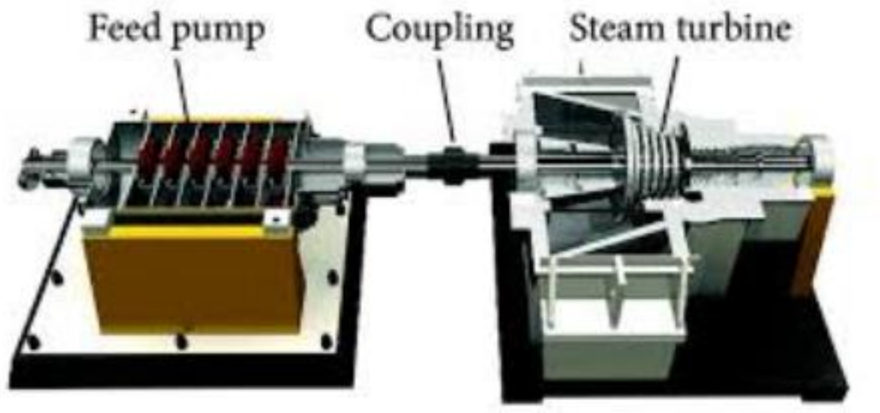
- Steam turbine comes under the classification of a mechanical machine that isolates thermal energy form the forced steam and converts this into mechanical energy.
- As the turbine produce rotatory motion, it is most appropriate for the operation of electrical generators.
- The name itself indicates the device is driven by steam and when the vaporous stream flows across the turbine's blades, then the steam cools and then expands thus delivering almost the energy that it has and this is the continual process.
- The blades thus transform the device potential energy to that of kinetic movement. In this way, the steam turbine is operated to supply electricity. These devices make use of enhanced pressure of steam to rotate electric generators at extremely more speeds where the revolving speed of these are maximum than water turbines and wind turbines.

Steam Turbine

A conventional steam turbine has a rotating speed of 1800-3600 revolutions per minute nearly 200 times more spins than that of a wind turbine.

Steam Turbine Working Principle

- The operating principle of this device is based on the dynamic movement of the steam.
- The increased pressure steam which comes out from the nozzles hits the revolving blades that are close-fitted to the disc which is placed on the shaft.
- As because of this increased velocity in the steam, it develops energetic pressure on the device blades where then the shaft and blades start to revolve in a similar direction.
- In general, the steam turbine isolates the energy of the stem and then transforms it into the kinetic energy which then flows through the nozzles.



- So, the transform of kinetic energy performs mechanical action to the rotor blades and this rotor has a connection with the steam turbine generator and this performs as the intermediary.
- Because the construction of a device is so streamlined, it generates minimal noise when compared to other kinds of rotating devices.
- In most of the turbines, the revolving blade speed is linear to that of the steam speed flowing across the blade.
- When the vapor gets expanded in the single-phase itself from that boiler force to the exhausted force, then the vapor velocity is extremely increased.
- Whereas the major turbine which is used in nuclear plants where the steam expansion rate is nearly 6 MPa to 0.0008 MPa having a rate of speed at 3000 revolutions per 50 Hz of frequency and 1800 revolutions at 60 Hz frequency.

Types of Steam Turbine

Steam turbines are classified based on many parameters and there are many types in this. The types to be discussed are as follows:

BASED ON THE STEAM MOVEMENT

Based on the steam movement, these are classified into different types which include the following.

- Impulse Turbine

Here, the extreme speed steam that flows out from the nozzle hits the rotating blades which are placed on the rotor periphery section. As because of striking, the blades alter their rotating direction having no change in the pressure values. The pressure caused because of momentum develops the rotation of the shaft. Examples of this kind are Rateau and Curtis turbines.

- Reaction Turbine

Here, the expansion of steam will be there in both the moving and constant blades when the stream flows across these. There will be a continuous pressure drop across these blades.

