



**SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES.  
(AUTONOMOUS)  
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING  
NBA ACCREDITED**

# **LECTURE NOTES**

**Subject Name: POWER SYSTEMS-I / 23EEE243**  
**Year / Branch : II Year /EEE**  
**Regulation : R23**  
**Prepared By : Dr.V. Maheswari**



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**23EEE243**

**POWER SYSTEMS-I**

**L T P C**  
**3 0 - 3**

**PRE-REQUISITE:** Basic electrical engineering

**COURSE EDUCATIONAL OBJECTIVES:**

1. Understand the different types of power plants, operation of power plants
2. Understand the concepts of distribution systems, underground cables, economic aspects and tariff
3. Understand various substations that are located in distribution systems
4. Apply the above concepts to illustrate different power generation layouts
5. Analyze various economic aspects related to power generation and distribution

**UNIT-I: HYDROELECTRIC AND THERMAPOWER STATIONS:**

**(09)**

Selection of site, general layout of a hydroelectric power plant with brief description of major components and principle of operation. Selection of site, general layout of a thermal power plant. Brief description of components: boilers, super heaters, economizers and electrostatic precipitators, steam turbines: impulse and reaction turbines, condensers, feed water circuit, cooling towers and chimney.

**UNIT-II: NUCLEAR POWER STATIONS:**

**(09)**

Location of nuclear power plant, working principle, nuclear fission, nuclear fuels, nuclear chain reaction, nuclear reactor components: moderators, control rods, reflectors and coolants, types of nuclear reactors and brief description of PWR, BWR and FBR. Radiation: radiation hazards and shielding, nuclear waste disposal

**UNIT-III: SUBSTATIONS:**

**(09)**

**Air Insulated Substations** – indoor & outdoor substations, substations layouts of 33/11 kV showing the location of all the substation equipment. Bus bar arrangements in the sub-stations: simple arrangements like single bus bar, sectionalized single bus bar, double bus bar with one and two circuit breakers, main and transfer bus bar system with relevant diagrams.

**Gas Insulated Substations (GIS)** – advantages of gas insulated substations, constructional aspects of GIS, comparison of air insulated substations and gas insulated substations.

**UNIT-IV: DISTRIBUTION SYSTEMS:**

**(09)**

Classification of Distribution systems, A.C Distribution, Overhead versus Underground system, Connection schemes of Distribution system, Requirements of Distribution system, Design considerations in Distribution system.

**Underground Cables:**

Types of cables, construction, types of insulating materials, calculation of insulation resistance, stress in insulation and power factor of cable. Capacitance of single and 3-Core belted Cables. Grading of cables: capacitance grading and inter sheath grading.



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**UNIT-V: ECONOMIC ASPECTS & TARIFF:**

**(09)**

**Economic Aspects** – load curve, load duration and integrated load duration curves, discussion on economic aspects: connected load, maximum demand, demand factor, load factor, diversity factor, plant capacity factor and plant use factor, base and peak load plants.

**Tariff Methods**– Costs of generation and their division into fixed, semi-fixed and running costs, desirable characteristics of a tariff method, tariff methods: simple rate, flat rate, block-rate, two- part, three-part, and power factor tariff methods, Time of Day (TOD) tariff and Time of Use (TOU) tariff

**COURSE OUTCOMES:**

On successful completion of the course, students will be able to		POs related to COs
<b>CO1</b>	Understood the different types of power plants, operation of power plants	<b>PO1,PO2</b>
<b>CO2</b>	Understood the concepts of distribution systems, underground cables, economic aspects and tariff	<b>PO1,PO2</b>
<b>CO3</b>	Understood various substations that are located in distribution systems	<b>PO1,PO2</b>
<b>CO4</b>	Applied the above concepts to illustrate different power generation layouts	<b>PO1,PO2,PO3</b>
<b>CO5</b>	Analyzed various economic aspects related to power generation and distribution	<b>PO1,PO2,PO3</b>

**TEXT BOOKS:**

1. S. N. Singh, Electric Power Generation, Transmission and Distribution, PHI Learning Pvt Ltd, New Delhi, 2nd Edition, 2010
2. J. B. Gupta, Transmission and Distribution of Electrical Power, S. K. Kataria and sons, 10th Edition, 2012.

**REFERENCE BOOKS:**

1. J. Nagarath & D.P. Kothari, Power System Engineering, McGraw-Hill Education, 3rd Edition, 2019.
2. C. L. Wadhwa, Generation, Distribution and Utilization of Electrical Energy, New Age International Publishers, 6th Edition, 2018.
3. V. K. Mehta and Rohit Mehta, Principles of Power System, S. Chand, 4th Edition, 2005.
4. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1985.
5. Handbook of switchgear, BHEL, McGraw-Hill Education, 2007.

**REFERENCE WEBSITE:**

1. <https://nptel.ac.in/courses/108102047>

**CO-PO MAPPING:**

CO-PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
<b>CO.1</b>	3	3										
<b>CO.2</b>	3	3										
<b>CO.3</b>	3	3										
<b>CO.4</b>	3	3	2									
<b>CO.5</b>	3	3	2									
<b>CO*</b>	3	3	2									

Faculty In charge  
(Dr.V.Maheswari)



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**UNIT-I: HYDROELECTRIC AND THERMAPOWER STATIONS:**

**Course Objectives:**

1. To understand the **basic principles of power generation** in hydroelectric and thermal power plants.
2. To study the **factors involved in the selection of suitable sites** for hydroelectric and thermal power stations.
3. To explain the **general layout and operation of hydroelectric power plants** and identify the functions of major components such as dam, reservoir, penstock, turbine, and generator.
4. To analyze the **general layout and working of thermal power plants** including boilers, superheaters, economizers, turbines, condensers, cooling towers, and chimneys.
5. To understand the **operation of steam turbines (impulse and reaction types)** and pollution control equipment such as electrostatic precipitators used in thermal power plants.

# POWER SYSTEMS-I

## UNIT-I: HYDROELECTRIC AND THERMAL POWER STATIONS:

(09)

Selection of site, general layout of a hydroelectric power plant with brief description of major components and principle of operation. Selection of site, general layout of a thermal power plant. Brief description of components: boilers, super heaters, economizers and electrostatic precipitators, steam turbines: impulse and reaction turbines, condensers, feed water circuit, cooling towers and chimney.

# Hydro Power Plant Site Selection:

**The factor which includes for selection of Hydro Power plant are:**

- Environmental effect
- The water availability
- Water storage
- Head of water
- Site accessibility
- Distance from the load center
- Types of the land of the site
- Water Pollution
- Geological Investigation

### **❑Environmental effect:**

Environmental effect is one of major problem which should be not occur so the place can be choose which is free from hazards and chemical effects and so on.

### **❑The water availability:**

In Hydro Plant water is an essential fuel. Water availability is needed to plant for the rotating turbine blade and generating electricity.

### **❑Water storage:**

After the availability of water, we must store the water in a dam So we can constantly provide water to the turbine and with high-pressure energy as explained above.

### **❑Head of water:**

To increase the flow of water from Dam to turbine blades.

### **❑Site Accessibility:**

It is also one of an important factor. The power generated from the plant that can be utilized easily. It should have transportation facility be road or train.

### **❑Distance from the load center:**

If there is more distance between power plant to the load center then transmission cable is used more and hence cost will be increased and so on.

### **❑Types of the land of the site:**

The Power plant needs more space and it should be kept in mind that land cost must be cheap.

### **❑Water Pollution:**

Water pollution is one of the major factor. The plants should be free from water pollution. If there is water pollution then chances of loss of equipment is much.

### **❑Geological Investigation:**

Plant construction should be strong and stable. This construction can withstand natural calamities like thunderstorms and earthquakes, etc.

## • **Hydro Power Plant Definition**

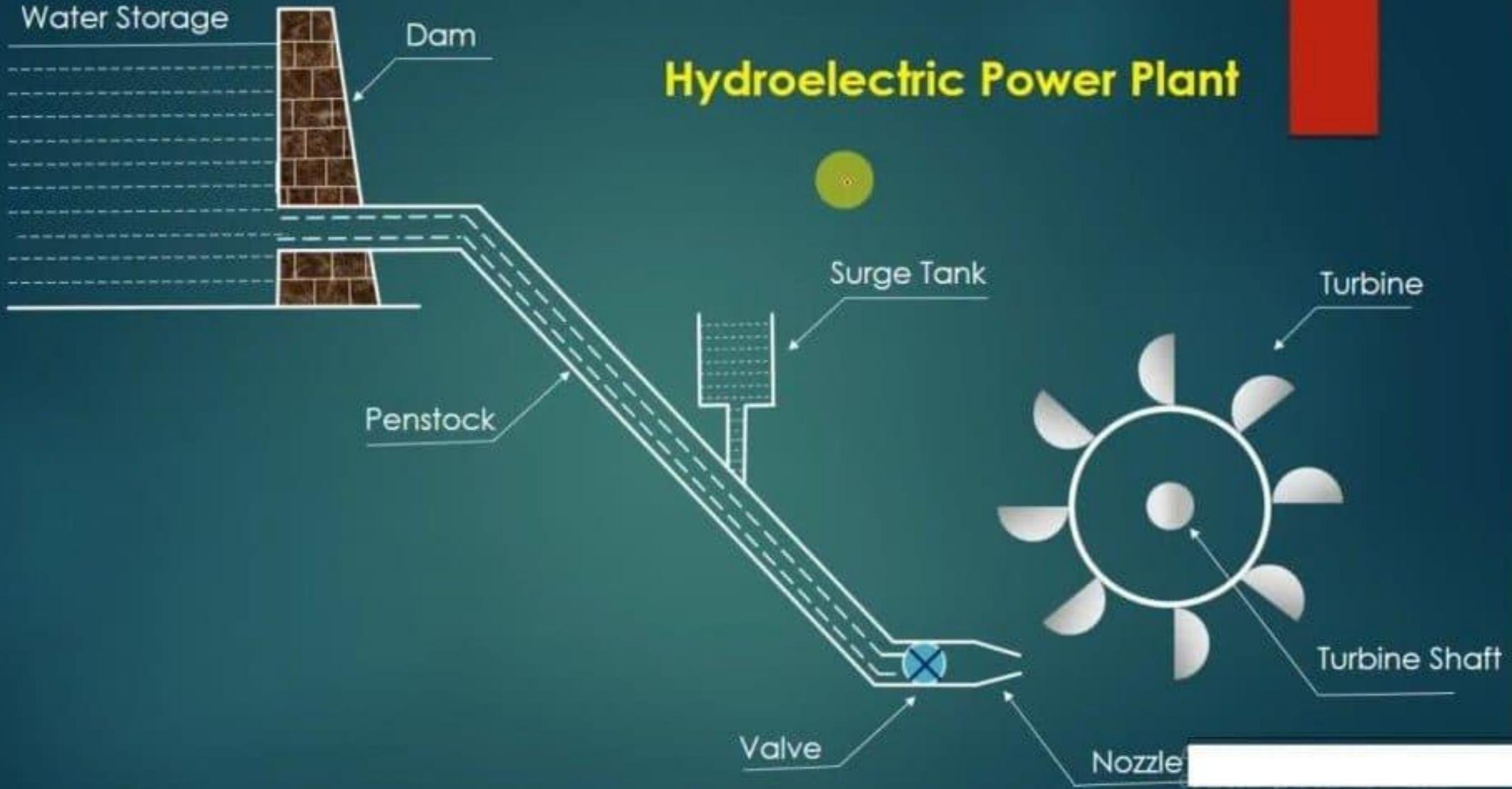
Hydro Power Plant is an electricity-producing plant in which the water is an essential fuel, the **potential energy is being converted into kinetic energy** and **kinetic energy is further converted into mechanical and into electrical energy** with the help of a turbine and motor.

- **Hydro Power Plant Layout or Construction:**

**The following Construction or Layout of Hydro Power Plant:**

- Head pond or Reservoir
- Control gate
- Penstock
- Turbine
- Draft Tube
- Tail Race
- Transmission Line
- Generator
- Transformer
- Power House

# Hydroelectric Power Plant



## □ **Headpond:**

There is one reservoir which is having a large area in which A huge amount of water is being stored here. So the energy here is in the form of Potential energy.

We Know Potential Energy is  $mgh$  [Mass\*Gravitational force\* Height]

## □ **Control Gate:**

There are having multiple control gates in a single hydro power plant. The work of control gate is to regulate the flow of water. When the control gate is fully opened the speed of water flowing is maximum.

## □ **Penstock:**

The penstock is also called Pipe. The water stored at the dam or head pond is being released by the control gate, the water starts moving to the turbine. The Head pond is having high heights and the Turbine is situated below.

So the speed of water gets increased because of gravitational force. The material of the penstock is hard steel being used.

### □ **Valve and Nozzle:**

The valve work is similar to the control gate and Nozzle work is striking water in a specific direction [Pressure is high] that is a turbine blade.

### □ **Surge tank:**

Surge tank is an additional and essential component which is used to accumulate the water which is in pipe when we want to close the turbine working. Or you can say it is used for avoiding the pipe burst.

### □ **Turbine:**

Turbine is a device which is used for generation of electricity. Turbine work is, the fluid having kinetic energy is being converted into rotational energy.

The high kinetic energy water comes through the penstock to the nozzle and strikes the turbine blades. The turbine blades start rotating. So the rotational energy can also be called mechanical energy.

### **□Draft Tube:**

Draft tube is a mechanical component which is used for enlarging the area of pipe for sending maximum fluid to the other side.

### **□Tail Race:**

Tailrace carries water away from the plant. Hence the water is sent to the river.

### **□Transmission Line:**

The transmission line carries power from the power unit or transformer and transfers or supplies from one source to another. It is made up of conductor.

### **□Generator:**

When the turbine buckets start rotating, the turbine shafts also rotate. The motors are attached to the turbine shafts which are also rotating and a generator is attached to them which generates electricity.

## ❑Transformer:

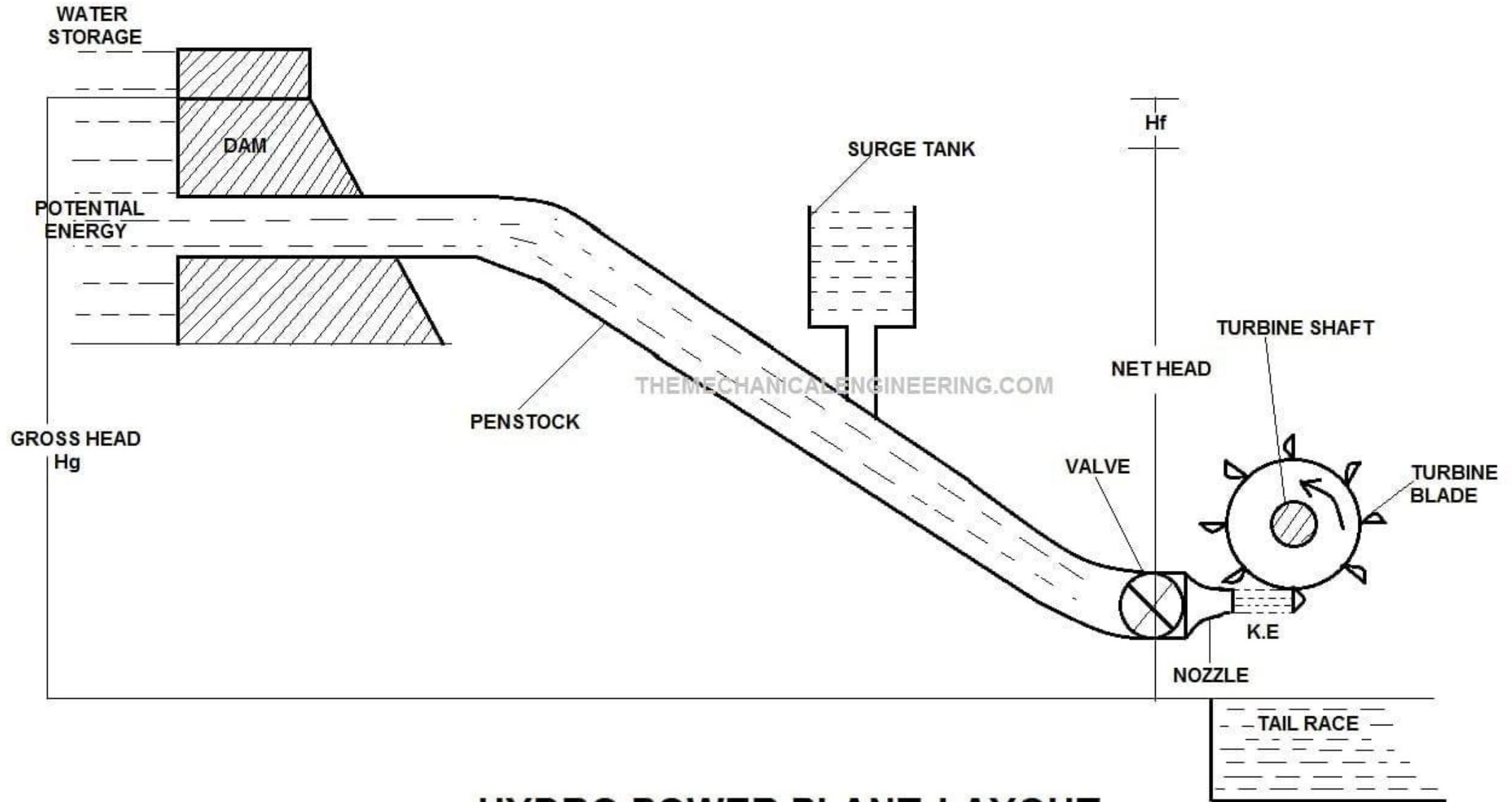
The transformer is attached to the generator. The electricity generated is now controlled by the transformer. The work of transformer is to set up or set down the voltage.

## ❑Power House:

The name power house means there is a house in which the power is being stored and released to the transformer and so on.

## **Hydro Power Plant Working:**

- In a large amount of water is available or you can say a river.
- The water is being stored in the reservoir which is in the form of potential energy. With the use of the control gate, the water is being released and water starts flowing into the penstock.
- Here two components are attached 1. Surge tank, Valve, and Nozzle.



# HYDRO POWER PLANT LAYOUT

Prepared By Dr.V.Maheswari Professor –EEE

- ❑ Initially, the valve is closed. But when the water reaches up to the max level that can create high pressure then we open the valves. The water with high pressure starts flowing and strikes to the turbine blades through the nozzle.
- ❑ The turbine blades start rotating. So till now, we observed the water which is having PE is now converting into KE.
- ❑ In the turbine blade, an electric motor is attached to the turbine shafts. So rotation of turbine blades also rotates the turbine shafts, which also rotates the electric motor. Hence Kinematic energy into mechanical energy and then further it is converted into electric energy.
- ❑ The energy generated is sent to the powerhouse, Transformer and Transmission line.
- ❑ The water which is rotating the turbine blades is now sent to the river via a tailrace.

- The hydropower plant is constructed to store the water in a large amount. When the water reaches up to the max level then it is being released which also causes the flood in some area (due to sudden release of water).

### **ADVANTAGES:**

- ❑ Hydro-generation has a unique and significant role to play particularly in the operation of interconnected power systems.
- ❑ The rapidly fluctuating loads are served most economically by Hydro-plant.
- ❑ The fuel needed for the thermal plant has to be purchased, whereas in Hydro-plant the fuel cost is totally absent.
- ❑ Hydroelectric plants are quick to respond to the change of load compared with thermal Power Plant or nuclear plants.

## **DISADVANTAGES:**

- The capital cost (cost per kilowatt capacity) installed ) of the hydro plant is considerably more than the thermal plant.
- It takes a considerable long time for its erection compared with thermal plants.
- Power generation by the hydro plant is only dependent on the quantity of water available which in turn depends on the natural phenomenon of rain. The dry year is more serious for the hydroelectric project.
- The site of Hydroelectric station is selected on the criterion of water availability at economical head such sites are usually away from the load center.
- The transmission of power from the power station to the load center requires long transmission lines. Therefore investment required for long transmission lines and loss of power during transmission is an unfavorable factor for the economical selection of hydro plants.

# Site Selection of Steam Power Plant:

## 1. Availability of raw materials

- ❑ Huge quantity of coal and fuel are required to run a steam (thermal) power plant. Therefore, it is important to locate the plant as near as possible to the coal fields to reduce the transportation cost.
- ❑ If it is not possible to locate the plant near the coal field, then it should be located near the railway station or near to a port.

## 2. Ash disposal facilities

- ❑ As a huge quantity of coal is burnt, this results in a huge quantity of ash too. The ash handling problem is more serious as compared to handling of coal because it comes out very hot and is very corrosive.
- ❑ If not disposed properly it will result in environmental pollution and other hazards. Therefore, there must be sufficient space to dispose this large quantity of ash.

### **3. Nature of land**

The land should have good bearing capacity about  $1 \text{ MN/m}^2$  as it has to withstand the dead load of plant and force transmitted to the foundation due to working of heavy machinery.

### **4. Cost of land**

Large area is required to build a thermal power plant, therefore the land price should be affordable (cheap). For eg: Large plant in the heart of city will be very costly.

### **5. Availability of water**

Water is the working fluid in a steam power plant, and a large quantity of water is converted to steam in order to run the turbine. It is important to locate the plant near the water source to fulfill its water demand through out the year.

## **6. Size of the plant**

The capacity of the plant decides the size of the plant, large plant requires large area and the smaller plant requires considerably smaller area. Therefore, the size of the plant and its capacity play an important role in site selection of steam power plant.

## **7. Availability of workforce**

During construction of plant, enough labour is required. The labour should be available at the proposed site at cheap rate.

## **8. Transportation facilities**

Availability of proper transportation is another important consideration for the site selection of steam power plant as a huge quantity of raw materials (coal & fuel) through out the year and heavy machinery are to be brought to the site during the installation.

## **9. Load center**

The plant must be near to the load center to which it is supplying power in order to decrease transmission loss and minimize transmission line cost.

## **10. Public problems**

The plant should be away from the town or city in order to avoid nuisance from smoke, ash, heat and noise from the plant.

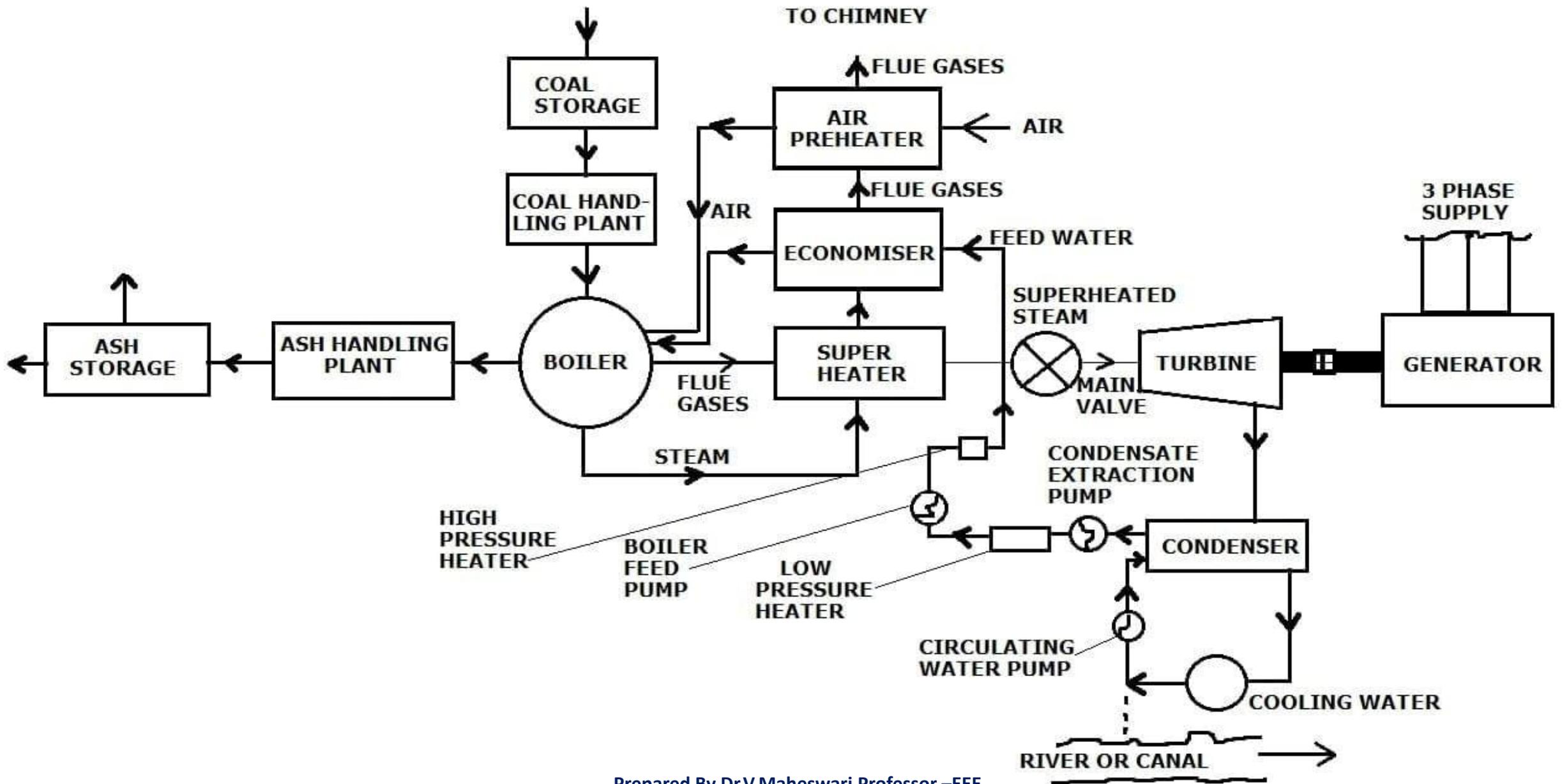
## **11. Future extension**

A choice for future extension of the plant should be made in order to meet the power demand in future.

# THERMAL POWER PLANT

## **Thermal Power Plant Definition:**

- Thermal Power Plant is an electric producing power plant in which fuel (such as coal, liquefied fuel, uranium and Natural Resources) is used to generate heat and that heat is further utilized to heat the water to make steam and that steam is used to rotate the turbine and further electricity generates with the help of 3 phase supply generator.



- **Coal:**

- It is the most common source of energy that is being used since industrialization. The modern steam boiler burns coal mainly as the primary fuel in any of its available forms. Different ranks of coal available are peat, lignite, bituminous, and anthracite.

- **Coal Storage and Handling Plant:**

- As name suggest storage and handing it means that the coal is stored in the storage and as per the demand it supply to the next.

- **Boiler:**

- Boiler is a closed vessel in which fuel burn and produces flue gases that flue gases is further used to heat the water to make steam.
- There are two main types of boiler: Fire Tube boiler and Water Tube boiler.

## **Boiler Feed Pump:**

The feed water is supply to next accessories by the boiler feed pump.

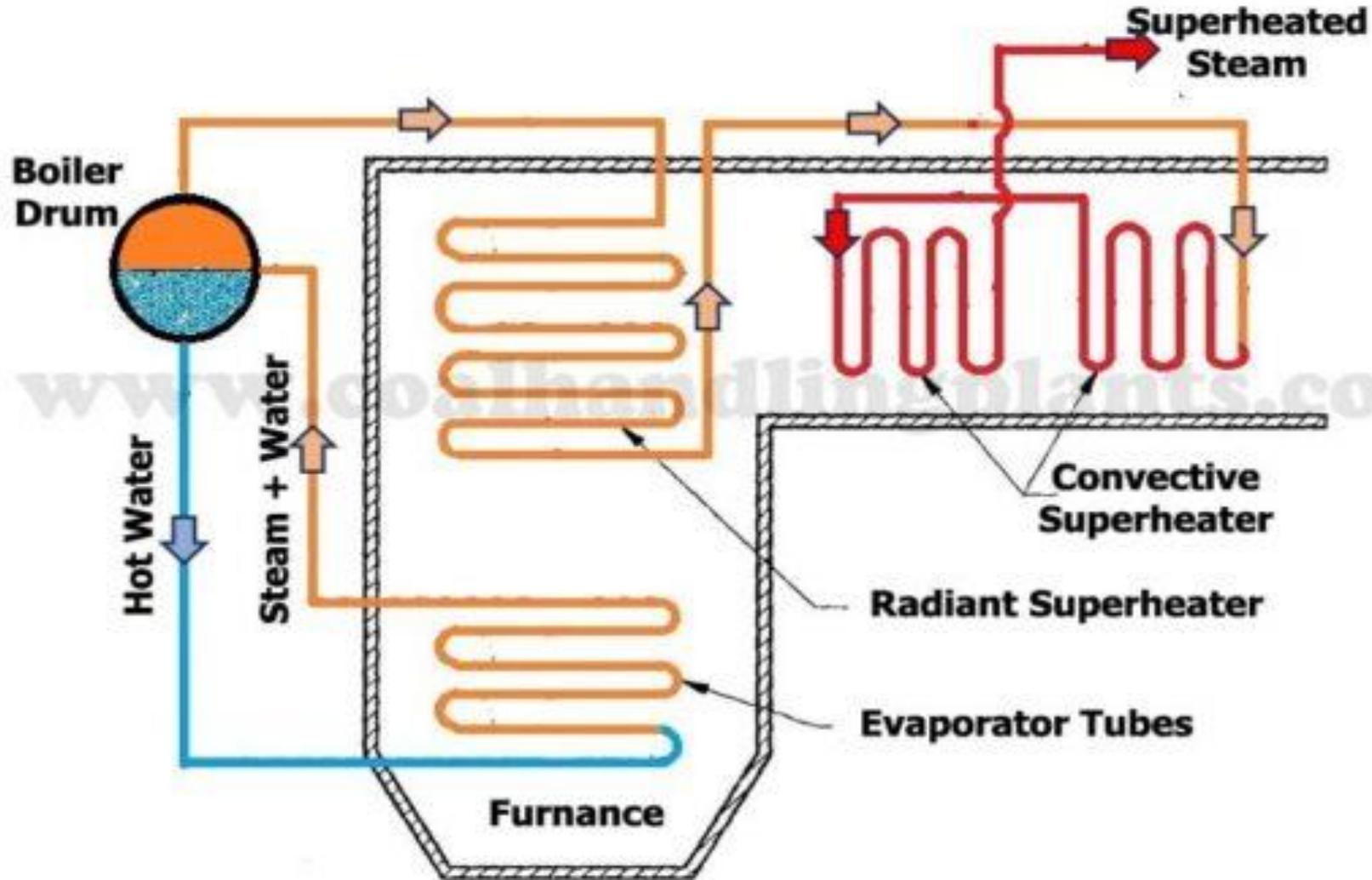
## **Super heater:**

Name itself indicates that it increases the temperature of any substances. Super heater is a external system which helps to increases the temperature of substances and to improve boiler efficiency.

## **The main functions of a superheater are:**

- To increase the temperature of steam beyond the saturation level.
- To improve Rankine cycle efficiency by reducing the specific steam consumption.
- To avoid moisture carryover and ensure dry steam reaches the turbine.
- To prevent corrosion and erosion in turbine blades

# Super heater:



## Economizer:

The economizer transfers heat from the flue gases to the boiler feedwater, which helps to preheat the water before it enters the boiler.

This reduces the amount of fuel that is needed to heat the water, which can save energy and money.

## Benefits of installing a boiler economizer

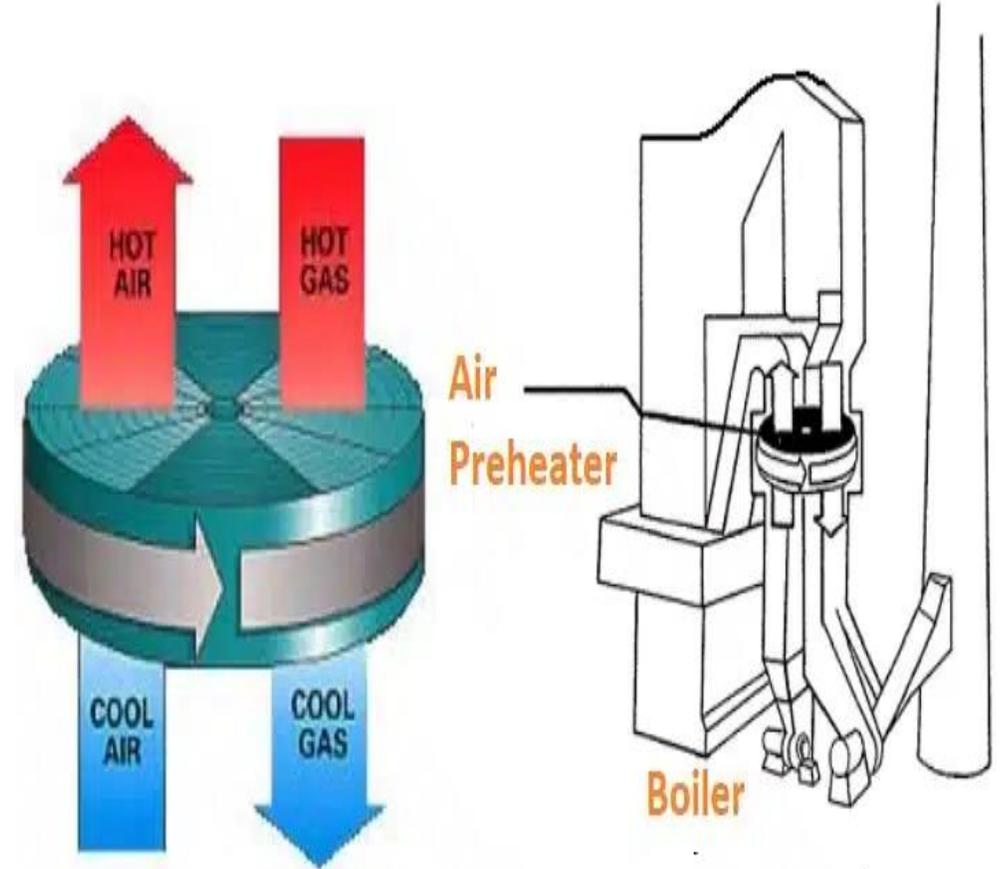
- **Reduced fuel consumption:** Economizers can reduce fuel consumption by up to 20%, which can lead to significant savings on energy costs.
- **Reduced emissions:** Economizers help to reduce emissions by reducing the amount of fuel that needs to be burned.
- **Improved boiler efficiency:** Economizers can improve boiler efficiency by up to 10%.
- **Increased system life:** Economizers can help to extend the life of a boiler by reducing the amount of wear and tear on the boiler components.
- **Reduced maintenance costs:** Economizers require very little maintenance, which can save money in the long run.

# Electrostatic Precipitator

- **Definition:** An electrostatic precipitator is a device that removes pollution-causing particles from a gas using an electrostatic charge.
- **Types of Electrostatic Precipitators:** There are two main types: dry and wet electrostatic precipitators.
- **Dry Electrostatic Precipitator:** Collects dry particles by charging them and trapping them on oppositely charged electrodes.
- **Wet Electrostatic Precipitator:** Collects wet particles by charging them and using continuously sprayed liquid collectors to form sludge.
- **Applications:** Used in thermal power plants and industrial settings to clean air and reduce pollution.

# Air Preheater:

- **Heat Recovery:** Hot flue gases, after passing through other heat exchangers (like economizers), still contain significant heat.
- **Heat Transfer:** The air preheater, typically a rotary plate type, brings these hot flue gases into close contact with the colder incoming combustion air.
- **Preheating:** Heat transfers from the gas to the air, raising the air's temperature.
- **Improved Combustion:** Hotter air leads to more efficient fuel burning in the boiler.
- **Benefits:**
  - **Increased Efficiency:** Less fuel is needed to heat the air, boosting overall plant performance.
  - **Fuel Savings:** Direct reduction in fuel required for the same heat output.
  - **Better Combustion:** Hotter air promotes more complete and stable combustion.



# Steam Turbine in Power Plant

- ❑ A steam turbine in power plant is a rotating machine that utilize high pressure steam to move the moving blades that are mounted onto the rotor of the turbine
- ❑ In the boiler, feed water at a certain pressure and temperature is heated to the saturated liquid state, vaporized to the saturated vapor state, and saturated steam then passes through the superheater and is heated to its desired temperature. Superheated high pressure steam is then piped to the steam turbines which drive the generators.
- ❑ **The steam turbine in power plant consists of three stages:**
  - ❑ High Pressure (HP) Stage
  - ❑ Intermediate Pressure (IP) Stage
  - ❑ Low Pressure (LP) Stage

# Impulse Turbine

- The type of hydro-turbine, where the turbine is rotated by the impulse force of the water jet is known as **impulse turbine**.
- In the impulse turbine, the pressure of water is converted into kinetic energy in a nozzle and then the velocity of the water jet drives the turbine.
- The main components of an impulse are: set of runner blades and nozzle. The nozzle converts the pressure of water jet into kinetic energy, after discharging from the nozzle, the water jet strikes the runner blades and turns the runner through its axis. In this way, the impulse force of water jet drives the turbine.
- The most common examples of impulse turbines are ? **Pelton wheel turbine, Turgo turbine**, and **Cross flow turbine**.

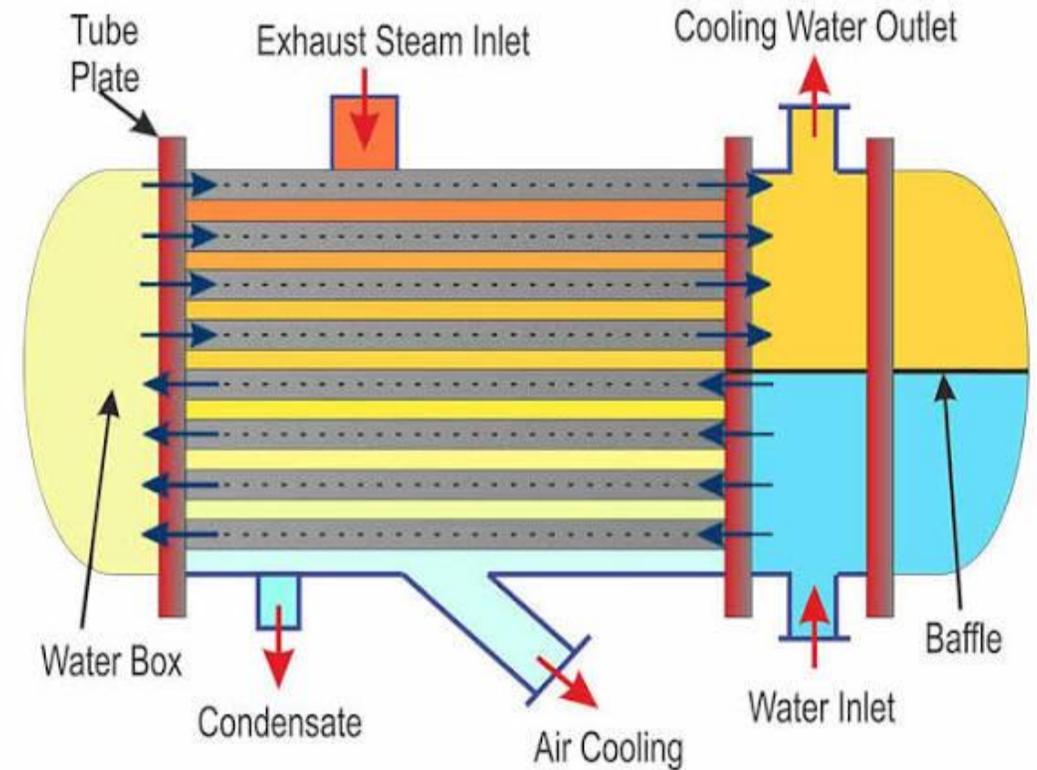
## Reaction Turbine:

- ❑ The type of hydro turbine, which uses the pressure as well as velocity of the moving water to spin the runner is called a **reaction turbine**.
- ❑ The reaction turbines are placed in the water stream where the water enters the turbine casing and after rotating the blades, the water leaves the turbine casing.
- ❑ The **Francis turbine** and the **Kaplan turbine** are the two most popular reaction type water turbines. A typical reaction turbine consists of rows of fixed blades and rows of moving blades.
- ❑ In the reaction turbine, the moving water can produce a reaction force on the runner blades, which can rotate the runner on its axis. After moving the runner blades, the water leaves the turbine casing.