Advantages/Disadvantages

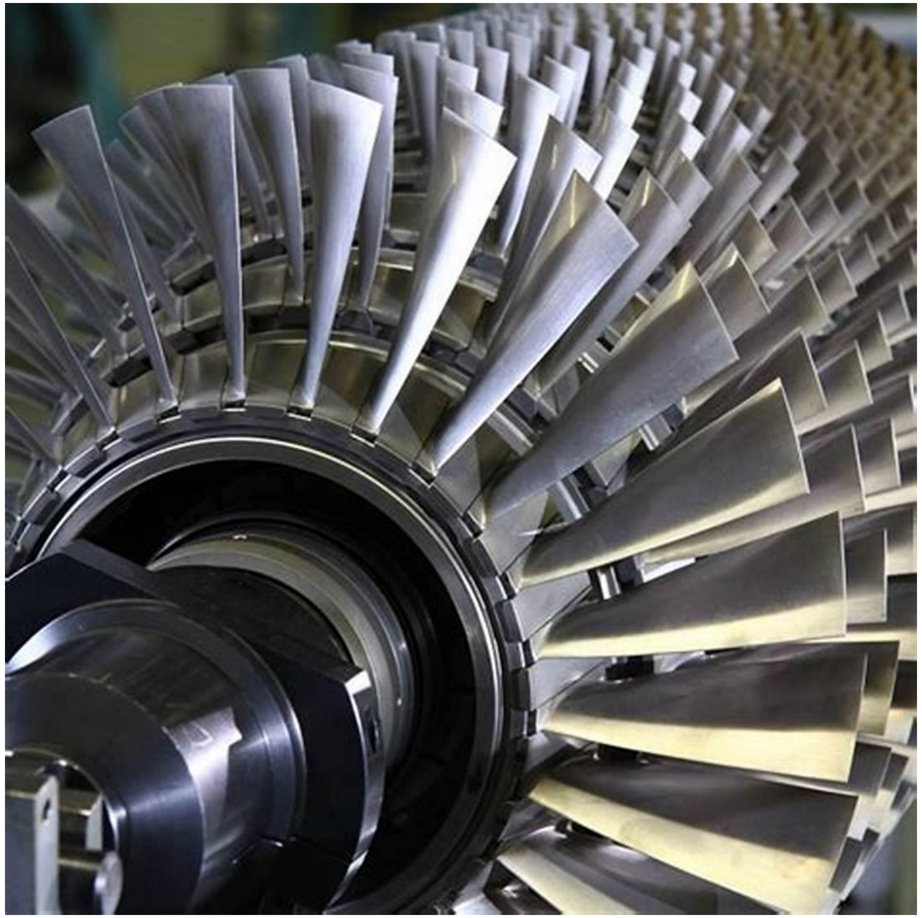
- The advantages of a steam turbine are

  High Efficiency

  They have high reliability

- The disadvantages of a steam turbine are

  Costly Installation and Maintenance



Applications of Steam Turbine :

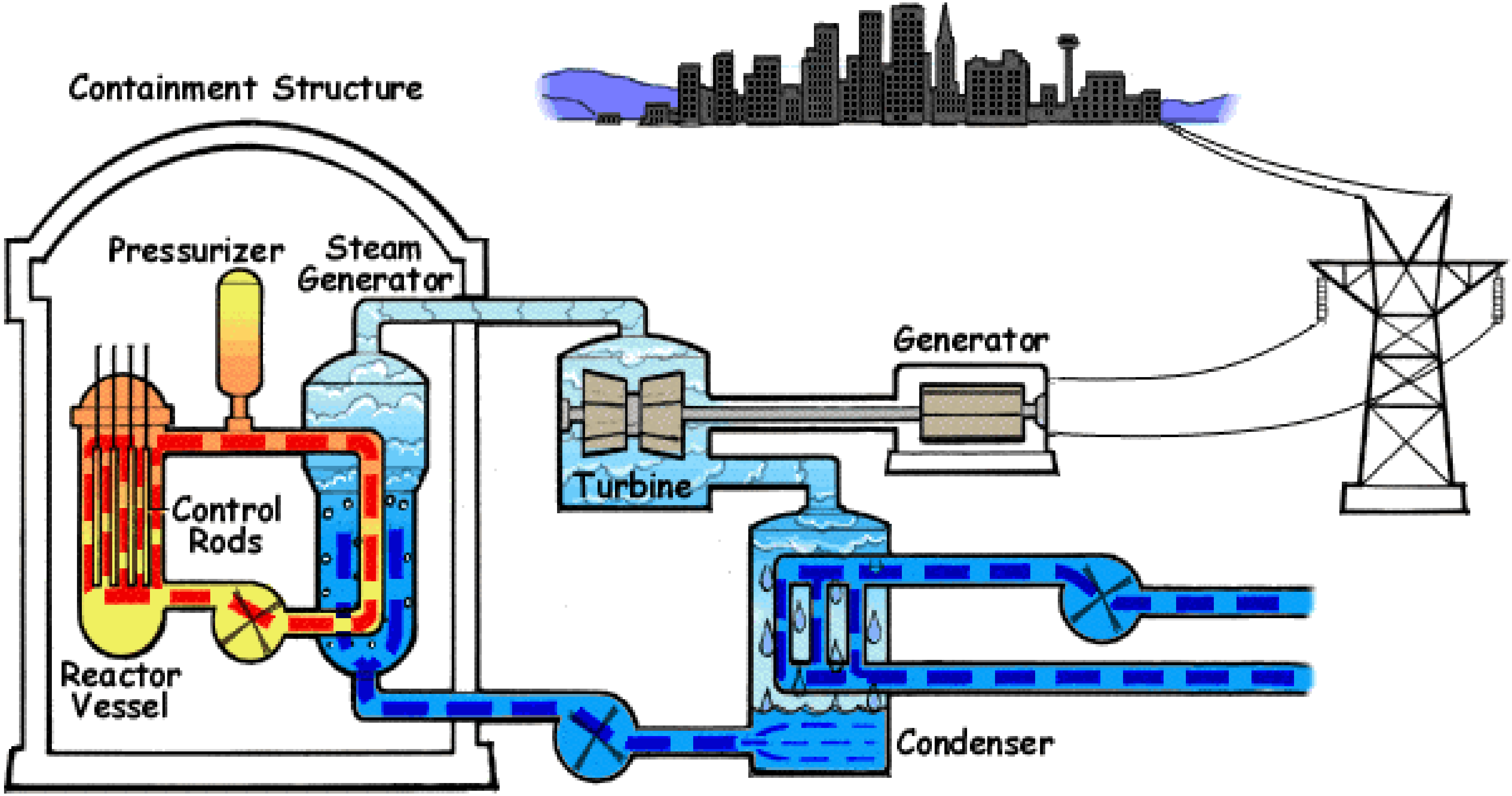
- Mixed pressure turbines
- Implemented in engineering domains
- Power generation tools

Nuclear Power Plant

- What is a Nuclear Power Plant?
  - A facility that generates electricity using nuclear reactions. A controlled nuclear reaction is used for making heat, which is used to produce steam needed to drive the turbines.
  - Nuclear energy is contained within the center of atoms (i.e. nucleus).
  - If nucleus of a large element e.g. uranium 235 is split apart into multiple nuclei of different element compositions, huge amounts of energy are released in the process.
  - This process is known as nuclear reaction and the heat emitted is used to produce steam for driving the turbine.