# Condenser:

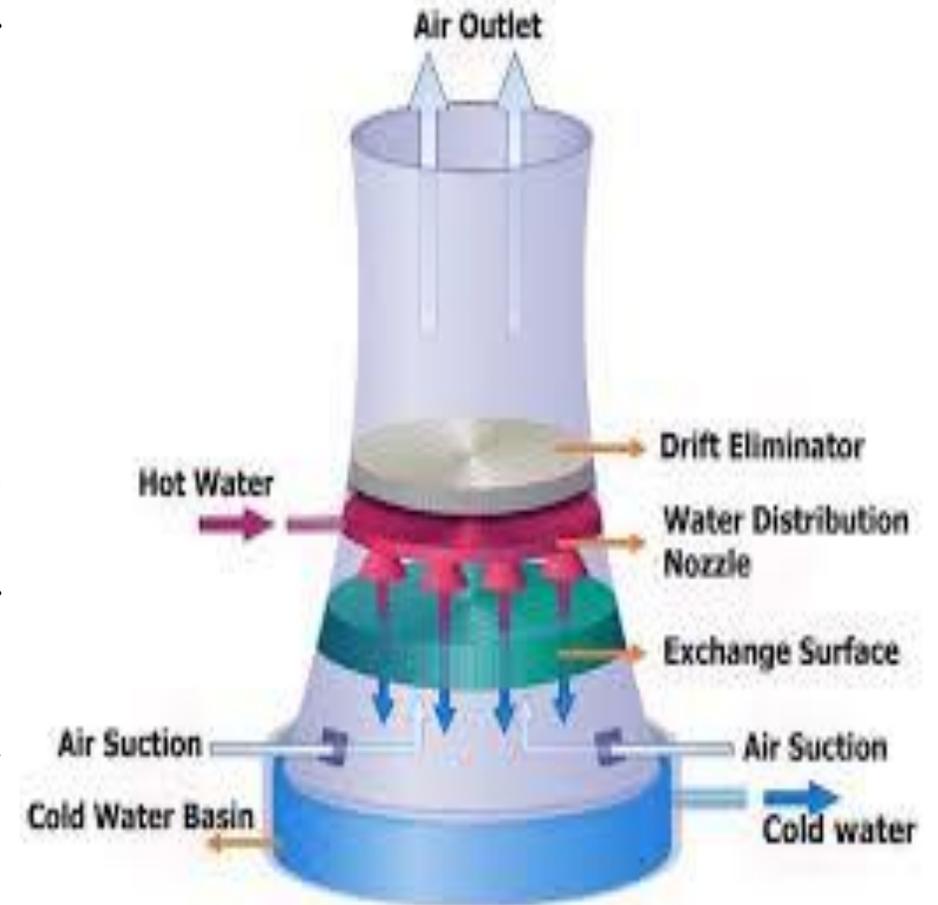
## Functions:

- **Condensation:** Converts low-pressure steam back to water.
- **Vacuum Creation:** The large volume reduction from steam to water creates a vacuum, maximizing the pressure drop across the turbine for greater energy extraction and efficiency.
- **Water Recovery:** Recovers pure feedwater for the boiler, reducing water consumption.
- **Heat Rejection:** Rejects the heat of condensation to the cooling medium (water or air).



# Cooling Tower:

- **Function:** To cool large volumes of hot water from the condenser back down so it can be reused to condense steam, completing the cycle.
- **Process:** Hot water is sprayed or dispersed inside; cool air (drawn in from the bottom) contacts the water, causing some to evaporate, which cools the remaining water.
- **Appearance:** Large, often hyperbolic concrete structures, known as natural draft towers, which use their height for the chimney effect to pull air through.
- **Output:** Visible steam (water vapor) rising from the top



## Chimney (Stack):

- **Function:**

To safely discharge flue gases (byproducts of burning fuel, like coal) high into the atmosphere, diluting pollutants and minimizing local environmental impact.

- **Process:**

Hot combustion gases rise through the tall stack due to buoyancy (chimney effect), carrying pollutants far from ground level.

- **Appearance:**

Tall, slender, often metal or concrete structures, distinct from the massive cooling towers.

- **Output:**

Invisible gases, though sometimes visible smoke or steam if pollutants condense

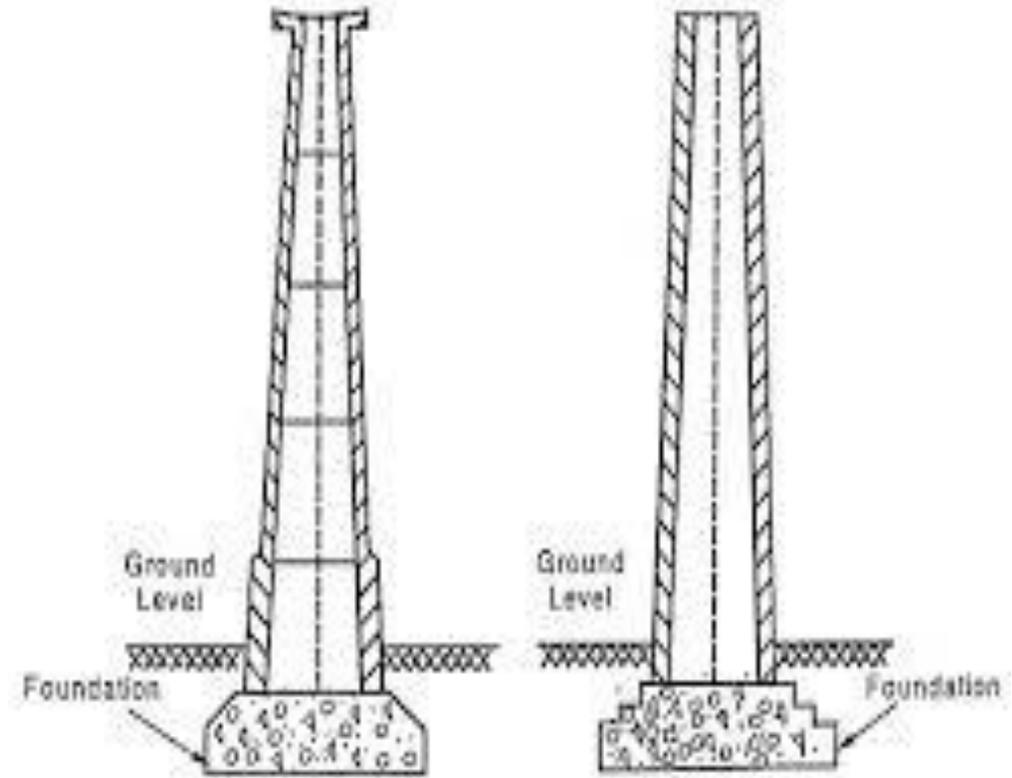


Fig:1.52 (a) Brick Chimney

Fig:1.52 (b) Reinforced Chimney

Fig:1.52. Chimney

## **Thermal Power Plant Working:**

- As you can see the above diagram is general layout of Thermal Power Plant. The coal is inserted into coal storage. Here coal is being crushed and send to the boiler.
- In the boiler there is feed water supplied through economizer. Coal is being heated here it produces flue gases, that flue gases is used to heat the feed water to make change the phase of water into steam.
- From the boiler the coal which is burnt and becomes ashes will now send to the ash handling plant and further ash storage.
- The steam generated in the boiler is now sends to the superheater here it again gets heated at high temperature to became only steam. This steam is now sent to the turbine.

- In turbine there is blades are attached. The turbine further attached to the generator for generation of electricity.
- Now the steam strikes to the turbine blades, the turbine blades starts rotating [PE is converted into KE and further used for generation of electricity]
- Here some amount of steam which is not used will now come to the condenser and here it loses his heating properties. Now again with water it sends to the economizer for reptation process.

- **Efficiency Of A Thermal Power Station**

❑ A huge amount of heat is lost in various stages of the plant. Major part of heat is lost in the condenser. That is why the efficiency of thermal plants is quite low.

❑ **Thermal Efficiency:** The ratio of 'heat equivalent of mechanical energy transmitted to the turbine shaft' to the 'heat of coal combustion' is called as thermal efficiency.

$$\text{Thermal Efficiency} = \frac{\text{Heat equivalent of mech. energy transmitted to the turbine shaft}}{\text{Heat produced by coal combustion}}$$

❑ Thermal efficiency of modern thermal power stations is about 30%. It means, if 100 calories of heat are produced by coal combustion, the mechanical energy equivalent of 30 calories will be available at the turbine shaft.

- **Overall Efficiency:** The ratio of 'heat equivalent of electrical output' to the 'heat of coal combustion' is called as overall efficiency.

$$\text{Overall Efficiency} = \frac{\text{Heat equivalent of electrical output}}{\text{Heat produced by coal combustion}}$$

electricityeasy.com

- The overall efficiency of a thermal plant is about 29% (slightly less than the thermal efficiency).

## **Thermal Power Plant Advantages:**

**The various advantages of thermal power plant compare to other plants are:**

1. The fuel used coal which is quite cheap and available.
2. The initial cost is low.
3. It can be installed anywhere.
4. The generation cost is quite less.

## **Thermal Power Plant Disadvantages:**

1. Overall efficiency is low [below thirty percent].
2. The handling of ash is a major problem in steam plants.
3. It pollutes the atmosphere due to the production of a huge amount of smoke therefore Global warming increases.
4. This cubic capacity of the building required for gas turbine plants is about 50 percent of the steam plant. The total weight of the material required for the gas turbine plant is also 50-60 percent of the steam plant. Therefore considerable savings in capital cost is possible having the same efficiency as a steam plant.
5. The site of the steam power plant is dictated by the availability of large cooling water, whereas an open-cycle gas turbine plant can be located near the load center as no cooling water is required.

# Part A:

1. List any **two important factors** considered for the **selection of a site for a hydroelectric power plant**.
2. What is meant by the **general layout of a hydroelectric power plant**?
3. Name any **two major components** of a hydroelectric power plant.
4. State the **principle of operation** of a hydroelectric power plant.
5. Mention **two criteria** for the **selection of a site for a thermal power plant**.
6. What is the **function of a boiler** in a thermal power plant?
7. Define **superheater** and state its purpose.
8. What is an **economizer**? Why is it used in thermal power plants?
9. What is the function of an **electrostatic precipitator (ESP)**?
10. Differentiate between **impulse turbine and reaction turbine** (any one point).

# Part A:

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4. State the **principle of operation** of a hydroelectric power plant.
5. Mention **two criteria** for the **selection of a site for a thermal power plant**.
6. What is the **function of a boiler** in a thermal power plant?
7. Define **superheater** and state its purpose.
8. What is an **economizer**? Why is it used in thermal power plants?
9. What is the function of an **electrostatic precipitator (ESP)**?
10. Differentiate between **impulse turbine and reaction turbine** (any one point).

## 10 Mark Question:

1. Explain in detail the **selection of site for a hydroelectric power plant**, highlighting technical, environmental, and economic factors.
2. With a neat diagram, explain the **general layout of a hydroelectric power plant** and briefly describe the **major components**.
3. Describe the **principle of operation of a hydroelectric power plant** with the help of an energy conversion process.
4. Explain the **selection of site for a thermal power plant**, discussing fuel, water supply, transportation, and environmental considerations.
5. With a neat sketch, explain the **general layout of a thermal power plant**.
6. Explain the **construction and working of boilers** used in thermal power plants.
7. Describe the **function and working of superheaters and economizers** in a thermal power station.
8. Explain the **working principle of electrostatic precipitators** and discuss their importance in pollution control.
9. Compare **impulse turbines and reaction turbines** with respect to construction, working principle, and applications.
10. Explain the **steam–water cycle in a thermal power plant**, describing **steam turbine, condenser, feed water circuit, cooling tower, and chimney**

## Objective Type Questions (MCQs)

1. The main source of energy in a hydroelectric power plant is:

- A) Coal
- B) Nuclear fuel
- C) Flowing water
- D) Wind

**Answer:** C) Flowing water

2. Which factor is most important for selecting a site for a hydroelectric power plant?

- A) Availability of coal
- B) High water head
- C) Proximity to city
- D) Availability of skilled labor

**Answer:** B) High water head

3. The function of a **penstock** in a hydroelectric power plant is to:

- A) Store water
- B) Control turbine speed
- C) Carry water to turbine
- D) Generate electricity

**Answer:** C) Carry water to turbine

4. The component that converts hydraulic energy into mechanical energy is:

- A) Generator
- B) Turbine
- C) Transformer
- D) Draft tube

**Answer:** B) Turbine

5. Which type of turbine is used for **high head and low discharge**?

- A) Kaplan
- B) Francis
- C) Pelton
- D) Propeller

**Answer:** C) Pelton

6. The basic principle of a thermal power plant is:

- A) Chemical energy → Electrical energy
- B) Mechanical energy → Electrical energy
- C) Thermal energy → Mechanical energy → Electrical energy
- D) Nuclear energy → Electrical energy

**Answer:** C) Thermal energy → Mechanical energy → Electrical energy

7. Which factor is **NOT** considered for selecting a thermal power plant site?

- A) Availability of fuel
- B) Water supply
- C) Scenic beauty
- D) Transportation facilities

**Answer:** C) Scenic beauty

8. The main function of a **boiler** is to:

- A) Produce steam
- B) Condense steam
- C) Heat feed water
- D) Remove ash

**Answer:** A) Produce steam

9. A **superheater** is used to:

- A) Increase steam pressure
- B) Remove moisture from steam
- C) Increase steam temperature
- D) Condense steam

**Answer:** C) Increase steam temperature

10. Which device improves the **efficiency of a boiler** by heating feed water?

- A) Condenser
- B) Superheater
- C) Economizer
- D) Chimney

**Answer:** C) Economizer

**11.**The main purpose of an **electrostatic precipitator** is to:

- A) Control steam pressure
- B) Reduce smoke temperature
- C) Remove fly ash from flue gases
- D) Increase boiler efficiency

**Answer:** C) Remove fly ash from flue gases

**12.**Which turbine works on the principle of **impulse**?

- A) Francis
- B) Kaplan
- C) Reaction
- D) Pelton

**Answer:** D) Pelton

**13.**In a **reaction turbine**, energy transfer takes place due to:

- A) Kinetic energy only
- B) Pressure energy only
- C) Both pressure and kinetic energy
- D) Potential energy only

**Answer:** C) Both pressure and kinetic energy

**14.**The function of a **condenser** in a thermal power plant is to:

- A) Increase steam pressure
- B) Convert steam into water
- C) Remove impurities
- D) Generate power

**Answer:** B) Convert steam into water

**15.**Which of the following is used to cool circulating water in thermal power plants?

- A) Boiler
- B) Cooling tower
- C) Economizer
- D) Chimney

**Answer:** B) Cooling tower

**16.**The feed water circuit mainly helps in:

- A) Fuel combustion
- B) Steam generation
- C) Reusing condensed water
- D) Removing ash

**Answer:** C) Reusing condensed water

**17.**Which component maintains **draught** in a thermal power plant?

- A) Cooling tower
- B) Boiler
- C) Chimney
- D) Economizer

**Answer:** C) Chimney

**18.**The efficiency of a thermal power plant is generally:

- A) 60–70%
- B) 45–50%
- C) 30–40%
- D) 80–90%

**Answer:** C) 30–40%

**19.**Which turbine is suitable for **low head and high discharge**?

- A) Pelton
- B) Francis
- C) Kaplan
- D) Impulse

**Answer:** C) Kaplan

**20.**The primary function of a **draft tube** is to:

- A) Increase water velocity
- B) Reduce pressure loss
- C) Recover kinetic energy
- D) Control water flow

**Answer:** C) Recover kinetic energy



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**Course Outcomes:**

After studying this topic, students will be able to:

1. **Explain the working principle** of hydroelectric and thermal power plants.
2. **Identify suitable site selection criteria** for establishing hydroelectric and thermal power stations.
3. **Describe the layout and components** of a hydroelectric power plant and their functions.
4. **Explain the layout and working components** of a thermal power plant including boilers, turbines, condensers, and feedwater systems.
5. **Differentiate between impulse and reaction turbines** and explain the role of pollution control equipment in thermal power plants.

**BOOK/NPTEL LINK REFERENCE FOR UNIT -1**

1. V. K. Mehta and Rohit Mehta, Principles of Power System, S. Chand, 4th Edition, 2005.
2. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1985.
3. NPTEL – Power Plant Engineering  
<https://nptel.ac.in/courses/112105123>
4. NPTEL – Energy Resources and Technology  
<https://nptel.ac.in/courses/103103206>

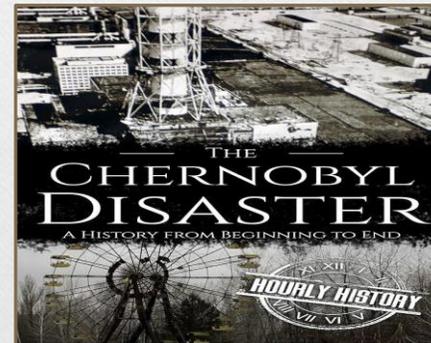
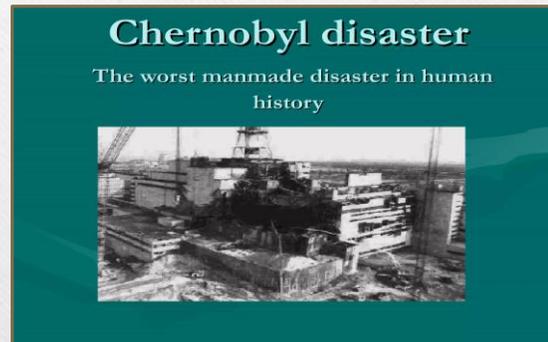
**ASSIGNMENT TOPICS:**

**Case Study:**

1. Chernobyl disaster
2. Bhopal disaster

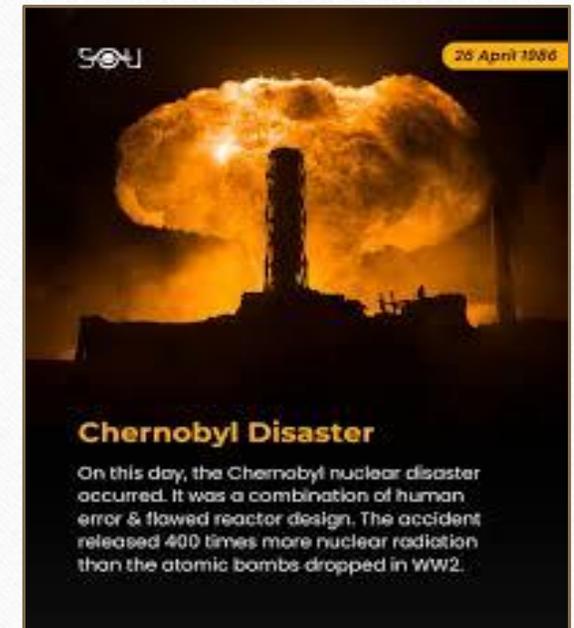
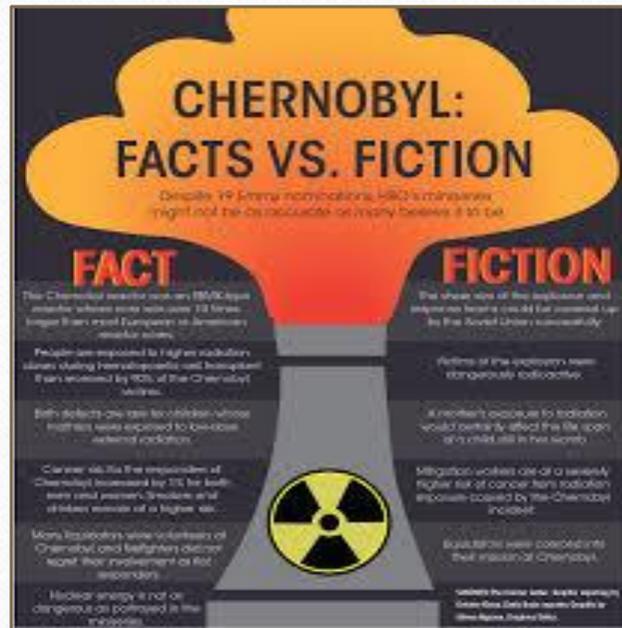
**“RADIATION HAZARDS OCCURED IN CHERNOBYL”**  
**(A LINGERING TREAT)**

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# INTRODUCTION

The Chernobyl Disaster of 26 April 1986 triggered the release of “RADIOACTIVE CONTAMINATION” into the atmosphere in the form of both particulate and gaseous “RADIOISOTOPES”. AS of 2025, it remains the World’s largest known release of “Radioactivity into the NATURAL ENVIRONMENT”



## ➤ **Causes Of The Chernobyl Disaster:**

### **1.Reactor design Flaws:**

- > The reactor type used was RBMK(High Power Channel-Type Reactor),which had serious design weaknesses.
- > It become unstable at low power levels and could suddenly increase power.

### **2. Operator Mistakes:**

- > Plant operators violated safety rules during a late-night experiments.
- > They turned off several safety systems to perform the test.

### **3. Poor Safety Culture:**

- > Safety producers were ignored.
- > Workers were not fully trained to handle the dangerous conditions.

### **4. Power Surge And Explosion:**

- > The unstable reactor caused a sudden power surge.
- > Steam pressure led to explosion and the Reactor core was exposed.

## ➤ **Effects Of The Disaster:**

### **1. Human Health Effects:**

- > Two workers died immediately during the explosion.
- > 28 firefighters and workers died within weeks due to the Acute Radiation Syndrome.
- > Thousands later developed into Cancers, especially “Thyroid Cancers”.

### **2. Environmental Damage:**

- > Huge amount of radioactive materials were released into the Atmosphere.
- > Radioactive fallout spread across Ukraine, Russia and parts of Europe.

### **3. Evacuation and Abandoned Cities:**

- > About 1,16,000 people were evacuated (remove from a place of danger).
- > A restricted 30-km exclusion zone still exists today.

### **4. Long- Term Social And Economic Effects:**

- > Long-Term monitoring of millions of people.
- > Increased global awareness about the Nuclear Safety.

## **CURRENT STATUS:**

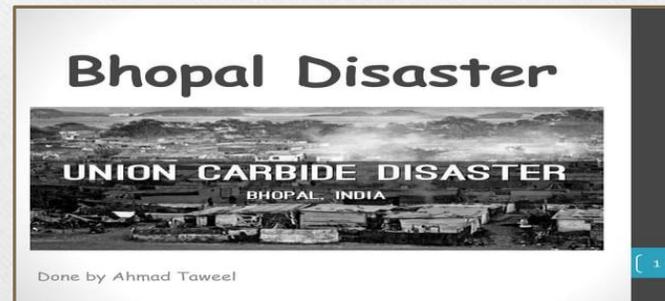
- The Chernobyl Exclusion Zone (CEZ) remains largely uninhabitable.
- Ongoing efforts to contain and decommission the damaged reactor.
- Monitoring and Mitigating efforts continue to address environmental and health concerns.

## **LONG-TERM RISKS:**

- Radioactive materials will persist for thousands of years (e.g., Pu-239 has a half-life of 24,100 years).
- Potential for groundwater contamination and radioactive material migration.

# THE BHOPAL DISASTER(1984)

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# INTRODUCTION

- Bhopal gas tragedy, a disaster that happened by a Gas leak is considered as one of the world's worst Industrial catastrophes (sudden large disaster) that occurred on the night of December 2-3, 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal, Madhya Pradesh, INDIA.

The Statesman

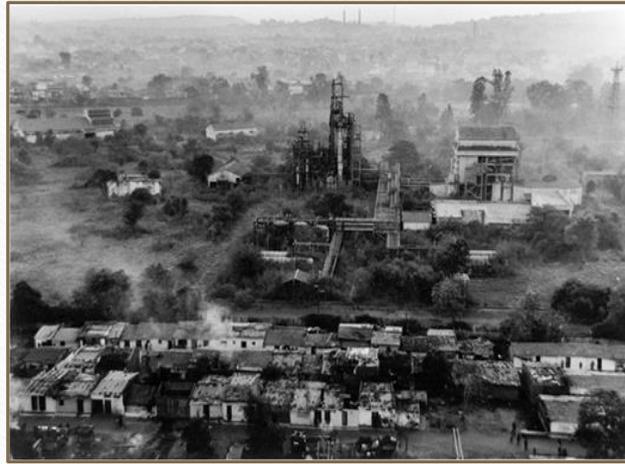
# 41 YEARS SINCE THE BHOPAL GAS TRAGEDY

Understanding what happened that night and why its consequences still shape lives today.

**DECEMBER 3, 1984**



Read More



\*The Bhopal gas tragedy (commonly referred to as Bhopal disaster) was a gas leak incident in India, considered one of the world's worst industrial catastrophes.

\*It occurred on the night of 2nd-3rd December 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal, Madhya Pradesh.

\*A leak of methyl isocyanate (MIC) gas and other chemicals from the plant resulted in the exposure of hundreds of thousands of people.



### THE AFFECTED AREA

- Around 1 a.m. on Monday, the 3rd of December, 1984, in the city of Bhopal, Central India, a poisonous vapour burst from the tall stacks of the Union Carbide pesticide plant.
- This vapour was a highly toxic cloud of methyl isocyanate.
- 2,000 died immediately
- 300,000 were injured
- 7,000 animals were injured, of which about one thousand were killed.




## ➤ **Causes of the Bhopal Disaster:**

### **1. Gas Leak (Methyl Isocyanate-MIC):**

A large amount of toxic methyl isocyanate (MIC) gas leaked from a storage tank in the pesticide plant.

### **2. Poor Maintenance and Safety Systems:**

Important safety systems such as the gas scrubber, flare tower and refrigeration system were either not working or turned off to save money.

### **3. Water Entering the MIC Tank:**

Water accidentally entered the MIC storage tank, causing a “Chemical Reaction” that increased pressure and releases toxic gas.

### **4. Lack Of Proper Training:**

Workers were not properly trained to handle emergency situations or dangerous chemicals.

### **5. Negligence and Poor Management:**

The plant management ignored safety warnings and reduced maintenance.

## ➤ **Effects Of The Bhopal Disaster:**

### **1.Massive Loss Of Life:**

Thousands of people died within the first few days , and many more died later due to exposure.

**Immediate Deaths:** Official figures states 2,259 deaths occurred immediately.

**Initial Weeks:** Estimates suggest 8,000 people died within the first two weeks.

### **2.Health Problems:**

Survivors suffered from:

- 1) Breathing difficulties
- 2) Eye irritation and blindness
- 3) Lung damage
- 4) Cancer and other long-term diseases.

### **3.Environmental Pollution:**

Soil and groundwater around the factory were contaminated with toxic chemicals.

## **CURRENT STATS:**

- The current status of the Bhopal Gas tragedy shows that its effect still continues even after more than 40 years.
- Many survivors and their children still suffer from respiratory diseases, cancer, kidney problems, eye damage, and birth defects.
- Tests found cancer-causing chemicals in groundwater “far above safe levels”, affecting local communities for decades.
- Recent Cleanup Actions(2024-2025): In 2025 authorities removed about 337 tones of hazardous waste from the former factory site.

## **LONG-TERM EFFECTS:**

- Many survivors suffer from chronic diseases such as-
  - > Breathing problems(asthma , lung damage)
- Psychological and social effects: Many survivors experience
  - > Trauma and Depression
  - > Loss of family members, reduced quality of life.

THANK YOU





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**UNIT-2: NUCLEAR POWER STATIONS**

**Course Objectives:**

1. To understand the **basic principle of electricity generation in nuclear power plants** based on nuclear fission.
2. To study the **criteria for selecting suitable locations** for nuclear power stations.
3. To explain the **nuclear chain reaction and the role of nuclear fuels** used in reactors.
4. To understand the **construction and function of major nuclear reactor components** such as moderators, control rods, reflectors, and coolants.
5. To study the **different types of nuclear reactors** such as Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR), and Fast Breeder Reactor (FBR), along with radiation hazards and nuclear waste disposal methods.

## **UNIT-II: NUCLEAR POWER STATIONS: (09)**

*Location of nuclear power plant, working principle, nuclear fission, nuclear fuels, nuclear chain reaction, nuclear reactor components: moderators, control rods, reflectors and coolants, types of nuclear reactors and brief description of PWR, BWR and FBR. Radiation: radiation hazards and shielding, nuclear waste disposal*

### **SITE SELECTION FOR NUCLEAR POWER PLANT:**

Assessment of public safety results in greater concern for site selection for a Nuclear power plant. All the natural factors are taken into account like transport of radioactive material to the public during normal operating condition as well as highly unlikely event of an accident that would result in release of radioactive material to the environment.

**The various factors that are taken into account while selecting the site for a nuclear power plant are:**

#### **1. Water availability**

The site must be equipped with ample quantity of water as the plants require substantially greater quantity of cooling water, because of its higher turbine heat rate and feed water required for steam generation. Therefore, the site must be nearer to a river, reservoir, sea or ocean.

#### **2. Distance from load centre**

The power plant should be located near the load centre as this will reduce the cost of transmission line and also reduces transmission loss.

Note: The power plant is located near the load centre while meeting other requirements like reasonable land cost, adequate cooling water, away from population distribution, local zone restriction, accessibility for fuel shipment, etc.

### **3. Distance from populated area**

The plant should be away from the population in order to avoid the radioactive hazard.

### **4. Transportation facilities**

The site should be accessible by rail and road as heavy machinery are to be brought to the site during the installation and fuel during its operation.

### **5. Waste disposal**

The waste of a nuclear power plant are very radioactive therefore sufficient space must be there to dispose the radioactive waste.

### **6. Cost of the land**

Large area is required to built a nuclear power plant, therefore the land price should be reasonable.

### **7. Nature of land**

The land should have good bearing capacity of about 1 MN/m<sup>2</sup> and must not come under earthquake prone zone. The land is studied for its past history of tremors and earthquake in order to design the plant that can withstand the severest earthquake.

### **8. Future extension**

A choice for future extension of the plant should be made in order to meet the energy demand in future.

### **9. Availability of workforce**

During construction of the plant enough labour is required. The labour should be available at the proposed site at cheap rate.

## 10. Size of the plant

The capacity of the plant decides the size of the plant, large plants require large area. Therefore the capacity of the plant also plays a vital role in the selection of site.

Year	Gross Generation (MUs)	Capacity Factor (%)	Availability Factor (%)
2025-26 (Upto Nov-2025)	35942	77	83
2024-25	56681	87	88
2023-24	47971	85	85
2022-23	45855	87	87
2021-22	47112	88	88
2020-21	43029	81	83
2019-20	46472	82	87
2018-19	37813	70	73
2017-18	38336	70	72
2016-17	37674	80	82
2015-16	37456	75	77
2014-15	37835	82	88
2013-14	35333	83	88
2012-13	32863	80	90
2011-12	32455	79	91
2010-11	26472	71	89

S.No	plant	unit	Type	capacity	Date of commercial operation
01	<a href="#">Tarapur Atomic Power Station (TAPS), Maharashtra</a>	1	BWR	160	October 28, 1969
02	<a href="#">Tarapur Atomic Power Station (TAPS), Maharashtra</a>	2	BWR	160	October 28, 1969
03	<a href="#">Tarapur Atomic Power Station (TAPS), Maharashtra</a>	3	PHWR	540	August 18, 2006
04	<a href="#">Tarapur Atomic Power Station (TAPS), Maharashtra</a>	4	PHWR	540	September 12, 2005
05	<a href="#">Rajasthan Atomic Power Station (RAPS), Rajasthan</a>	1	PHWR	0	December 16, 1973
06	<a href="#">Rajasthan Atomic Power Station (RAPS), Rajasthan</a>	2	PHWR	200	April 1, 1981
07	<a href="#">Rajasthan Atomic Power Station (RAPS), Rajasthan</a>	3	PHWR	220	June 1, 2000
08	<a href="#">Rajasthan Atomic Power Station (RAPS), Rajasthan</a>	4	PHWR	220	December 23, 2000
09	<a href="#">Rajasthan Atomic Power Station (RAPS), Rajasthan</a>	5	PHWR	220	February 4, 2010
10	<a href="#">Rajasthan Atomic Power Station (RAPS), Rajasthan</a>	6	PHWR	220	March 31, 2010

## **NUCLEAR FISSION (CURRENT TECHNOLOGY)**

- **Process:** A heavy, unstable nucleus (Uranium-235) is bombarded with neutrons, causing it to split (fission) into smaller nuclei, releasing immense energy and more neutrons.
- **Fuel:** Enriched Uranium (U-235).
- **Waste:** Produces long-lived radioactive waste requiring careful disposal.
- **Safety:** Requires robust control systems to manage chain reactions and prevent meltdowns, though modern reactors are very safe.
- **Application:** The established method used in all operating nuclear power plants today to generate electricity.

## **NUCLEAR FUSION (FUTURE POTENTIAL)**

- **Process:** Two light nuclei (like deuterium and tritium, isotopes of hydrogen) collide and fuse to form a heavier nucleus (helium), releasing even more energy than fission.
- **Fuel:** Hydrogen isotopes, abundant in water, making fuel nearly limitless.
- **Waste:** Produces helium (a harmless gas) and energetic neutrons, with significantly less long-lived radioactive material than fission.
- **Safety:** Inherently safer; no risk of meltdown or runaway chain reactions.
- **Application:** Still in experimental stages (like the ITER project), but offers a clean, sustainable energy source for the future.

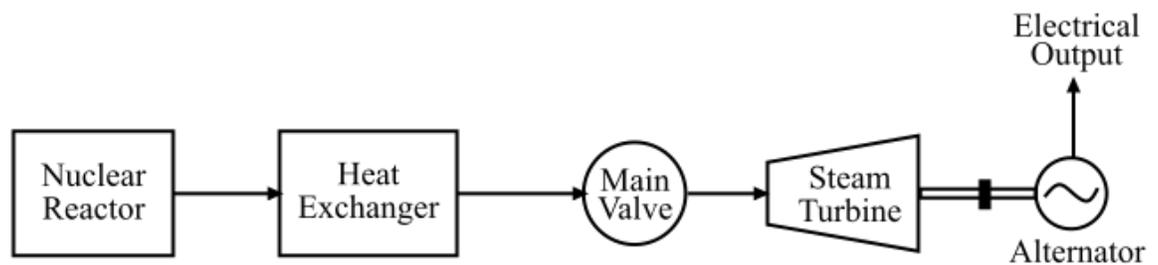
A power generating station which converts heat energy of the nuclear fission into electrical energy is called the **nuclear power plant**.

The most important characteristic of a nuclear power plant is that a large amount of electrical energy can be produced from a relatively small amount of nuclear fuel. Therefore, the running cost of a nuclear power plant is lower than the thermal and diesel power plants.

In practice, it has been found that the complete fission of 1 kg of Uranium ( $U^{235}$ ), which is a radioactive material can produce energy equivalent to that can be produced by the burning of 4500 tons of coal. Therefore, the nuclear energy can be used for producing low cost electrical energy at a large scale so that the problem of energy crisis can be overcome.

## **BLOCK DIAGRAM AND WORKING OF NUCLEAR POWER PLANT**

The block diagram of a typical nuclear power plant is shown in the figure.



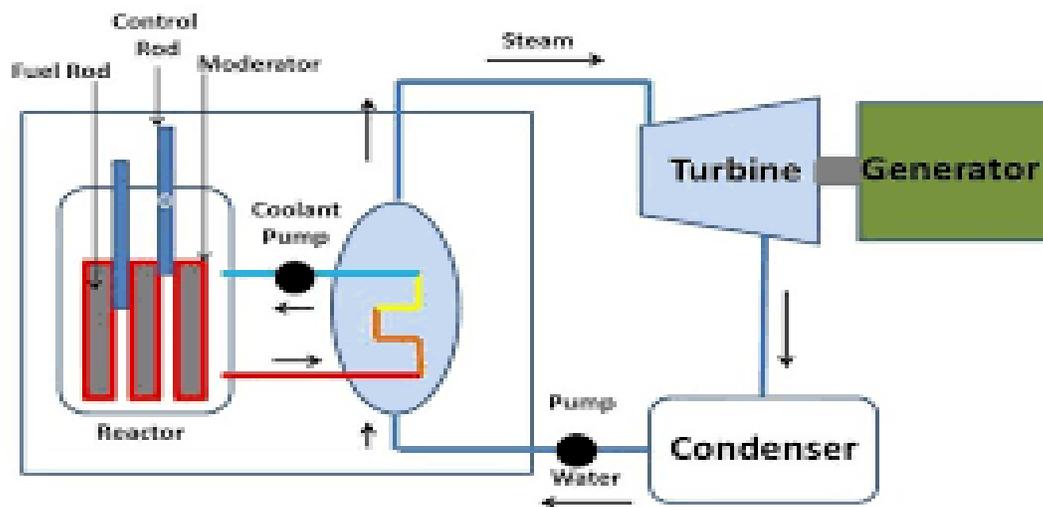
In a nuclear power plant, heavy elements such as Uranium ( $U^{235}$ ) or Thorium ( $Th^{232}$ ) are subjected to nuclear fission (i.e., breaking up of nuclei of heavy atoms into two nearly equal parts with release of large amount of energy) in an equipment called the *nuclear reactor*.

The heat energy, released in the nuclear fission, is utilised for producing the steam at high pressure and temperature. This steam runs a steam turbine which converts the heat energy of steam into

mechanical energy. The steam turbine drives the electric generator which converts the mechanical energy of the turbine into electrical energy.

A nuclear power plant works by using nuclear fission (splitting uranium atoms) in a reactor to generate intense heat, which boils water into high-pressure steam; this steam then spins a turbine connected to a generator, producing electricity, similar to fossil fuel plants but with a nuclear reactor as the heat source. The key steps involve controlled fission, heat transfer to water, steam production, turbine rotation, and electricity generation, with the spent steam being cooled and recycled.

### **Working Principle of a Nuclear Power Plant:**



**Nuclear Power Plant**

A nuclear power plant generates electricity using the heat produced by nuclear fission reactions. The working principle can be explained in the following steps:

## **1. Nuclear Fission Reaction**

- The core of the nuclear reactor contains fuel rods made of fissile material, usually Uranium-235 or Plutonium-239.
- When a neutron strikes the nucleus of a fissile atom, it splits into two smaller nuclei, releasing a large amount of heat energy and more neutrons.
- These released neutrons cause further fission reactions, creating a chain reaction.

## **2. Heat Generation**

- The heat generated from the fission reactions raises the temperature of the reactor core.
- This heat is transferred to a coolant (usually water) circulating through the reactor core.

## **3. Heat Transfer and Steam Production**

- The heated coolant carries the thermal energy to a heat exchanger or steam generator.
- In the steam generator, the heat from the coolant converts water into steam.

## **4. Electricity Generation**

- The high-pressure steam drives a turbine connected to an electrical generator.
- As the turbine blades rotate, the generator converts mechanical energy into electrical energy.

## 5. Cooling and Recirculation

- After passing through the turbine, the steam is condensed back into water in a condenser.
- The condensed water is pumped back to the steam generator to repeat the cycle.
- The coolant in the reactor core is also circulated continuously to maintain the heat transfer.

### **Nuclear Reactor:**

**Definition:** The nuclear reactor is an essential system in a nuclear power plant. They include nuclear chain reactions to generate heat using a method called fission. The heat which is generated can be used to make steam for spinning a turbine. So that electricity can be generated. In global, there are hundreds of commercial reactors are there, in that above 90 reactors are located in the USA. So nuclear power is one of the largest energy sources for reliable and carbon-free electricity.

### **Working of Nuclear Reactor:**

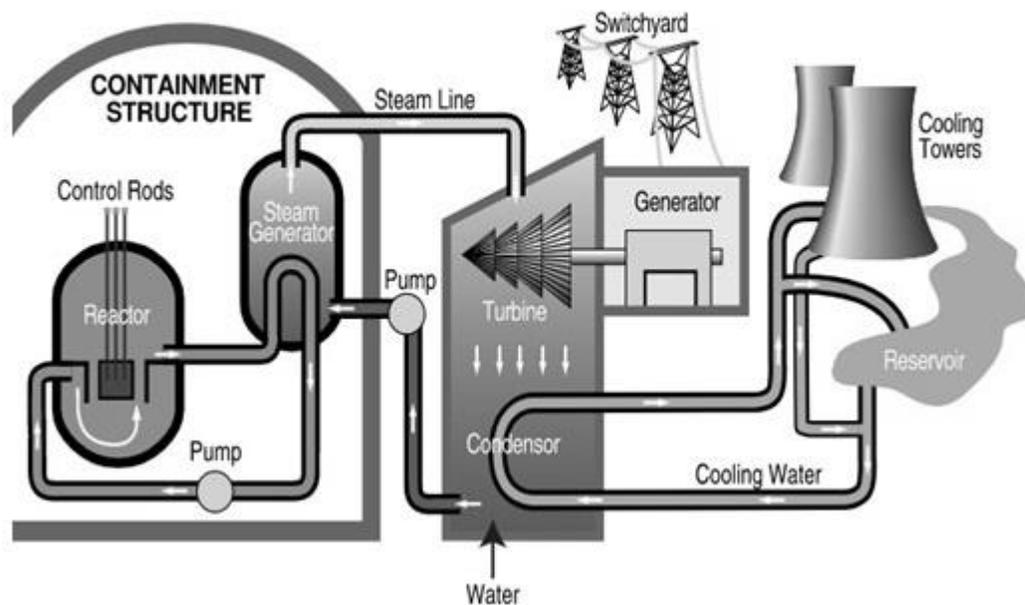
The main function of the nuclear reactor is to control nuclear fission. The nuclear reactor working principle is nuclear fission and it is one kind of method used for splitting the [atoms](#) to generate electricity. Nuclear reactors use uranium that will process into tiny ceramic pellets & stacked jointly into fuel rods. A fuel assembly can be formed by a bunch of above 200 fuel rods. Usually, a reactor core can be fabricated through these assemblies based on the level of power.