- Importance:
  - Provides a significant portion of global electricity.
  - Low greenhouse gas emissions.

Nuclear Power Plant

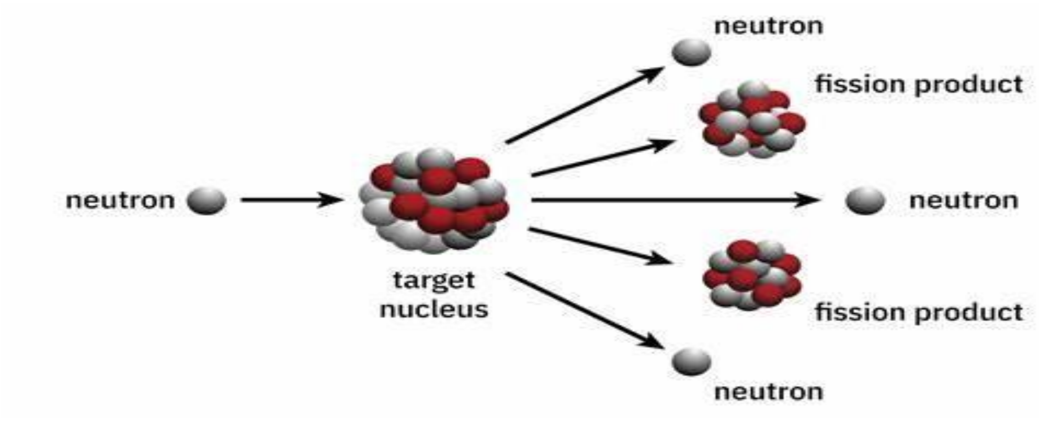


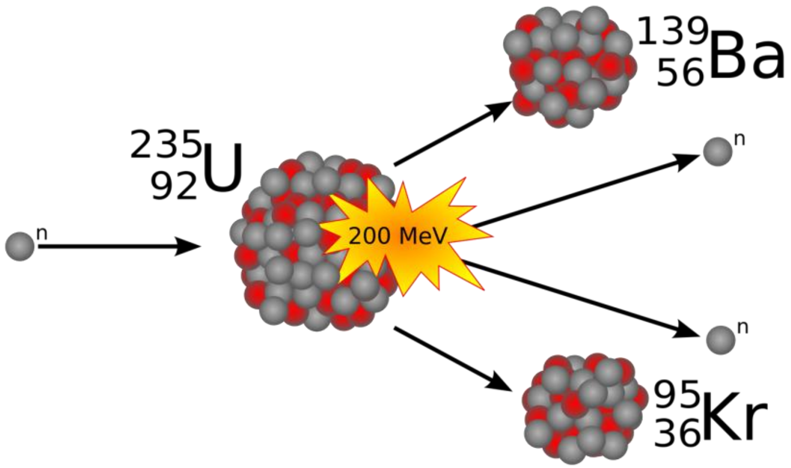
Components of a Nuclear Power Plant

1. Reactor Core:
   - Contains nuclear fuel (e.g., uranium).
   - Site of nuclear fission reactions.
2. Moderator:
   - Slows down neutrons for efficient fission (e.g., water, graphite).
3. Coolant:
   - Transfers heat from the reactor core.
4. Turbine and Generator:
   - Converts thermal energy into electrical energy.
5. Containment Structure:
   - Ensures safety by enclosing radioactive materials.

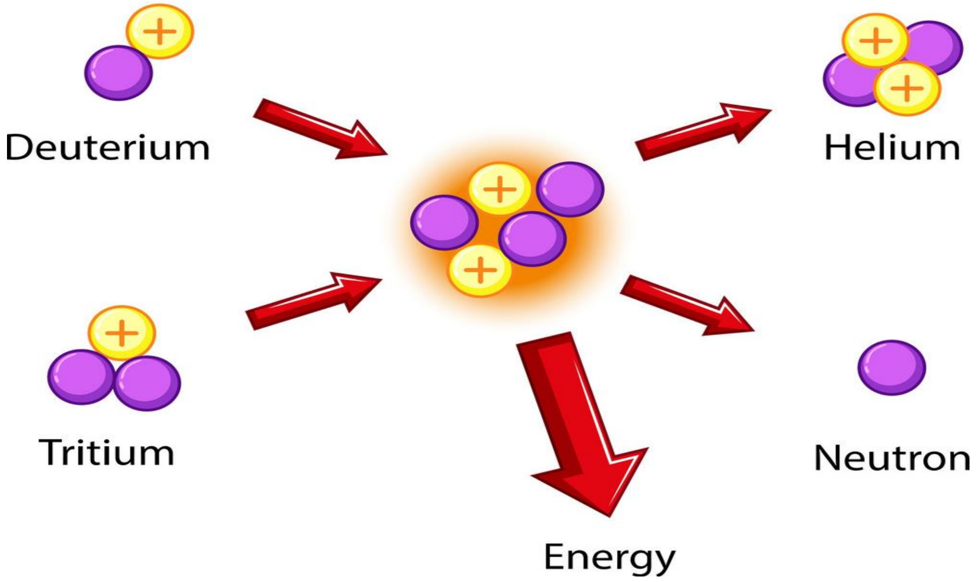
Two methods to produce Nuclear Energy:

Fission : It is splitting of large nuclei atoms such as uranium inside a nuclear reactor.