In the vessel of a nuclear reactor, the fuel rods are placed within the water. So that it can act like a coolant as well as mediator to assist while reducing the speed of the neutrons. These neutrons can be generated through fission to maintain the chain reaction.

After that, control rods can be placed into the reactor core for reducing the rate of reaction. The generated heat through the fission process can make the water into steam to rotate a turbine for generating carbon-free electricity.

### **Components**

The essential components of the nuclear reactor mainly include the following. The nuclear reactor diagram is shown below.



**Nuclear Reactor Block Diagram**

- Core
- Reflector
- Control Rods
- Moderator
- Coolant
- Turbine
- Containment
- Cooling Towers
- Shielding

### **Core**

The core in the reactor includes nuclear fuel to generate the heat. It includes uranium with less enriched, control systems & structural materials. The shape of the core is a circular cylinder with a diameter of 5 to 15 meters. The core includes a number of individual fuel pins.

### **Reflector**

The reflector is arranged around the core to replicate the back of the neutrons that overflow from the surface of the core.

### **Control Rods**

Nuclear reactor control rods are designed with heavy mass elements. The main function of this is to soak up the neutrons. So that it can continue or stop a reaction. The main examples of these rods are lead, cadmium, etc.

These rods are mainly used for starting the reactor, maintain the reaction at a constant level, and shut down the reactor.

## **Moderator**

The main function of the moderator in a nuclear reactor is to slow down the neutrons from high energy levels as well as high velocities. So that there is a chance for the neutron to hit the fuel rods will be increased.

The modern moderators used at present mainly include water H<sub>2</sub>O, heavy water D<sub>2</sub>O, Beryllium, and Graphite. The properties of the moderator are the stability of thermal is high, radiation & chemical stability, non-corrosiveness, etc.

## **Coolant**

The material that is used to transfer the heat from fuel to a turbine through the core like water, liquid sodium, heavy-water, helium, or something else is known as coolant. The characteristic of coolant mainly include melting point is low, the boiling point is high, non-toxicity, less viscosity, the stability of radiation & chemical, etc. The commonly used coolants are Hg, He, Co<sub>2</sub>, H<sub>2</sub>O.

## **Turbine**

The main function of the turbine is to transfers the heat energy from the coolant device to electricity.

## **Containment**

The containment separates the nuclear reactor from the surroundings. Generally, these are available in dome-shaped and designed with high-density and steel-reinforced concrete.

## Cooling Tower

These are used by some types of power plants to put the surplus heat that cannot be changed to heat energy because of the thermodynamic laws. These towers are the hyperbolic symbols for nuclear energy. These towers can generate simply freshwater vapor.

## Shielding

It protects the working men from the radiation effect. In the fission process, particles like alpha, beta, gamma, fast & slow neutrons can be formed. So to give safety from them, concrete or lead thick layers are used around the reactor. The alpha & beta particles can be stopped by using thick layers of plastics or metals.

## Radiation Hazards

### Types of Nuclear Radiation

Radiation	Nature	Penetrating Power	Hazard Level
<b>Alpha (<math>\alpha</math>)</b>	Helium nucleus	Very low	High if inhaled/ingested
<b>Beta (<math>\beta</math>)</b>	Fast electrons	Moderate	Skin & internal damage
<b>Gamma (<math>\gamma</math>)</b>	Electromagnetic waves	Very high	Severe whole-body exposure
<b>Neutrons (<math>n</math>)</b>	Neutral particles	Very high	Highly dangerous, causes activation

## **Biological Effects of Radiation**

Radiation damages living cells by ionization.

### **(a) Somatic Effects (affect exposed person)**

- Skin burns
- Radiation sickness
- Cataracts
- Cancer
- Sterility

### **(b) Genetic Effects (affect future generations)**

- DNA mutations
- Birth defects
- Hereditary diseases

## **Radiation Exposure Units**

- Absorbed dose: Gray (Gy)
- Dose equivalent: Sievert (Sv)
- Permissible dose limit (workers): ~20 mSv/year

## **Radiation Hazards in Nuclear Power Plants**

- Reactor core leakage
- Spent fuel handling
- Radioactive coolant
- Waste storage
- Accidental releases (e.g., Fukushima, Chernobyl)

## **Radiation Shielding**

### Purpose of Shielding

- Protect workers, public, and environment
- Reduce radiation to permissible levels
- Ensure safe operation and maintenance

### Shielding Principles

1. Time – Minimize exposure time
2. Distance – Increase distance from source
3. Shielding – Use suitable materials

### Shielding Materials

Radiation      Shielding Material

Alpha      Paper, clothing

Beta      Plastic, aluminum

Gamma      Lead, concrete

Neutrons      Water, paraffin, concrete

## **Types of Shielding in Nuclear Plants**

- Reactor shielding: Thick concrete walls
- Biological shielding: Around reactor core
- Thermal shielding: Protects structure from heat
- Containment building: Prevents radiation escape

## **Reactor Shield Design**

- Multi-layer shielding

- High-density concrete
- Lead and steel layers
- Neutron absorbers (boron, cadmium)

## **NUCLEAR WASTE DISPOSAL:**

### Classification of Nuclear Waste

<b>Type</b>	<b>Examples</b>	<b>Activity Level</b>
<b>Low-Level Waste (LLW)</b>	Gloves, tools	Low
<b>Intermediate-Level Waste (ILW)</b>	Resins, cladding	Medium
<b>High-Level Waste (HLW)</b>	Spent fuel	Very high

### Sources of Nuclear Waste

- Nuclear power plants
- Research reactors
- Medical applications
- Nuclear fuel reprocessing

### Nuclear Waste Disposal Methods

#### **(a) Delay and Decay**

- Temporary storage
- Used for short-lived isotopes

#### **(b) Dilution and Dispersion**

- Controlled release (now discouraged)

#### **(c) Concentrate and Contain**

- Most preferred method
- Waste immobilized and stored

### **Disposal Techniques**

#### 1. Near-Surface Disposal

- For low-level waste
- Concrete vaults or trenches

#### 2. Deep Geological Disposal

- For high-level waste
- Underground repositories (300–1000 m)
- Stable rock formations

#### 3. Spent Fuel Pools

- Water acts as coolant and shield

#### 4. Dry Cask Storage

- Steel and concrete casks
- Passive cooling

### **Waste Immobilization Methods**

- Vitrification: Waste mixed with molten glass
- Encapsulation: Concrete/bitumen
- Ceramic matrices

### **Safety Measures in Waste Disposal**

- Multi-barrier concept
- Radiation monitoring

- Long-term surveillance
- Geological stability analysis

## **Advantages and Challenges**

### **Advantages**

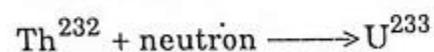
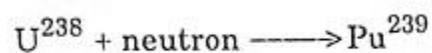
- Controlled waste management
- Minimal environmental impact if properly handled
- Long-term containment

### **Challenges**

- Long half-life of waste
- Public acceptance
- High cost
- Long-term safety assurance

### **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. The fast breeder reactor system is shown in Fig. 3.11.



## Fast Breeder Reactor (FBR)

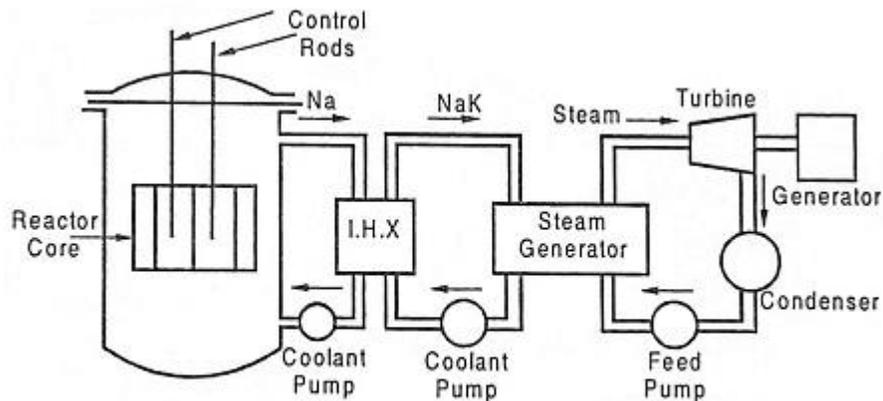


Fig:3.11 Fast Breeder Reactor

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

In this Fast Breeder Reactor (FBR) system, the core containing  $\text{U}^{235}$  is surrounded by a blanket of fertile material  $\text{U}^{238}$ . In this reactor, no moderator is used. The fast-moving neutrons liberated due to fission of  $\text{U}^{235}$  are absorbed by  $\text{U}^{238}$  which gets converted to fissionable material  $\text{Pu}^{239}$  which is capable of sustaining chain reaction. Thus, the reactor is very important because it breeds fissionable materials from fertile material  $\text{U}^{238}$  available in large quantities.

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)

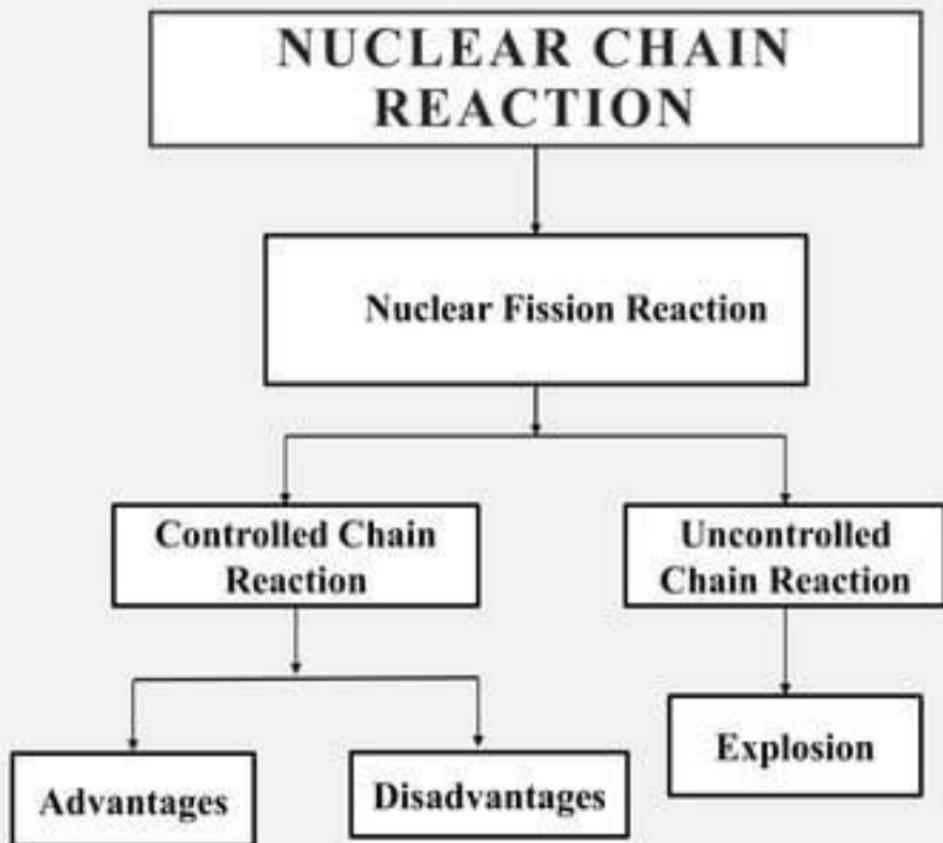
Carbon dioxide.

**Sodium has the following advantages:**

Sodium has very low absorption cross-sectional area.

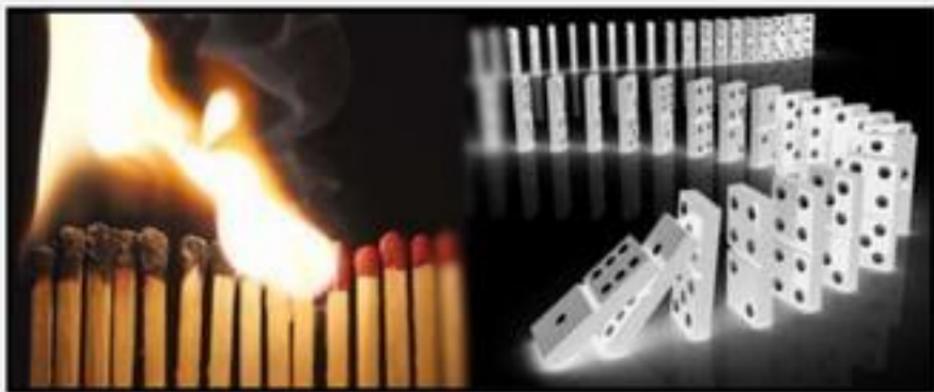
Sodium possesses good heat transfer properties at high temperature and low pressure.

Sodium does not react any of the structural materials used in primary circuits.



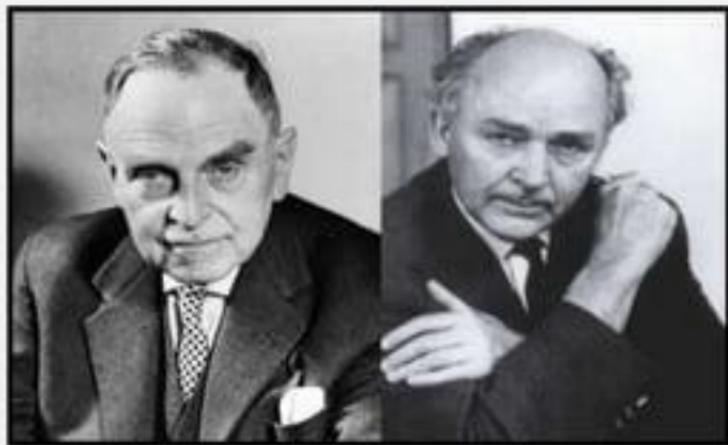
## What is chain reaction?

- A chain reaction is a chemical process in which products themselves promote or spread the reaction.
- A self-sustained reaction or a series of reaction caused by the previous one.
- For example:
  - Burning of match stick when placed in series.
  - Falling of dominos placed on trajectory.



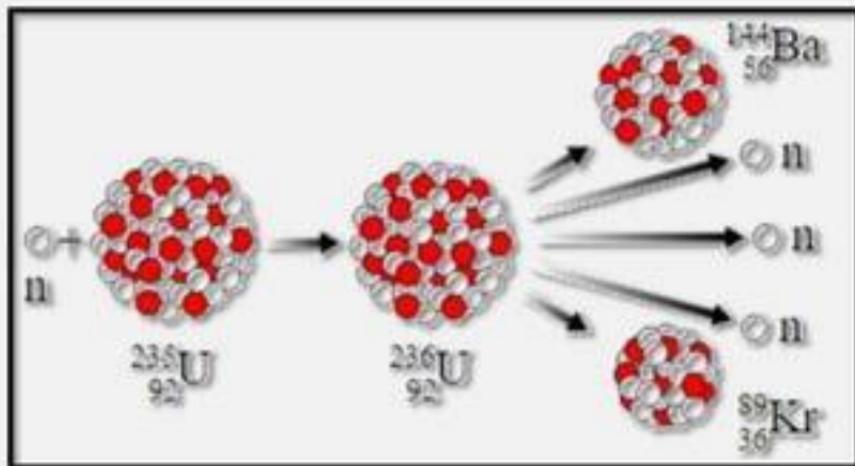
# Nuclear Chain Reaction

- The chain reaction in which bombardment of nucleus involves is called nuclear chain reaction.
- One single nuclear reaction that causes one or more than one consecutive nuclear reactions and thus leads to the happening of a self-propagating series of these reactions.
- This process involves bombardment of nucleus of any heavy element by neutrons called fission process or reaction.
- Hann Stresemann and Otto Hahn in 1939 proved theoretically that fission of heavy element is possible and the large amount of energy released can be used in power generation.



# Nuclear Fission process

- A heavy nucleus is bombarded with slow moving neutrons and two nuclei produced with more neutrons and high amount of energy is released.

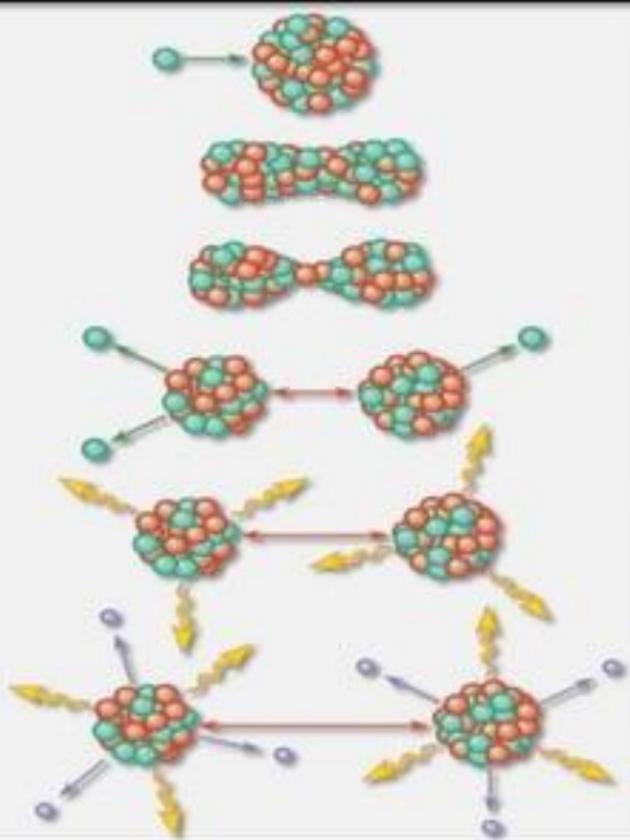


- Let suppose we are considering U-235 as a heavy element. A slow moving electron is set to strike on it and resulting two lighter nuclei(Ba-144 and Kr-89) produced along with 3 moving neutrons and high amount of energy which can be denoted as Q.
- The isotope which is used as targeted material is called fissile isotope.

## Mechanism of Fission process

- The neutron strikes the nucleus and is absorbed.
- The absorbed neutron causes the nucleus to undergo deformation.
- In about  $10^{-14}$  sec, one of the deformation is so drastic that the nucleus cannot recover.
- The nucleus fissions, releasing an average of two to three neutrons.
- In about  $10^{-12}$  sec, the fission fragments lose their kinetic energy and come to rest, emitting a number of gamma rays. These fragments are called fission products.

## MECHANISM OF FISSION PROCESS



## CHAIN REACTION IN NUCLEAR FISSION

SAME ONLY



"The chain reaction is a series of nuclear fissions in which the neutrons produced in each fission cause additional fissions."

## Some Examples of Nuclear Fission Reaction

Some nuclear fission reactions are as under:

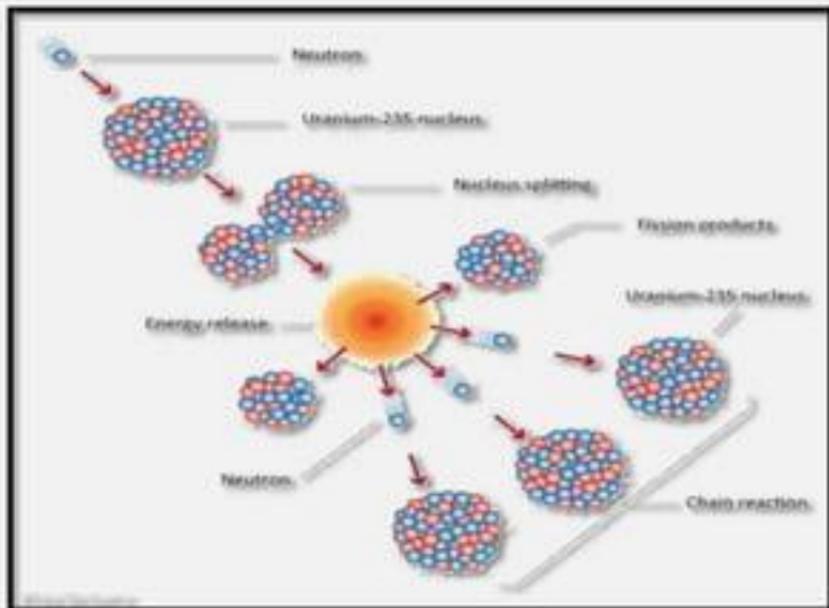
- $^{235}\text{U}_{92} + ^1_0\text{n} \rightarrow ^{137}\text{Te}_{52} + ^{97}\text{Zr}_{40} + 2^1_0\text{n} + Q$
- $^{235}\text{U}_{92} + ^1_0\text{n} \rightarrow ^{144}\text{Ba}_{56} + ^{89}\text{Kr}_{36} + 3^1_0\text{n} + Q$
- $^{235}\text{U}_{92} + ^1_0\text{n} \rightarrow ^{148}\text{La}_{37} + ^{85}\text{Br}_{35} + 3^1_0\text{n} + Q$
- $^{239}\text{Pu}_{94} + ^1_0\text{n} \rightarrow ^{144}\text{Ce}_{58} + ^{94}\text{Kr}_{36} + 2^1_0\text{n} + Q$
- $^{239}\text{Pu}_{94} + ^1_0\text{n} \rightarrow ^{134}\text{Xe}_{54} + ^{103}\text{Zr}_{40} + 3^1_0\text{n} + Q$

In these reactions we see that there are many different products for same element. In a chain reaction these are all the possibilities of products.

When uranium-235 is bombarded by neutron firstly the products are Ba and Kr but further the fissile isotopes are Rb and Cs and many more combinations.

# Fission as a chain mechanism

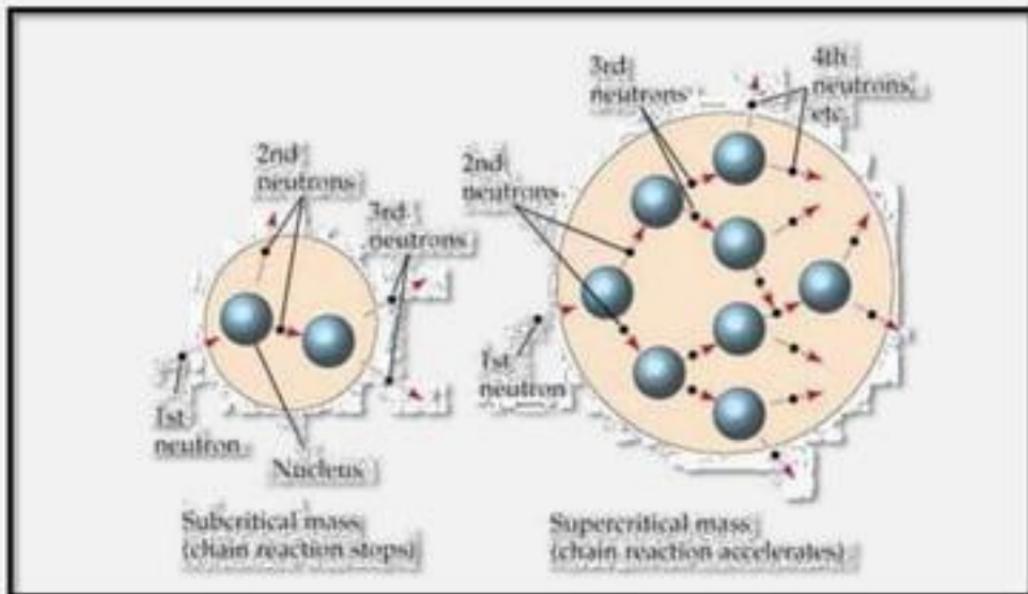
- The nucleus release high speed neutrons, when bombarded by a neutron.
- The released neutron are then target to surrounding nucleus and split more with more release of neutrons.
- The splitting continues and the reaction is said to be chain reaction. This type of reaction responsible in explosives.



# Critical Mass

- In order for a fission chain reaction to occur, the sample of fissionable material must have a certain minimum mass.
- Otherwise, neutrons escape from the sample before they have the opportunity to strike another nucleus and cause additional fission.
- The chain stops if enough neutrons are lost.
- The amount of fissionable material large enough to maintain the chain reaction with a constant rate of fission is called the **critical mass**.
- When a critical mass of material is present, only one neutron from each fission is subsequently effective in producing another fission.

- The critical mass of uranium-235 is about 1 kg. If more than a critical mass of fissionable material is present, very few neutrons escape.
- The chain reaction thus multiplies the number of fissions, which can lead to a nuclear explosion.
- A mass in excess of a critical mass is referred to as a **supercritical mass**.



## Why we use Uranium-235 and Plutonium?

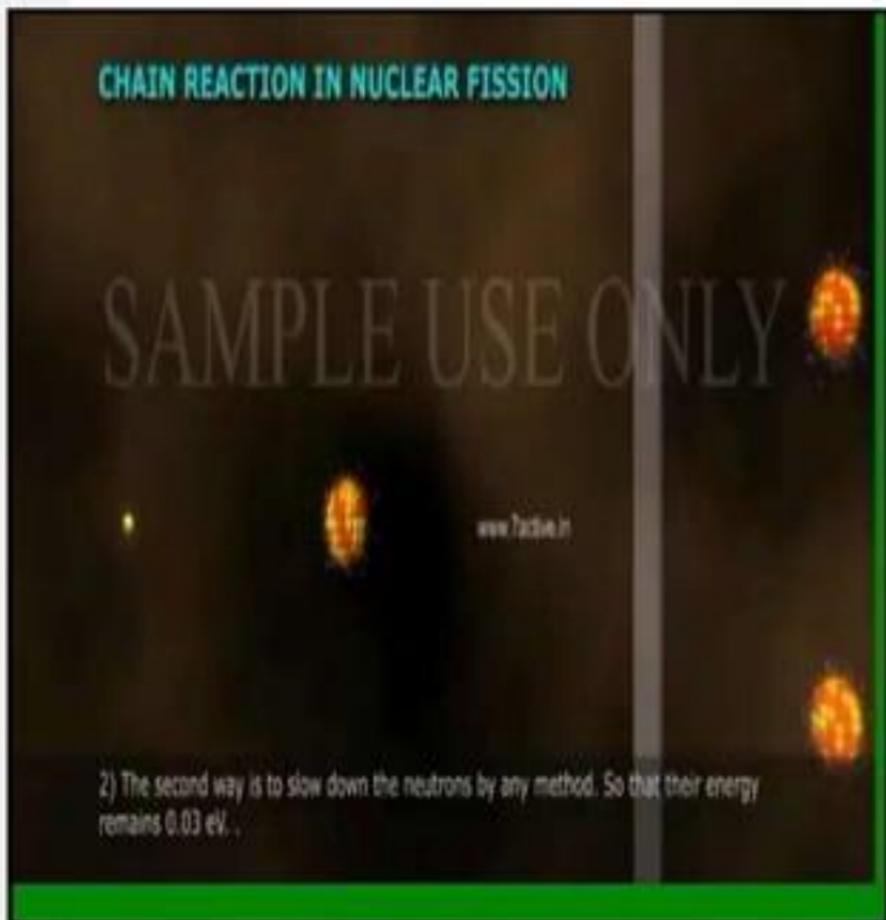
- The most common isotope, U-238, was not suitable for a nuclear weapon because there is a fairly high probability that an incident neutron would be captured to form U-239 instead of causing a fission.
- However, U-235 has a high fission probability as compared to U-238.
- U-235 has abundance of 0.7% in nature. So large amount of uranium was needed to fulfil the requirements of U-235.
- Also it cannot be separated chemically from U-238 because isotopes are much chemically similar.
- Recent study had also predicted that plutonium 239 would have a high fission probability. However, plutonium 239 is not a naturally occurring element and would have to be made.

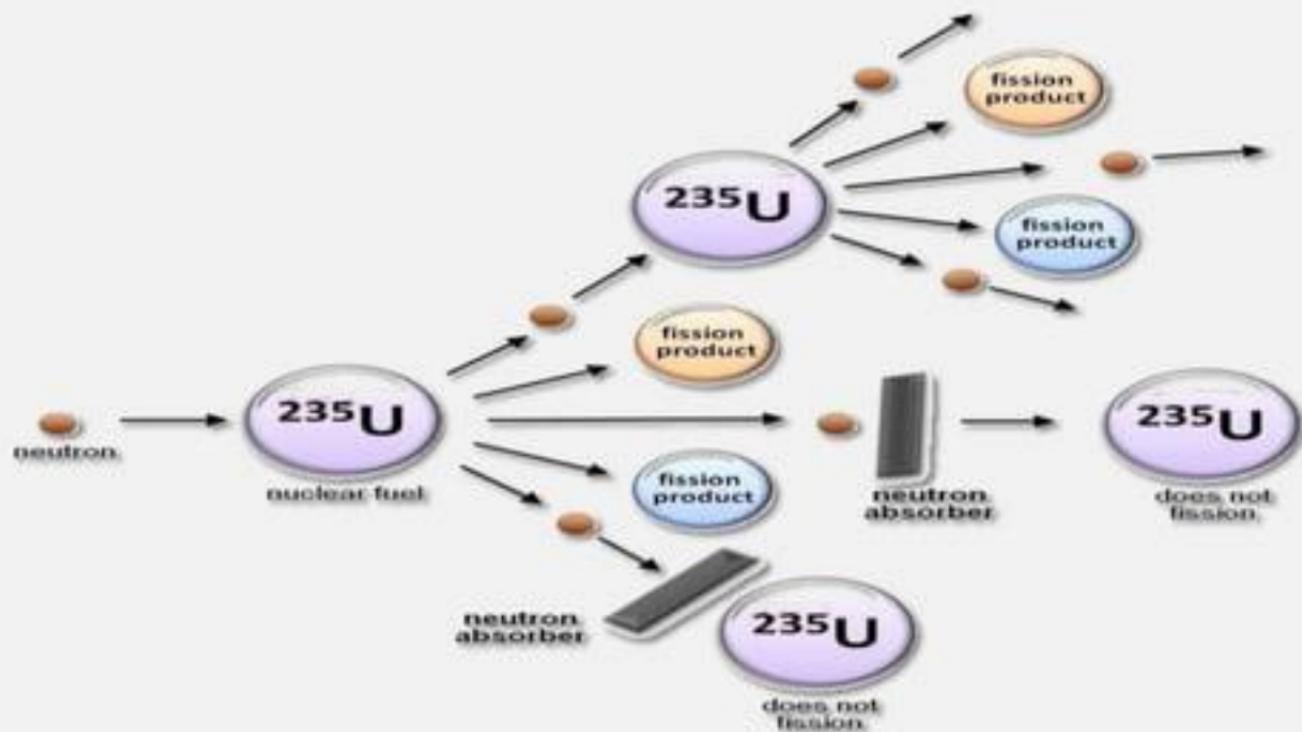
# Types of Fission chain process

- There are two types of Fission process:
  - Controlled Fission Process
  - Uncontrolled Fission Process

## CONTROL CHAIN REACTION

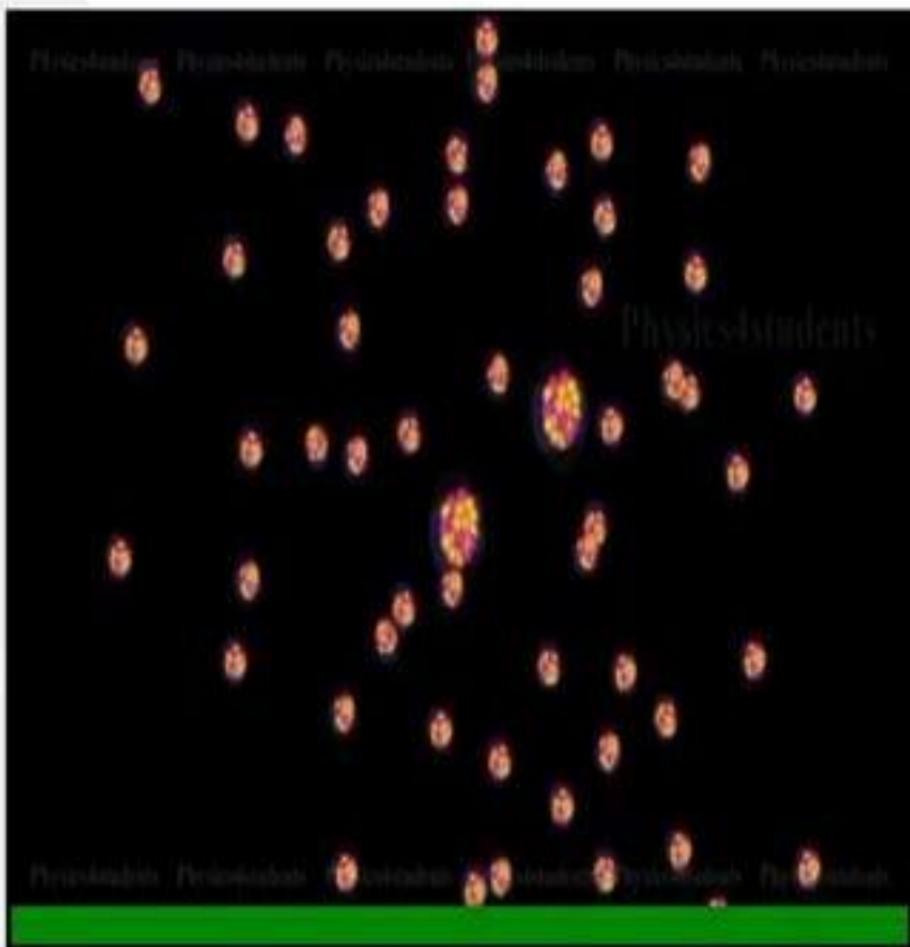
- To sustained **controlled** nuclear **reaction**, for every 2 or 3 neutrons released, only one must be allowed to strike another uranium nucleus.
- Most reactors are **controlled** by means of **control** rods that are made of a strongly neutron-absorbent material such as boron or cadmium. ...
- So in order to control the power it is necessary to introduce non fission nuclear absorption in the system, example: insert control rods.





## UNCONTROLLED CHAIN REACTION

- These types of reactions occurs in nuclear bombs in which reactions have no control measures. And this reaction carried out by in absence of moderator.
- It release large amount of energy at a time.
- This rapid release of nuclear energy causes an explosion.
- In an uncontrolled chain reaction energy releases at large amount in a fraction of a second; an 84 trillion joules of energy produces from 22 pounds or 10 kg of uranium-235 which is highly refined or the equivalent of 20,000 tons of TNT.





## **Problem with Nuclear Fission Reactions**

There are two major problems associated with the system:

- There is always a risk that control rods would not work in any nuclear reactor because of human errors and failures or sabotage. In this case there is a cause of explosion or release of a large amount of radiation.
- The used fuel is highly radioactive and it must be stored safely for thousands of years. But used fuel still remains at various power plants in many cases. So as a result nuclear chain reactions have been decreased in many countries including the United States.

## **Advantages of fission process**

There are many advantages of fission process implied worldwide. Some are discussed here:

- Produced heat is converted to electricity.
- With little amount of fuel, large amount of heat is produces.
- 28 gram of uranium produce same amount of energy when 100 metric tons of coal is used.
- Does not contribute in global warming and causes pollution.
- The waste produced during process is very less.
- The nuclear reactor can support fission process up to 40 to 60 years.

## Disadvantages of Fission process

There are some negative point of fission reaction:

- Nuclear power reactors are very compact and building cost is very high.
- Reactors require high security.
- Small leakage from reactor can cause explosion.
- Fuel used in process is very expensive and present in trace amounts in nature.
- Possibility of uncontrolled nuclear fission can cause nuclear fallout.



## **Applications of Fission process**

There are various applications of nuclear fission:

- Generating electricity.
- Nuclear propulsion system to drive ships or submarines.
- Make neutrons for sensitive Elemental analysis and Industrial use.
- Nuclear weapon.
- Sensitive neutron detector.
- Radioisotopes for industrial use, therapeutic or diagnostic medical purposes.

# Types of Nuclear Reactors

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# Introduction

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## Nuclear Reactor:

A nuclear reactor is a device to initiate, and control, a sustained nuclear chain reaction.

The most common use of nuclear reactor is for the generation of electrical power also termed as nuclear power.

# Types of Nuclear Reactors

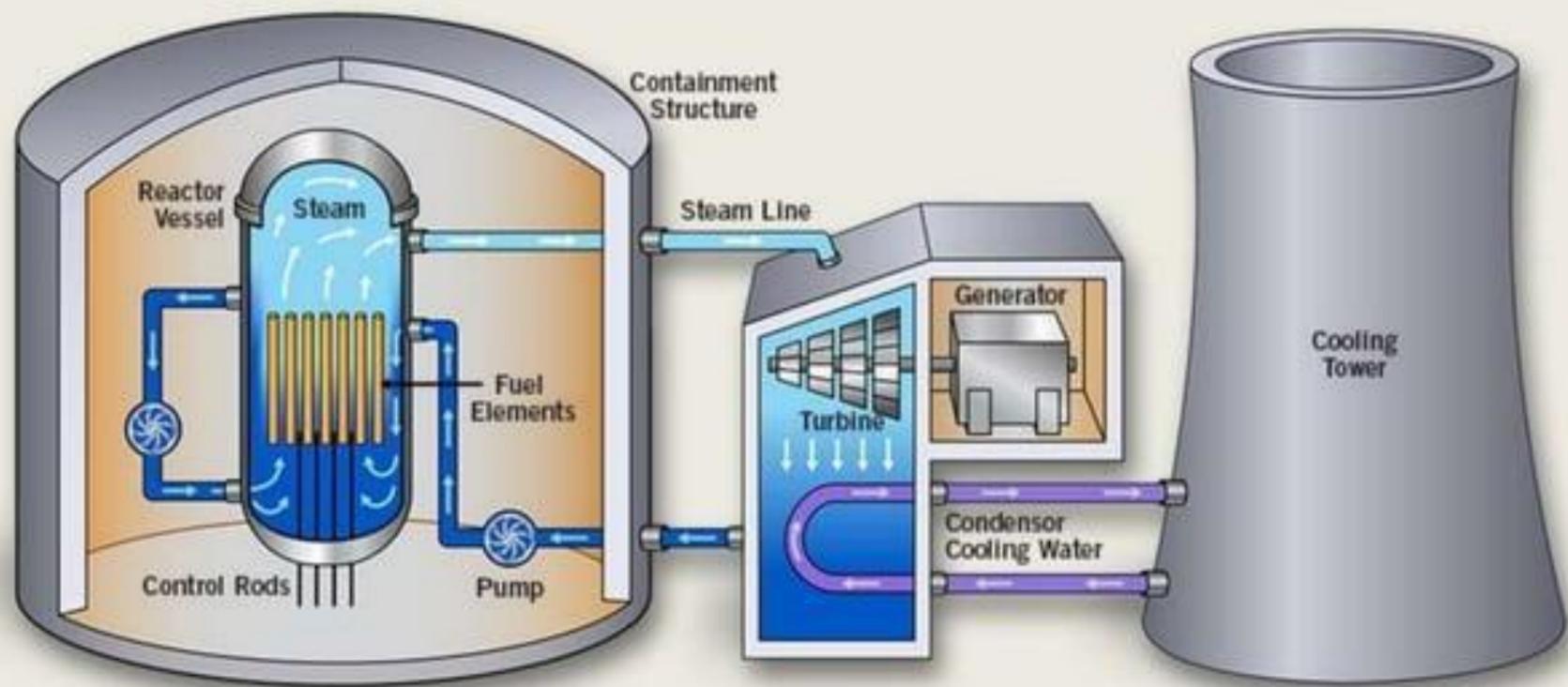
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1. BWR-Boiling Water Reactor
2. PWR-Pressurized Water Reactor
3. PHWR-Pressurised Heavy Water Reactor
4. GCR-Gas Cooled Reactor
5. AGR-Advanced Gas-Cooled Reactor
6. LGR-Light Water Cooled - Graphite Moderated Reactor