Fusion : It is combining of small nuclei atoms into larger ones.



Nuclear Fission in Power Plant

- Splitting of heavy elements when struck by a neutron is called fission.
- When heavy elements split they release energy (heat) and also provide additional neutrons as by products.
- These additional neutrons can be used for a chain reaction.
- In electrical power plant there is controlled release of energy where as in a atomic bomb there is uncontrolled release.

Reactor Core

- Reactor core contains the fuel in cylindrical tubes.
- The tubes are arranged in groups to make a fuel assembly and a group of fuel assemblies forms the reactor core.
- Suitable fuel is U 235as it is readily split and releases large amounts of heat energy.
- Nuclear reactors must control the amount of neutrons released in this reaction.
- The chain reaction can be controlled by using control rods.
- Control rods are made up of material (cadmium or boron) which can quickly absorb neutrons.
- The output power of the plant is controlled by the control rods

Types of Nuclear Reactors

1. Pressurized Water Reactor (PWR):
   - Uses water as a coolant and moderator.
2. Boiling Water Reactor (BWR):
   - Water boils in the reactor core to generate steam.
3. Fast Breeder Reactor (FBR):
   - Produces more fissile material than it consumes.

Advantages

- High Energy Output:
  - 1 kg of uranium = Energy from 10,000 kg of fossil fuel.
- Low Carbon Emissions:
  - Reduces greenhouse gas impact.
- Reliable:
  - Operates continuously for long periods.

Challenges

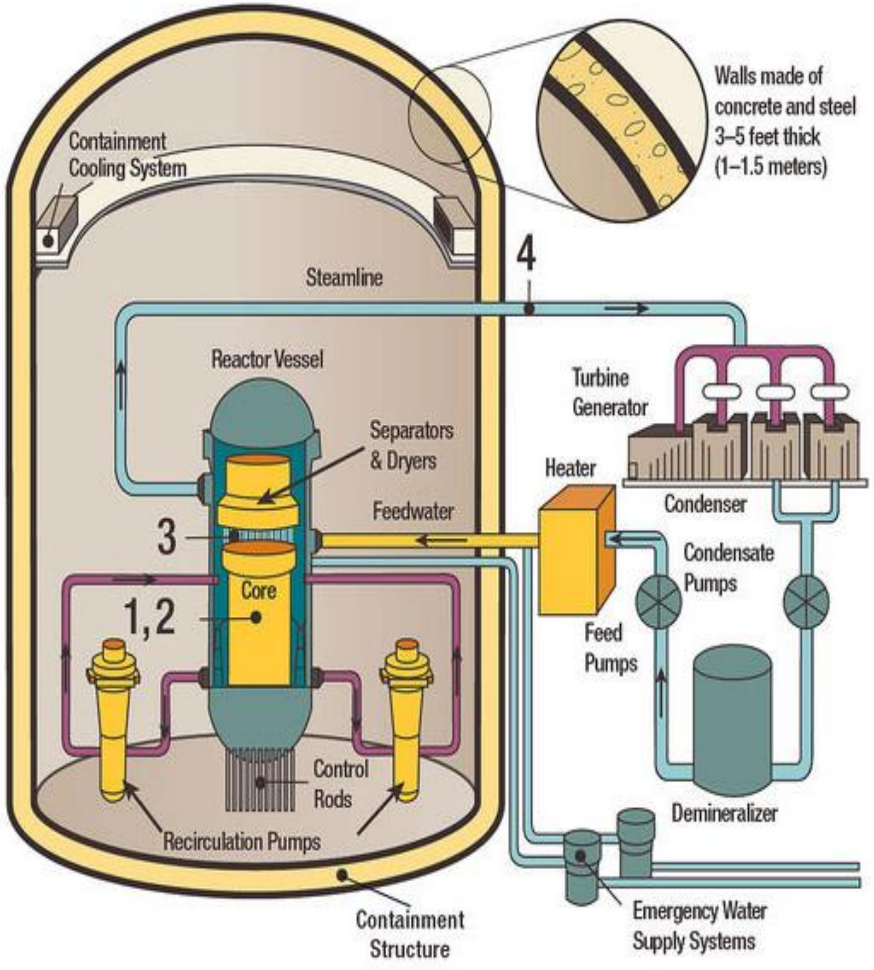
- Radioactive Waste:
  - Requires safe and long-term disposal.
- High Initial Cost:
  - Construction and decommissioning expenses.
- Safety Concerns:
  - Risks of accidents (e.g., Chernobyl, Fukushima).

Nuclear Safety Measures

1. Multiple Safety Systems:
   - Redundant cooling systems.
2. Emergency Shutdown:
   - Automatic scram systems.
3. Containment Design:
   - Structures to withstand extreme conditions.
4. Regular Inspections and Maintenance:
   - Ensures operational safety.

Boiling Water Reactor (BWR)

- A boiling water reactor (BWR) is second most common after the pressurized water reactor (PWR).
- It accounts for approximately 22% of the reactors installed in nuclear power plants worldwide.
- Designed primarily for electricity generation, the BWR uses light water as both a neutron moderator and core coolant.
- One of its particularities is that it operates with a single water circuit, in contrast to PWR reactors, which require separate primary and secondary circuits.
- Furthermore, because it operates at lower pressures, the BWR does not require as robust a casing as the PWR, which simplifies some aspects of its design.
- However, unlike the PWR, the BWR does not have a steam generator, which influences its configuration and operation.



Operation of a Boiling Water Reactor

- Fuel: enriched uranium oxide
- Ordinary water is used both as moderator and coolant.
- Feed water enter vessel at the bottom and heat produced by fission and converted into steam.
- This steam leaves reactor at top and passing through the condenser and return to reactor.
- The boiling water reactor uses a single cooling circuit, so the steam that drives the turbine is made up of water that has passed through the interior of the reactor.
- For this reason, the turbine building must be protected to avoid radioactive emissions.

Main features of a reactor (BWR)

- Direct steam generation
  - Unlike other types of reactors, such as the pressurized water reactor (PWR), in the BWR the water is heated directly inside the reactor core until it reaches its boiling point.
  - This means that the steam that drives the turbines to generate electricity comes directly from inside the reactor.
  - This design eliminates the need for a secondary circuit, simplifying heat transfer.
- Using water as a coolant and moderator

The reactor uses light water (H_2O) for two essential functions:

  - Coolant: Absorbs heat generated during nuclear fission.
  - Moderator: Reduces the speed of neutrons, allowing them to be more effective in causing new fissions.

This ensures that the chain reaction is sustainable and controlled.

- Relatively low operating pressure
  - Water boils inside the reactor at a lower pressure than in other reactors such as the PWR.
  - This translates into safer operating conditions and lower demands on construction materials.
- Direct interaction of steam with turbines
  - The steam generated in the core travels through a circuit directly to the turbines.
  - There, its kinetic energy is transformed into mechanical energy and then into electrical energy by a generator.

Since there is no intermediate heat exchange, the system has less energy losses.

- Power control system

The reactor power is regulated by:

  - The movement of the control rods, which absorb neutrons to slow the chain reaction.
  - Adjusting the flow of water through the core, which affects the amount of steam produced.
  - This system allows for rapid and precise regulation of the energy generated.

- Radioactive contamination in the primary circuit
  - Since the steam comes directly from the reactor core, it may contain small amounts of radioactive material.
  - For this reason, the entire circuit carrying the steam must be carefully shielded and monitored.

- Advanced security design
  - Although BWRs are simpler in design than other reactors, they include multiple safety systems, such as emergency cooling systems, primary and secondary containment to prevent the release of radioactive materials.

Advantages and disadvantages of boiling water reactor

Compared to other types of reactor, BWRs have the following strengths and weaknesses:

Advantages

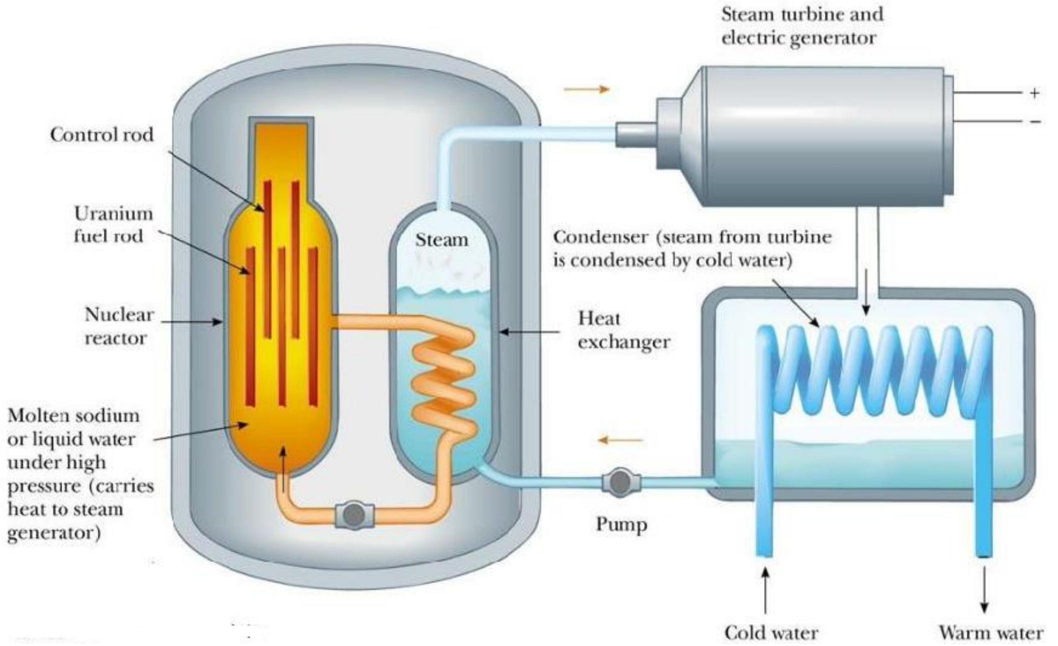
1. The nuclear fuel used by the nuclear reactor is uranium oxides enriched between 2% and 4%.
2. The boiling water reactor does not use steam generators or pressure compensators.
3. The first reactor circuit operates at a pressure of 70 atmospheres compared to 160 atmospheres used by PWR reactors (pressurized water reactor).
4. Requires lower operating temperatures, even in the fuel rods.
5. Due to the rejection of neutron absorption in boron and a slightly weaker neutron moderation (due to steam), the operating time of plutonium in such a reactor will be longer than in the PWR.
6. The pressure vessel is subjected to less irradiation than in a pressurized water reactor. For this reason, it does not become as brittle with age.