# BWR-Boiling Water Reactor

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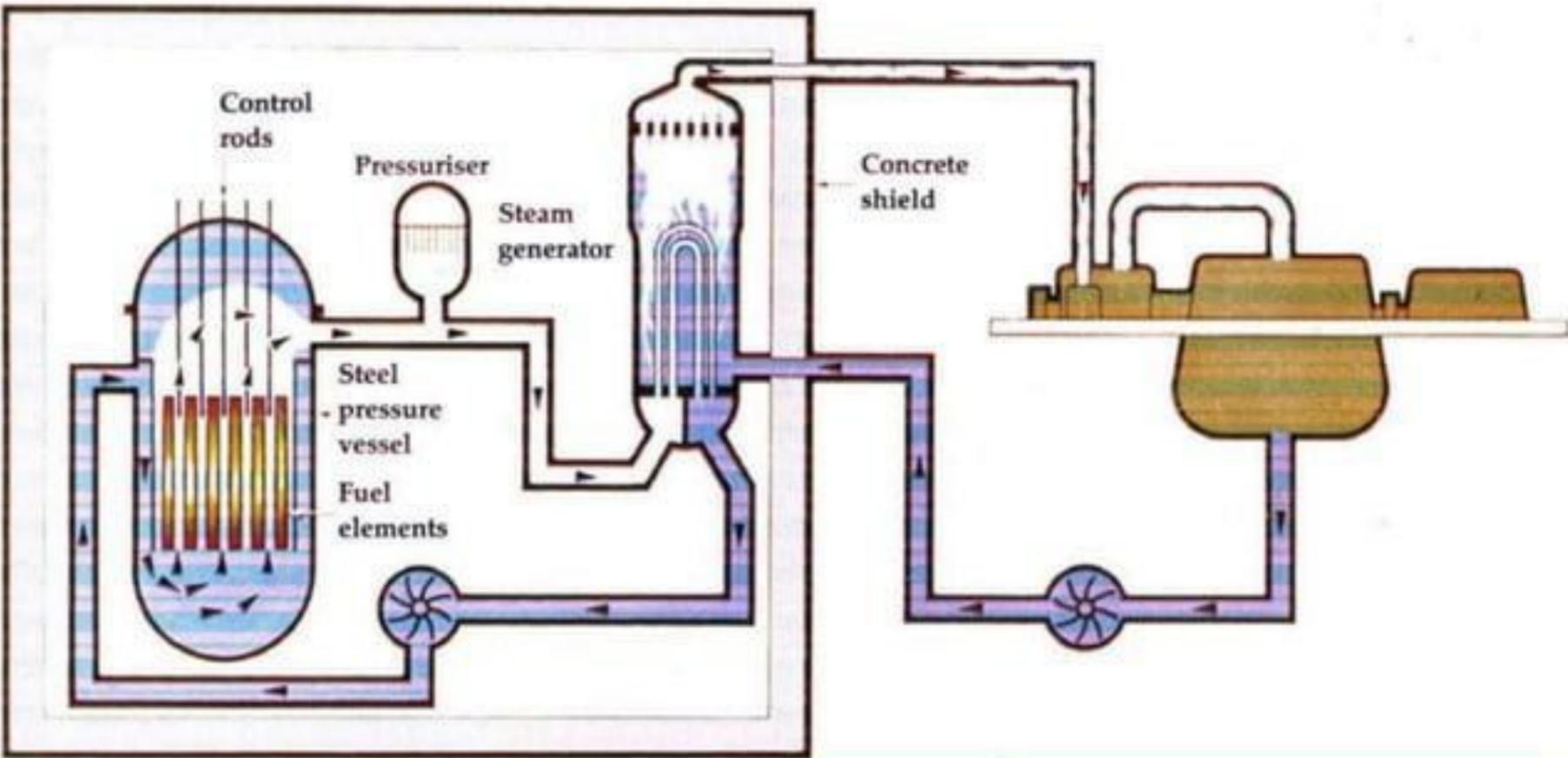
- In the boiling water reactor (BWR), the water which passes over the reactor core act as moderator and coolant. It is also the steam source for the turbine.
- The disadvantage of BWR is that any fuel leak might make the water radioactive and that radioactivity would reach the turbine and the rest of the loop.
- A typical operating pressure for BWR is about 70 atm at which the water boils at about 285°C temperature. This operating temperature gives a efficiency of only 42% with a practical operating efficiency of around 32%, somewhat less than the Pressurized Water Reactor(PWR).



# PWR-Pressurized Water Reactor

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- In the pressurized water reactor (PWR), the water which passes over the reactor core act as moderator and coolant but does not flow to the turbine. It is sent in a pressurized primary loop. The primary loop water produces steam in the secondary loop which drives the turbine.
- The advantage PWR is that a fuel leak in the core would not pass any radioactive contaminants to the turbine and condenser.
- Another advantage is that the PWR can operate at higher pressure and temperature, about 160 atm and about 315°C. This provides a higher efficiency than the boiling water reactor(BWR) , but PWR is more complicated and more costly to construct.



### **PART A – Two Mark Questions:**

1. Define **nuclear fission**.
2. What is a **nuclear chain reaction**?
3. Mention any two **criteria for selecting the location of a nuclear power plant**.
4. Define **moderator** used in a nuclear reactor.
5. State the function of **control rods** in a nuclear reactor.
6. What is meant by **critical mass**?
7. List any two **nuclear fuels** used in power reactors.
8. What is the role of a **coolant** in a nuclear reactor?
9. Define **radiation hazard**.
10. What is meant by **radioactive shielding**?
11. Mention any two **advantages of nuclear power plants**.
12. What is a **fast breeder reactor (FBR)**?
13. Write the function of a **neutron reflector**.
14. What is the working principle of a **nuclear power plant**?
15. State any two differences between **renewable and nuclear energy**.
16. What is meant by **radioactive waste**?
17. List any two **methods of nuclear waste disposal**.
18. What is **thermal neutron**?
19. Name any two **types of nuclear reactors**.
20. What is meant by **half-life of radioactive material**?

## **PART B – Ten Mark Questions**

1. Explain the **location requirements of a nuclear power plant** with suitable reasons.
2. Explain the **working principle of a nuclear power plant** with a neat diagram.
3. Describe the process of **nuclear fission** and explain how energy is released.
4. Explain **nuclear chain reaction** and discuss its controlled and uncontrolled forms.
5. Describe **nuclear fuels** used in reactors and explain their properties.
6. Explain the **construction and working of a nuclear reactor** with neat sketch.
7. Explain the **functions and types of reactor components**:
  - Moderator
  - Control rods
  - Reflectors
  - Coolants
8. Classify **types of nuclear reactors** and briefly explain their features.
9. With neat diagrams, explain the construction and working of:
  - Pressurized Water Reactor (PWR)
  - Boiling Water Reactor (BWR)
10. Explain **radiation hazards**, methods of **radiation shielding**, and **nuclear waste disposal techniques**.

## Objective Type Questions with Answers

### 1. Nuclear fission is the process of

- a) Combining two light nuclei
- b) Splitting of a heavy nucleus
- c) Emission of alpha particles
- d) Absorption of electrons

**Answer:** b) Splitting of a heavy nucleus

### 2. The commonly used fuel in nuclear power plants is

- a) Thorium-232
- b) Uranium-235
- c) Plutonium-240
- d) Uranium-238

**Answer:** b) Uranium-235

### 3. Energy in a nuclear power plant is produced due to

- a) Chemical reaction
- b) Combustion
- c) Nuclear fission
- d) Nuclear fusion

**Answer:** c) Nuclear fission

### 4. The main function of a moderator is to

- a) Absorb neutrons
- b) Slow down fast neutrons
- c) Reflect neutrons
- d) Control reactor temperature

**Answer:** b) Slow down fast neutrons

### 5. Which material is commonly used as a moderator?

- a) Cadmium
- b) Boron
- c) Graphite
- d) Lead

**Answer:** c) Graphite

**6. Control rods are made of materials that**

- a) Reflect neutrons
- b) Slow down neutrons
- c) Absorb neutrons
- d) Emit neutrons

**Answer:** c) Absorb neutrons

**7. Which of the following is used as a control rod material?**

- a) Uranium
- b) Graphite
- c) Boron
- d) Heavy water

**Answer:** c) Boron

**8. The function of a neutron reflector is to**

- a) Absorb neutrons
- b) Increase neutron leakage
- c) Reduce neutron leakage
- d) Increase temperature

**Answer:** c) Reduce neutron leakage

**9. The coolant in a nuclear reactor is used to**

- a) Slow neutrons
- b) Absorb radiation
- c) Remove heat
- d) Control fission rate

**Answer:** c) Remove heat

**10. Pressurized Water Reactor (PWR) uses \_\_\_\_\_ as coolant and moderator**

- a) Light water
- b) Heavy water
- c) Liquid sodium
- d) Carbon dioxide

**Answer:** a) Light water

**11. In BWR, water boils**

- a) Inside the steam turbine
- b) Inside the reactor core
- c) Inside the condenser
- d) Inside the cooling tower

**Answer:** b) Inside the reactor core

**12. Fast Breeder Reactor (FBR) mainly produces**

- a) Electricity only
- b) More fuel than it consumes
- c) Heavy water
- d) Steam directly

**Answer:** b) More fuel than it consumes

**13. Which reactor uses liquid sodium as coolant?**

- a) PWR
- b) BWR
- c) FBR
- d) PHWR

**Answer:** c) FBR

**14. The main advantage of nuclear power plant is**

- a) Low capital cost
- b) No radiation
- c) Large power generation
- d) Easy waste disposal

**Answer:** c) Large power generation

**15. The half-life of a radioactive material is the time required for**

- a) Complete decay
- b) Double the mass
- c) Half of atoms to decay
- d) Radiation to stop

**Answer:** c) Half of atoms to decay

**16. Radiation hazard mainly affects**

- a) Machines
- b) Human tissues
- c) Buildings
- d) Atmosphere

**Answer:** b) Human tissues

**17. Which radiation has maximum penetrating power?**

- a) Alpha
- b) Beta
- c) Gamma
- d) Neutron

**Answer:** c) Gamma

**18. Lead is commonly used for shielding against**

- a) Alpha rays
- b) Beta rays
- c) Gamma rays
- d) Neutrons

**Answer:** c) Gamma rays

**19. Nuclear waste is best disposed by**

- a) Open dumping
- b) Ocean discharge
- c) Deep geological burial
- d) Burning

**Answer:** c) Deep geological burial

**20. Which of the following is a fast neutron reactor?**

- a) PWR
- b) BWR
- c) FBR
- d) PHWR

**Answer:** c) FBR

**21. Heavy water is used in reactors mainly as**

- a) Fuel
- b) Moderator
- c) Coolant only
- d) Shield

**Answer:** b) Moderator

**22. Criticality of a reactor depends mainly on**

- a) Temperature
- b) Neutron economy
- c) Coolant flow
- d) Pressure

**Answer:** b) Neutron economy

**23. Which isotope of uranium is fertile?**

- a) U-235
- b) U-238
- c) U-233
- d) Pu-239

**Answer:** b) U-238

**24. The biological effect of radiation is measured in**

- a) Watt
- b) Sievert
- c) Tesla
- d) Pascal

**Answer:** b) Sievert

**25. Which gas is commonly used as coolant in gas-cooled reactors?**

- a) Hydrogen
- b) Carbon dioxide
- c) Oxygen
- d) Nitrogen

**Answer:** b) Carbon dioxide

**26. Nuclear fusion differs from fission because fusion involves**

- a) Splitting nuclei
- b) Heavy nuclei only
- c) Combining light nuclei
- d) Chain reaction

**Answer:** c) Combining light nuclei

**27. The breeder reactor converts fertile material into**

- a) Moderator
- b) Coolant
- c) Fissile material
- d) Waste

**Answer:** c) Fissile material

**28. The main hazard of nuclear power plants is**

- a) Noise pollution
- b) Thermal pollution
- c) Radiation exposure
- d) Air pollution

**Answer:** c) Radiation exposure

**29. Control rods are fully inserted during**

- a) Normal operation
- b) Startup
- c) Emergency shutdown
- d) Power generation

**Answer:** c) Emergency shutdown

**30. The main purpose of shielding in nuclear plants is to**

- a) Reduce heat
- b) Absorb neutrons only
- c) Protect personnel from radiation
- d) Increase efficiency

**Answer:** c) Protect personnel from radiation



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**Course Outcomes:**

After studying this topic, students will be able to:

1. **Explain the working principle** of hydroelectric and thermal power plants.
2. **Identify suitable site selection criteria** for establishing hydroelectric and thermal power stations.
3. **Describe the layout and components** of a hydroelectric power plant and their functions.
4. **Explain the layout and working components** of a thermal power plant including boilers, turbines, condensers, and feedwater systems.
5. **Differentiate between impulse and reaction turbines** and explain the role of pollution control equipment in thermal power plants.

**BOOK/NPTEL LINK REFERENCE FOR UNIT -1**

1. V. K. Mehta and Rohit Mehta, Principles of Power System, S. Chand, 4th Edition, 2005.
2. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1985.
3. NPTEL – Power Plant Engineering  
<https://nptel.ac.in/courses/112105123>
4. NPTEL – Energy Resources and Technology  
<https://nptel.ac.in/courses/103103206>

**ASSIGNMENT TOPICS:**

**Case Study:**

1. Chernobyl disaster
2. Bhopal disaster



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**UNIT-III: SUBSTATIONS**

**Course Objectives**

The objectives of studying Air Insulated Substations, Gas Insulated Substations, and Bus Bar Arrangements are:

1. To understand the fundamental concept and classification of substations, including indoor and outdoor air-insulated substations used in power systems.
2. To study the layout of 33/11 kV substations and identify the location and function of major equipment such as transformers, circuit breakers, isolators, bus bars, and protective devices.
3. To analyze different bus bar arrangements such as single bus bar, sectionalized bus bar, double bus bar, and main & transfer bus systems for reliability and operational flexibility.
4. To understand the construction and working principles of Gas Insulated Substations (GIS) and their application in modern power systems.
5. To compare Air Insulated Substations (AIS) and Gas Insulated Substations (GIS) in terms of space requirement, reliability, cost, maintenance, and operational efficiency.

## **UNIT-3**

### **AIS & GIS**

**Air Insulated Substations (AIS)** – Indoor & Outdoor substations, Substations layouts of 33/11 kV showing the location of all the substation equipment.

Bus bar arrangements in the Sub-Stations: Simple arrangements like single bus bar, sectionalized single bus bar, double bus bar with one and two circuit breakers, main and transfer bus bar system with relevant diagrams.

**Gas Insulated Substations (GIS)** – Advantages of Gas insulated substations, different types of gas insulated substations, single line diagram of gas insulated substations, constructional aspects of GIS, Installation and maintenance of GIS, Comparison of Air insulated substations and Gas insulated substations.

What is substation?

The assembly of apparatus used to change some characteristic(e.g. Voltage, a.c to d.c, frequency, power factor etc) of electric supply is called a sub-station.

Example: 33/11 kv Sub-Station.

**The following factors are considered while making site selection for a substation:**

1. Type of **Substation**
2. Availability of Suitable and Sufficient Land
3. Communication Facility
4. Atmospheric Pollution
5. Availability of Essential Amenities to the Staff
6. Drainage Facility.

## **CLASSIFICATION OF SUB STATIONS**

The Substation is a part of electrical Power System. That is the part of an electrical generation, transmission and distribution system. It is regarded as the source of energy supply for the local areas of distribution in which these are located. The main function is to receive energy transmitted at high voltage from the generating station, reduce the voltage to appropriate for local distribution and provide facilities for switching.

Some substations are simply switching stations where different connections between various transmission lines are made, others are converting substations which either convert ac into dc or vice versa or convert frequency from higher to lower or vice versa.

Substations have some additional functions. They provide points where safety devices may be installed to disconnect equipment or circuit in the event of fault. Voltage on the outgoing distribution feeders can be regulated at a substation.

A substations is convenient place for installing synchronous condensers at the end of the transmission line for the purposes of improving power factor and make measurements to check the operation of the various parts of the power system.

Street lighting equipment as well as switching controls for street lights can be installed in a substations.

### **SUBSTATION CAN BE CLASSIFIED ON THE BASIS OF FOLLOWING:**

1. Basis of Nature of Duties

#### **1. Step-Up or Primary Substations.**

Such substations are usually associated with generating stations. The generated voltage, which is usually low ( 3.3, 6.6, 11 or 33 KV), is stepped up to primary transmission voltage so that huge blocks of power can be transmitted over long distance to the load centers economically.

#### **2. Primary Grid Substations.**

Such substations are located at suitable load centers along the primary transmission voltage is stepped down to different suitable secondary voltages. The secondary transmission lines are carried over to the secondary substations situated at the load centers where the voltage is further stepped down to sub-transmission or primary distribution voltages.

### **3. Step-Down or Distribution Substations**

Such substations are located at the load centers, where the sub-transmission/primary distribution voltage is stepped down to secondary distribution voltage (415/240V). These are the substations which feed the consumers through distribution network and service lines.

### **2. Basis of Service Rendered**

#### **1. Transformer Substations:**

Transformers are installed on such substations to transform the power from one voltage level to another level as per needs.

#### **2. Switching Substations:**

Such substations are meant for switching operation of power lines without transforming the voltage. At such substations different connections are made between various transmission lines.

#### **3. Converting Substations:**

Such substations are meant for either converting ac to dc or vice versa or converting frequency from higher to lower or vice versa.

### **3. Basis of Operating Voltage**

1. High Voltage Substations ( HV Substations) involving voltage between 11 KV and 66 KV.
2. Extra High Voltage Substations (EHV Substations) involving voltages between 132 KV and 400 KV.
3. Ultra High Voltage Substations (USV Substations) operating on voltage above 400 KV.

### **4. Basis of Importance**

#### **1. Grid Substations.**

These are the substations from where bulk power is transmitted from one point to another point in the grid. These are important because any disturbance in these substations may cause the failure of the grid.

## **2. Town Substations:**

These substations step-down the voltages at 33/11 KV for further distribution in the towns and any failure in such substations results in the failure of supply for whole of the town.

## **5. Basis of Design**

### **1. Indoor Type Substation**

In such substations the apparatus is installed within the substation building. Such substations are usually for a voltage up to 11 KV but can be erected for the 33 KV and 66 KV when the surrounding atmosphere is contaminated with impurities such as metal corroding gases and fumes, conductive dust etc.

### **2. Outdoor Substation**

#### **(a) Pole Mounted Substations:**

Such substations are erected for distribution of power in localities. Single stout pole or H-pole and 4-pole structures with suitable platforms are employed for transformers of capacity up to 25 KVA, 125 KVA and above 125 KVA (but up to 250 KVA) respectively.

#### **(b) Foundation Mounted Substations:**

For transformers of capacity above 250 KVA the transformers are too heavy for pole mounting. Such substations are usually for voltage of 33,000 volts and above.

## **OUTDOOR SUBSTATIONS OVER INDOOR SUBSTATIONS**

### **Advantages:**

The outdoor substations have the following main advantages over indoor substations.

- i. All the equipment is within view and therefore fault location is easier.
- ii. The extension of the installations is easier, if required.
- iii. The time required in erection of such substations is lesser.
- iv. The smaller amount of building materials (steel-concrete) is required.

v. The construction work required is comparatively smaller and cost of the switch-gear installations is low.

vi. There is practically no danger of a fault which appears at one point being carried over to another point in the installation because the apparatus of the adjoining connections can be spaced liberally, without any appreciable increase in costs.

vii. Repairing work is easy.

**Disadvantages:**

i. The various switching operations with the isolators, as well as supervision and maintenance of the apparatus is to be performed in the open air during all kinds of weather.

ii. More space is required for the substation.

iii. Protection devices are required to be installed for protection against lightning surges.

iv. The length of control cables required is more.

v. The influence of rapid fluctuation in ambient temperature and dust and dirt deposits upon the outdoor substation equipment makes it necessary to install apparatus specially designed for outdoor service and, therefore, more costly.

**INDOOR TYPE SUBSTATIONS DESCRIPTION AND CLASSIFICATION:**

Indoor Type Substations is the substations in which the apparatus is installed within the substation building. Indoor Type Substations are usually for a voltage up to 11,000 V but can be erected for 33,000 V and 66,000 volts when the surrounding atmosphere is contaminated with impurities such as metal corroding gases and fumes, conductive dust etc.