Disadvantages

1. Impossibility of reloading nuclear fuel without stopping the nuclear reactor.
2. More complicated management.
3. The control rods must be introduced from below. In the event of a power loss, they would not be able to fall into the reactor due to gravity and the reactor would not be shut down.
4. Need for more feedback sensors.
5. A reactor vessel approximately 2 times larger in volume than a PWR of comparable power is required.
6. Although it is designed for lower pressure, it is more difficult to manufacture and transport.
7. Turbine contamination with water activation products: short-lived N-17 and traces of tritium. This makes maintenance work considerably more complicated.
8. Once the control rods are fully inserted, the reaction stops. However, the nuclear fuel continues to emit heat. This means that once the reactor is shut down, coolant must continue to be pumped in for one to three years to keep it safe.

Pressurized Water Reactor

- Pressurized Water Reactor uses enriched U as fuel.
- It is currently the most widely used type of nuclear reactor in nuclear power plants worldwide in order to generate electric power.
- There are more than 230 nuclear reactors worldwide built up with this system.
- The first purpose of the PWR model was to use it in a nuclear submarine.
- Pressurized water reactors (PWR) use enriched uranium as nuclear fuel.



The pressurized water reactor (PWR) Working:

- It is a thermal reactor, using enriched uranium oxide, clad in zircalloy as fuel.
- Water under pressure is used as coolant and moderator.
- The hot water from reactor flows to heat exchanger where its heat is transferred to feed water to generate steam.
- The secondary cooling operates at low pressure . The primary coolant then flows from the heat exchanger to primary circulating pump which its back to reactor.
- The steam is condensed in a condenser and condensate steam returns to heat exchanger forming a closed circuit.
- In case pressure of primary circuit is too high then water is sprayed into steam in pressurizer.

PWR reactor advantages:

- PWR-type reactors are very stable due to their tendency to reduce their power when the temperature increases.
- PWRs can be operated with a core that contains less fissile material than is necessary to reach the prompt critical conditions with instantaneous neutrons.
- It reduces the possibility of the reactor having an uncontrolled power surge making it safer.
- PWRs can use ordinary water as a moderator instead of requiring heavy water.

PWR nuclear reactor disadvantages:

- The water in the primary cooling system must be highly pressurized to keep the water in the liquid phase.
- However, it increases construction costs and the risk of an accident with the loss of refrigerant from the primary system.
- PWRs cannot change spent fuel while they are operating.
- Hot water from the primary with dissolved boric acid is corrosive to stainless steel, causing corrosion products (which are radioactive) to circulate through the primary circuit.
- It limits the reactor's useful life and requires unique systems for filtering corrosion products.
- Ordinary water is more absorbing of neutrons than heavy water.
- Therefore when using regular water as a moderator, it is necessary to use enriched uranium as fuel, which increases fuel cost.
- Since water acts as a neutron moderator, building a fast reactor with a PWR design is impossible.

Fast Breeder Reactor (FBR)

Breeding – The process of producing fissionable material from a fertile material such as Uranium 238 (U_{238}) and thorium 232 (Th_{232}) by neutron absorption is known as breeding.

$$U^{238} + \text{neutron} \longrightarrow Pu^{239}$$

$$Th^{232} + \text{neutron} \longrightarrow U^{233}$$

Pu^{239} and U^{233} are fissionable materials and can be used in chain reaction.

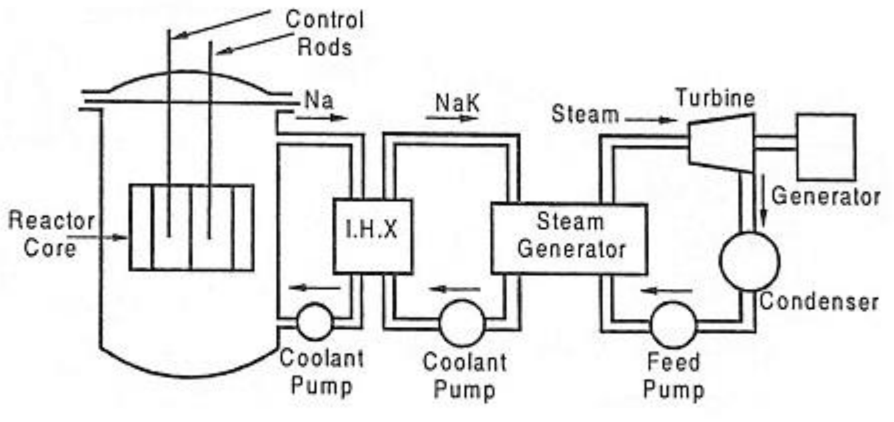


Fig:3.11 Fast Breeder Reactor

- In this Fast Breeder Reactor (FBR) system, the core containing U^{235} is surrounded by a blanket of ferrite material U^{238}.
- In this reactor, no moderator is used. The fast moving neutrons liberated due to fission of U^{235} are absorbed by U^{238} which gets converted fissionable material Pu239 which is capable of sustaining chain reaction.
- Thus, the reactor is very important because it breeds fissionable materials from fertile material U^{238} available in large quantities.
- In fast breeder reactor neutron shielding is provided by using Boron, light water, or graphite.
- The efficiency obtained by liquid sodium is about 42% whereas with other coolant it is 28%.

- This reactor system uses two liquid metal coolant circuits. Liquid sodium is used as primary coolant when circulated through the tubes of Intermediate Heat Exchanger (IHX) and transfers its heat to secondary coolant sodium potassium alloy.
- The secondary coolant transfers its heat to feed water while flowing through the tubes of steam generator.
- Considering safety and thermal efficiency, fast breeder reactors are better than conventional reactors.

The following coolants are commonly used for fast breeder reactors.

- Liquid metal (Na (or) NaK)
- Helium (He)
- Carbon dioxide.
- Sodium has the following advantages.
- Sodium has very low absorption cross-sectional area.
- Sodium possesses good heat transfer properties at high temperature and low pressure.
- Sodium does not react any of the structural materials used in primary circuits.

India has started **'core loading'** (process of placing nuclear fuel into the reactor's core) at its first Fast Breeder Reactor in Kalpakkam, Tamil Nadu. This is part of a three-stage nuclear program aimed at using thorium for nuclear power. The reactor transforms non-fissile material into fissile material, which can be used to generate electricity.

Heavy Water Reactor (PHWR)

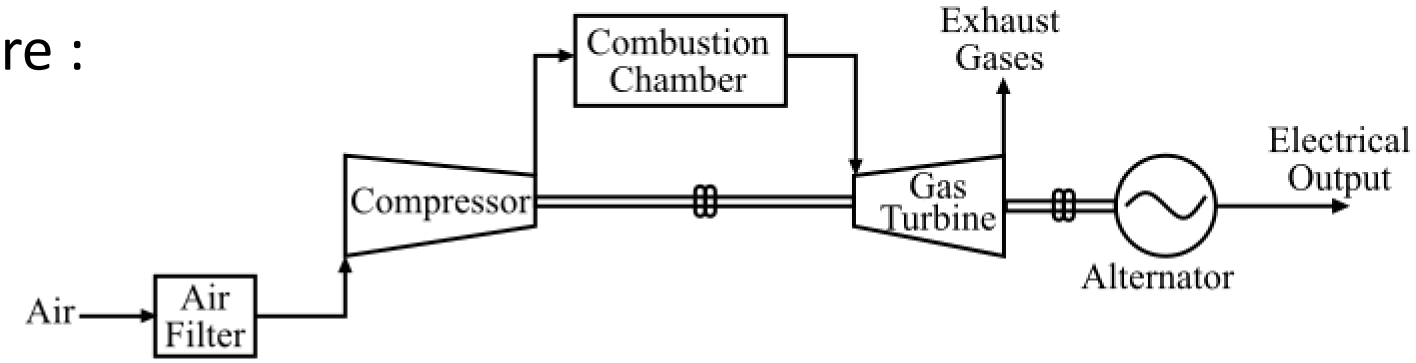
- Heavy water (D2O) is used as both the coolant and the moderator.
- It exhibits excellent moderation properties and in comparison to ordinary water.
- This enables the use of natural unenriched uranium as the fuel.
- The water pressure in the primary circuit is 9.3 MPa and the temperature is 300 °C.
- The moderator must be cooled because with increasing temperatures, its moderation properties worsen.
- The coolant transfers its energy to ordinary water in a steam generator and the generated steam then drives a turbine.

Gas Turbine Power Station

The schematic arrangement of a gas turbine power plant is shown in Figure .

The main components of plants are :

- Compressor Regenerator
- Combustion Chamber
- Gas Turbine
- Alternator
- Starting motor



Atmospheric air is drawn into the compressor and compressed to high pressure. The compressed air is supplied to the combustion chamber where heat is added to the air by burning the fuel and raising its temperature. The hot gas coming out from the combustion chamber is then passed to the turbine where it expands doing mechanical work.

The gas turbine power stations are primarily used as the standby power plants for hydroelectric power plants for driving auxiliaries in the power plants at starting.

Advantages of Gas Turbine Power Plant

A gas turbine power plant has following chief advantages –

- The design and layout of a gas turbine power plant is quite simple than a thermal power plant since no boilers and their auxiliaries are needed.
- As a gas turbine power station does not require boilers, feed water arrangement, etc. For this reason, it is much smaller in size than a thermal power plant of the same generating capacity.
- A gas turbine power plant requires less water as compared to a thermal power plant since no condenser is used.
- The capital and running costs are much lower than that of a thermal power plant of the same generating capacity.
- The maintenance cost is also quite small.
- The construction and operation of a gas turbine are much simpler than that of a steam turbine.
- In a gas turbine power plant, there are no standby losses.
- A gas turbine power plant can be put into operation quickly from the cold conditions.

Disadvantages of Gas Turbine Power Plant

The disadvantages of a gas turbine power plant are given as follows –

- The overall efficiency of a gas turbine power plant is very low, about 20%, because the exhaust gases from the turbine contain sufficient heat.
- The temperature of the combustion chamber is very high (about 1700 °C). Hence, its life is comparatively reduced.
- There is a problem in starting the gas turbine power plant since before starting the gas turbine, the compressor has to be operated for which power is needed from some external source.
- Although, once the plant is started, the external power is not required because the turbine itself supplies the necessary power to the compressor.
- For a gas turbine power plant, the net output of the plant is very low. It is because a greater part of the power developed by the turbine is used in driving the compressor.

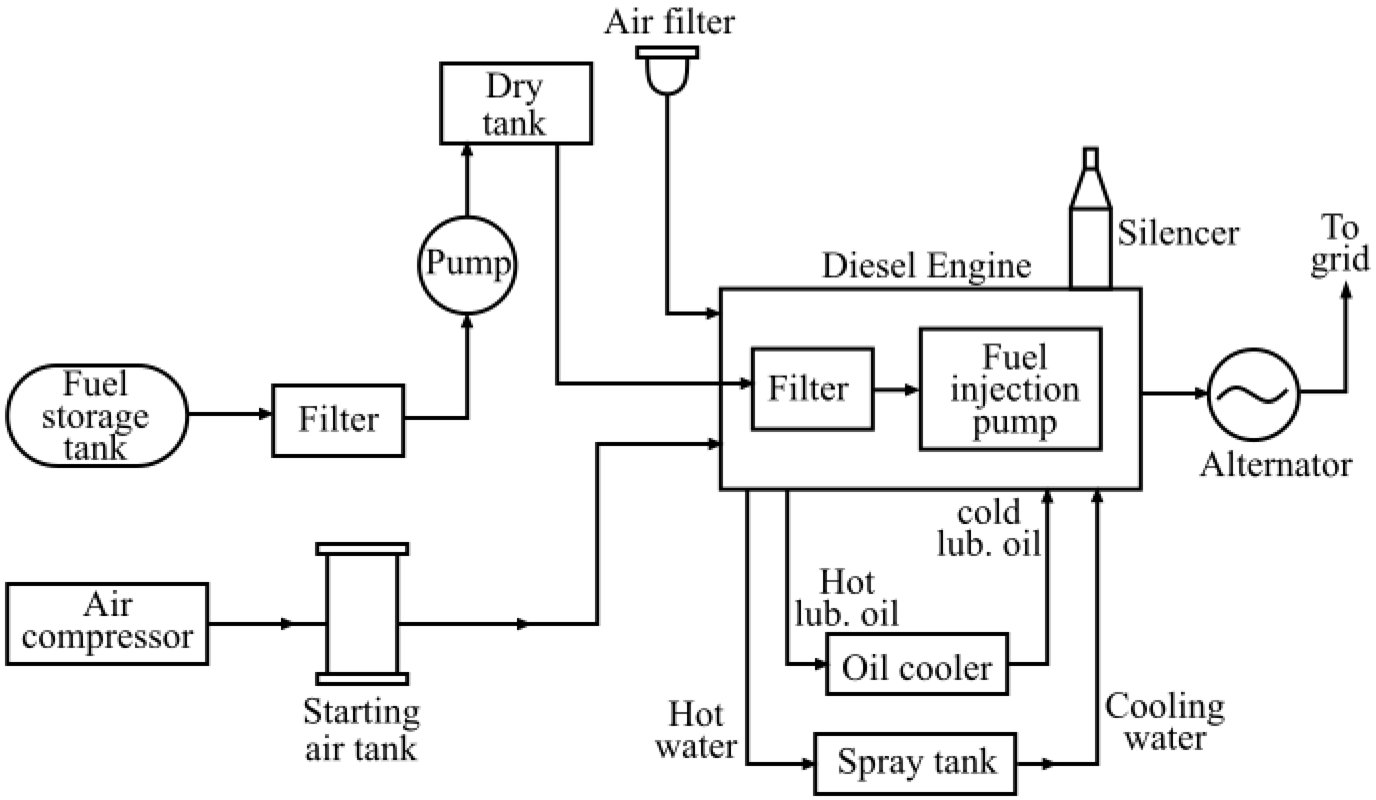
Diesel Power Plant

An electric power generating station in which the chemical energy of diesel is converted into electrical energy is known as **diesel power plant**. In other words, the diesel power plant is a power generating plant in which diesel engine is used as the prime mover for the generation of electrical energy.

Working of Diesel Power Plant

In a diesel power plant, the diesel engine is used as the prime mover to drive an alternator. The diesel (fuel oil) burns inside the engine and the products of this combustion acts as the working agent to produce mechanical energy. The diesel engine drives an electric generator which converts the mechanical energy into electrical energy.

Due to high cost of diesel, the diesel power plants are only used to produce small power. The diesel power plants are used at such places where demand of power is less and sufficient quantity of coal and water is not available. The diesel power plants are also used as standby sets for supplying power to important points such as hospitals, cinema halls, telephone exchanges, etc.



Advantages of Diesel Power Plant

The primary advantages of a diesel power plant are given as follows −

- The layout of a diesel power plant is quite simple.
- A diesel power plant requires less space because the number and size of its auxiliary equipment is small.
- A diesel power plant can be started quickly and it can pick up the load in a short time.
- A diesel power plant requires less water for cooling.
- For the same capacity, the overall cost of a diesel power plant is much less than that of a thermal power plant.
- For the same capacity, the thermal efficiency of a diesel power plant is higher than that of a thermal power plant.
- A diesel power plant requires less staff for the operation.
- A diesel power plant can be installed at any place.
- A diesel power plant does not have any standby losses.

Disadvantages of Diesel Power Plant

Following are some disadvantages of a diesel power plant −

- As the diesel (fuel oil) is costly, thus the diesel power plant has high running cost.
- The diesel power plant can only be used to generate small power.
- The cost of lubrication of a diesel engine is generally high.
- The diesel power plant does not work satisfactorily under overload conditions for a long period of time.
- The maintenance cost of a diesel power plant is generally high.