The switch-gear on supply or primary side will consist of oil circuit breakers only. The high voltage supply is given to the primary of the transformer through circuit breaker. From the bus-bar various feeders emerge out. The panel for each feeder consists of an isolator switch and circuit breaker.

In addition to isolator and circuit breaker, the panel is provided with the measuring instruments. As regards protection of feeders usually reverse power relay is employed. For the protection of oil filled transformers with conservator tanks Buchholz's relay is most common.

The auxiliaries of the indoor type substations are

1. Storage Batteries
2. Firefighting equipment such as water buckets, fire extinguishers, etc.

The batteries are used for the

- (i) Operation of the protective gear and switch operating solenoids and
- (ii) Emergency lighting in substations in case of failure of supply.

### **TYPES OF INDOOR SUBSTATIONS:**

According to construction indoor distribution transformer substations and high voltage switchboards are further subdivided into the following categories.

1. Substations of the integrally Built Type
2. Substations of the composite Built-Up Type
3. Unit Type Factory Fabricated substations and Metal Clad Switch boards

#### **1. Substations of the Integrally Built Type**

In this indoor substations types, the apparatus is installed on site. In such substations the cell structures are constructed of concrete or bricks.

#### **2. Substations of the Composite Built-Up Type**

In this indoor substations types, the assemblies and parts are factory or workshop prefabricated, but are assembled on site with in a substation switch-gear room. The compartments of such substations take form of metal cabinets or enclosures, each of which

contains the equipment of one main connection cell. Within such cabinets or enclosures an oil minimum circuit breaker, a load-interrupter switch and one or more voltage transformers may be mounted.

### **3. Unit Type Factory Fabricated Substations and Metal Clad Switchboards**

In this indoor substations types, electrical workshops and are shipped to the site of installations fully preassembled. After installations of substations and switchboards only connection to the incoming and outgoing power circuits are required to be made. Cubicles for unit type switchboards or substations take the form of fully enclosed metal-clad cabinets.

Metal-clad cubicles designed with withdrawal trucks and divided into several compartments are usually employed. The several compartments in which the cubicle is divided are control compartment, indicating and metering instrument and protective device compartment, circuit breaker and operating mechanism compartment, main bus-bar compartment and current transformers and cable sealing box compartment.

To prevent any possible opening or closing of the disconnecting devices when the circuit breaker is closed, these cubicles are designed with interlocks which prevent the truck from being rolled in or withdrawn when the circuit breaker is closed.

### **OUTDOOR SUBSATIONS/ AIR INSULATED SUBSTATION (AIS)**

The AIS uses air as the primary dielectric from phase to phase, and phase to ground insulation. They have been in use for years before the introduction of GIS.

Actually, most substations across all regions are AIS. They are in extensive use in areas where space, weather conditions, seismic occurrences, and environmental concerns are not an issue such as rural areas, and favorable offsite terrain.

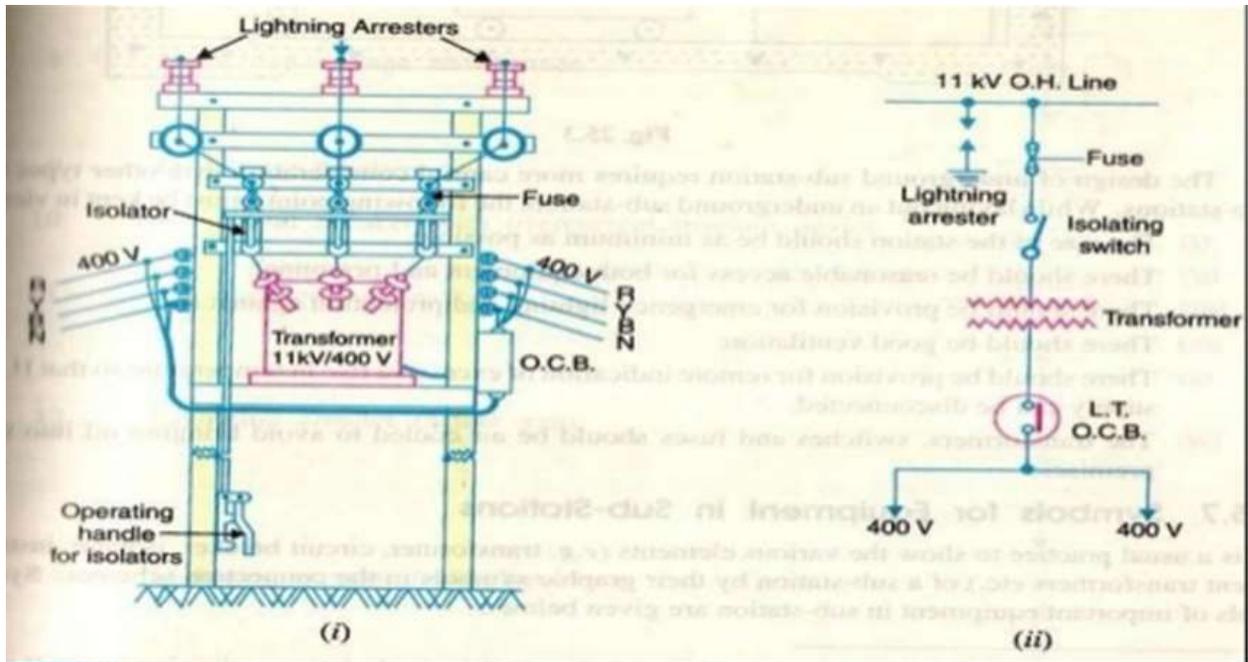
The indoor AIS version is only used in highly polluted areas, and salty conditions, as the air quality is compromised.

## **1. POLE MOUNTED SUBSTATION**

Pole mounted substations are erected for mounting distribution transformers of capacity up to 250 KVA. Such substations are cheapest, simple and smallest of substations. All the equipment is of outdoor type and mounted on the supporting structure of high tension distribution line. Triple Pole Mechanically Operated (TPMO) switch is used for switching “on” and “off” of high tension transmission line. HT fuse unit is installed for protection of high tension side. To control low tension side iron clad low tension switch of suitable capacity with fuses is installed. Lightning arresters are installed over the high tension line to protect the transformer from the surges. Substation is earthed at two or more places

Generally transformers of capacity up to 125 KVA are mounted on double pole structure and for transformers of capacity above 125 KVA but not exceeding 250 KVA 4-pole structure with suitable platform is used. This type of pole-mounted substation is erected in very thickly populated location.

The maintenance cost of such substations is low and by using a large number of such substations in a town it is possible to lay the distributors, at a lower cost. But owing to increase in number of transformers, total KVA is increased, no load losses increase and the cost per KVA is thus more. Economy is the main consideration when a choice is made for such substation. Typical 200 KVA pole mounted substation.



## 2. FOUNDATION MOUNTED SUBSTATION

Foundation Mounted Substation are built entirely in the open and in such substations all the equipment is assembled into one unit usually enclosed by a fence from the point of view of safety. Substations for primary and secondary transmission and for secondary distribution, (above 250 KVA) are foundation mounted outdoor type. Since equipment required for such substations is heavy, therefore, site selected for these substations must have a good access for heavy transport. Again, owing to exposed bus-bars and other associated equipment the clearances and spacing are not only to be governed by the operating voltage but also from the considerations of the encroachment form outside. Low level type substations are designed except when the space available is limited as these provide facility of easy inspection, cleaning and maintenance.

The switch-gear consists of circuit breakers of suitable type on both the sides but with the increased reliability of the modern transformers, the practice is to dispense with the circuit breaker on the incoming side from the economic considerations. The isolating switches thus serve the purpose.



## **OUTDOOR SUBSTATION ADVANTAGE DISADVANTAGES:**

### **Advantages of Air insulated Substation (AIS):**

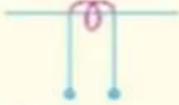
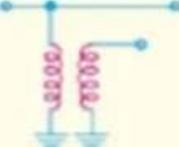
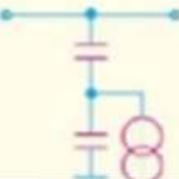
1. This type of substation arrangement is best suited for low voltage rating substations (step down substations) and for those substations where there is sufficient amount of space available for commissioning the equipment of the substation.
2. The construction work required is comparatively less to indoor switch yard and the cost of switchgear installation is also low.
3. In future the extension of the substation installation is easier.
4. The time required for the erection of air insulated substation is less compared to indoor substation.
5. All the equipment in AIS switch yard is within view and therefore the fault location is easier and related repairing work is also easy.
6. The primary choice for areas with extensive space

7. With quality design, the system is viable due to the low construction costs and cost of switchgear
8. Less construction time, thereby more suited for advanced installations
9. Easy maintenance as all the equipment is within view.
10. It is easy to notice and attend to faults.

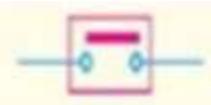
**Disadvantages of Air insulated Substation (AIS):**

1. More space is required for outdoor substation when compared to indoor gas insulated substation (GIS)
2. Outdoor switch yards are more open to faults as it is located in outside atmosphere which has some influence from pollution, salty environment and other environmental factors. Deposition of saline particles on insulators can cause insulator failures. They are also open to direct lightning strikes and other external events such as heavy winds, rains and cyclones. Therefore reliability wise air insulated substation or outdoor substations are relatively low compared to indoor substation
3. Regular maintenance is required compared to indoor substations (Maintenance for Gas Insulated Substation is very minimal and reliability is very high) as they are exposed to outside environment
4. More maintenance requirements, thus leading to high maintenance costs
5. The poor dielectric properties of air, as well as secondary factors such as humidity, pollutants, moisture means that more space is required for efficacy.

## SYMBOLS FOR EQUIPMENT IN SUBSTATIONS:

S.No.	Circuit element	Symbol
1	Bus-bar	
2	Single-break isolating switch	
3	Double-break isolating switch	
4	On load isolating switch	
5	Isolating switch with earth Blade	
6	Current transformer	
7	Potential transformer	
8	Capacitive voltage transformer	

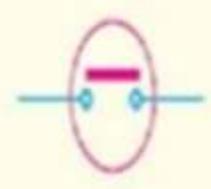
9 Oil circuit breaker



10 Air circuit breaker with overcurrent tripping device



11 Air blast circuit breaker



12 Lightning arrester (active gap)



13 Lightning arrester (valve type)



## ELECTRICAL BUS SYSTEM AND ELECTRICAL SUBSTATION LAYOUT

There are many different electrical bus system schemes available but selection of a particular scheme depends upon the system voltage, position of substation in electrical power system, flexibility needed in system and cost to be expended.

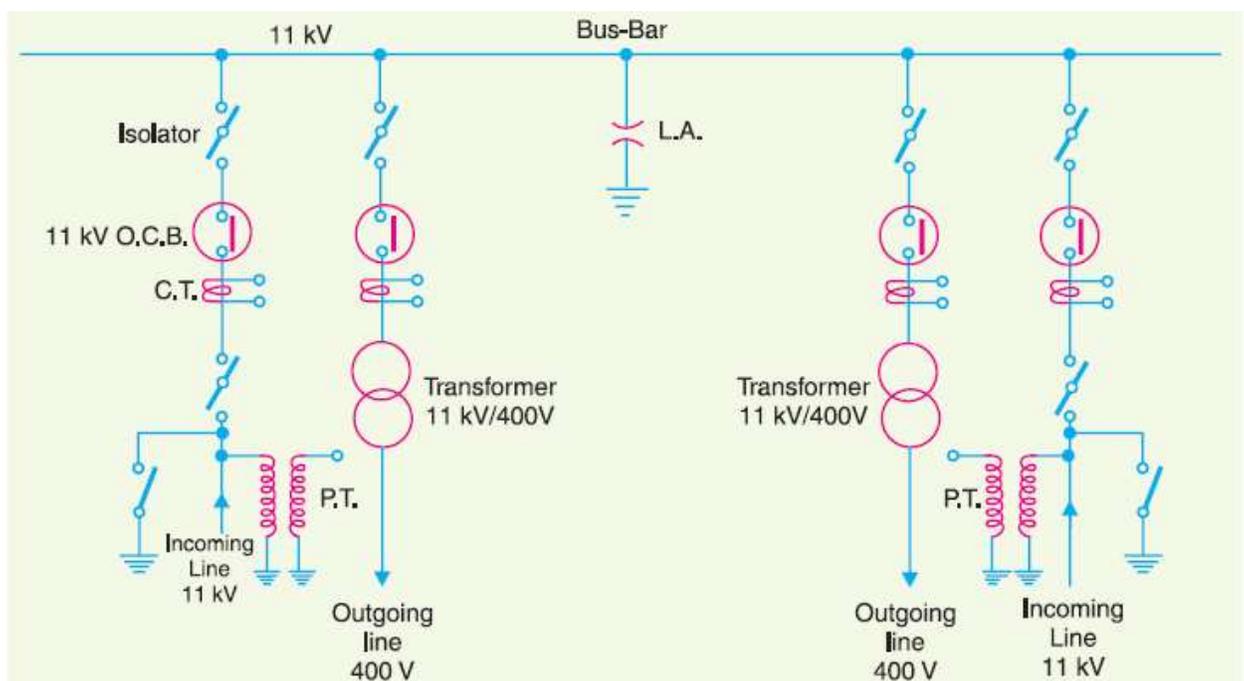
Considerable points to select a bus bar:

1. Simplicity of system.
2. Easy maintenance of different equipments.
3. Minimizing the outage during maintenance.
4. Future provision of extension with growth of demand.
5. Optimizing the selection of bus bar arrangement scheme so that it gives maximum return from the system.

Some very commonly used bus bar arrangement are discussed below-

### SINGLE BUS SYSTEM:

Single Bus System is simplest and cheapest one. In this scheme all the feeders and transformer bay are connected to only one single bus as show.



### **Advantages of Single Bus System**

1. This is very simple in design.
2. This is very cost effective scheme.
3. This is very convenient to operate.

### **Disadvantages of Single Bus System**

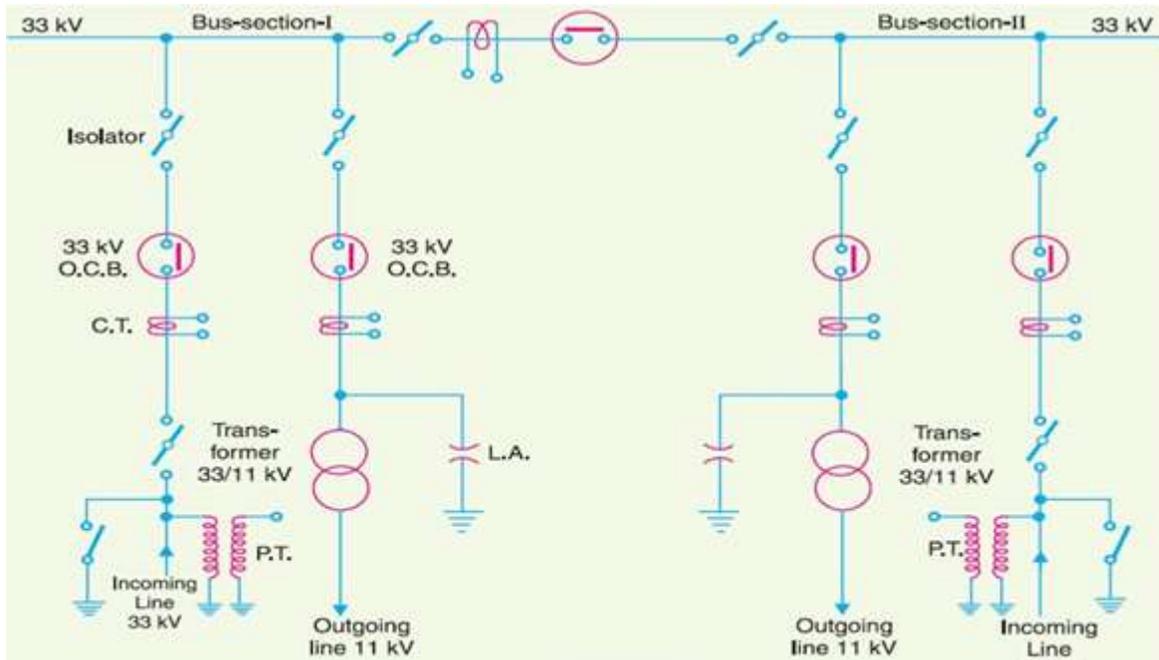
1. One but major difficulty of these type of arrangement is that, maintenance of equipment of any bay cannot be possible without interrupting the feeder or transformer connected to that bay.
2. The indoor 11 KV switchboards have quite often single bus bar arrangement.

### **SINGLE BUS SYSTEM WITH BUS SECTIONALIZER:**

Some advantages are realized if a single bus bar is sectionalized with circuit breaker. If there are more than one incoming and the incoming sources and outgoing feeders are evenly distributed on the sections as shown in the figure, interruption of system can be reduced to a good extent.

### **Advantages of Single Bus System with Bus Sectionalizer**

If any of the sources is out of system, still all loads can be fed by switching on the sectional circuit breaker or bus coupler breaker. If one section of the bus bar system is under maintenance, part load of the substation can be fed by energizing the other section of bus bar.

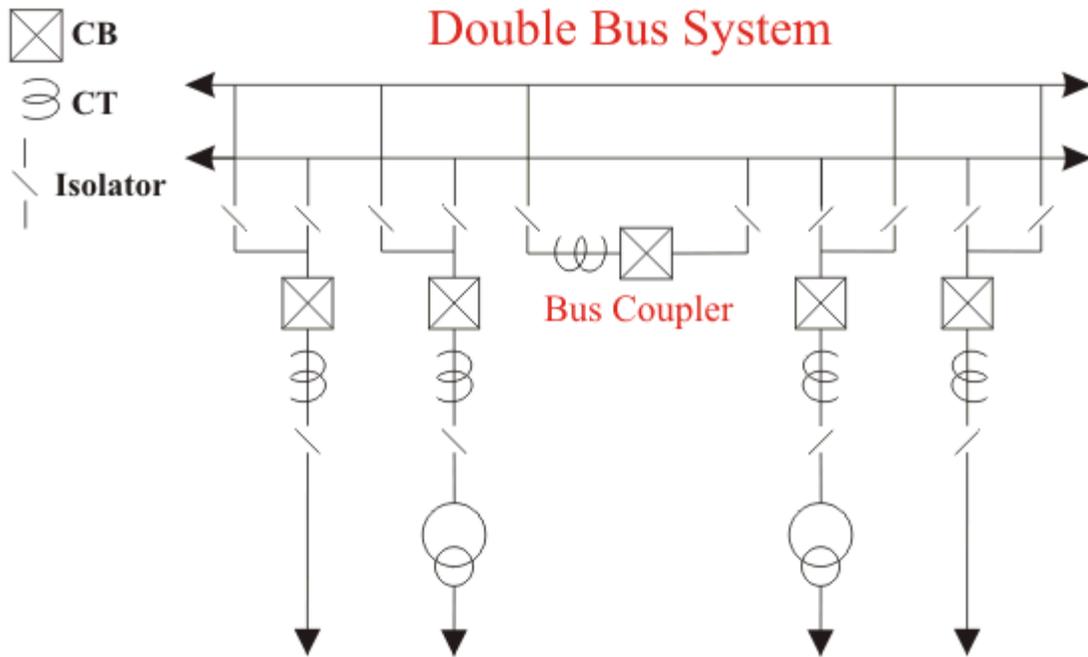


### **Disadvantages of Single Bus System with Bus Sectionalizer**

1. As in the case of single bus system, maintenance of equipment of any bay cannot be possible without interrupting the feeder or transformer connected to that bay.
2. The use of isolator for bus sectionalizing does not fulfill the purpose. The isolators have to be operated 'off circuit' and which is not possible without total interruption of bus – bar. So investment for bus-coupler breaker is required.

### **DOUBLE BUS SYSTEM:**

1. In double bus bar system two identical bus bars are used in such a way that any outgoing or incoming feeder can be taken from any of the bus.
2. Actually every feeder is connected to both of the buses in parallel through individual isolator as shown in the figure.



By closing any of the isolators one can put the feeder to associated bus. Both of the buses are energized and total feeders are divided into two groups, one group is fed from one bus and other from other bus. But any feeder at any time can be transferred from one bus to other. There is one bus coupler breaker which should be kept close during bus transfer operation. For transfer operation, one should first close the bus coupler circuit breaker then close the isolator associated with the bus to where the feeder would be transferred and then open the isolator associated with the bus from where feeder is transferred. Lastly after this transfer operation he or she should open the bus coupler breaker.

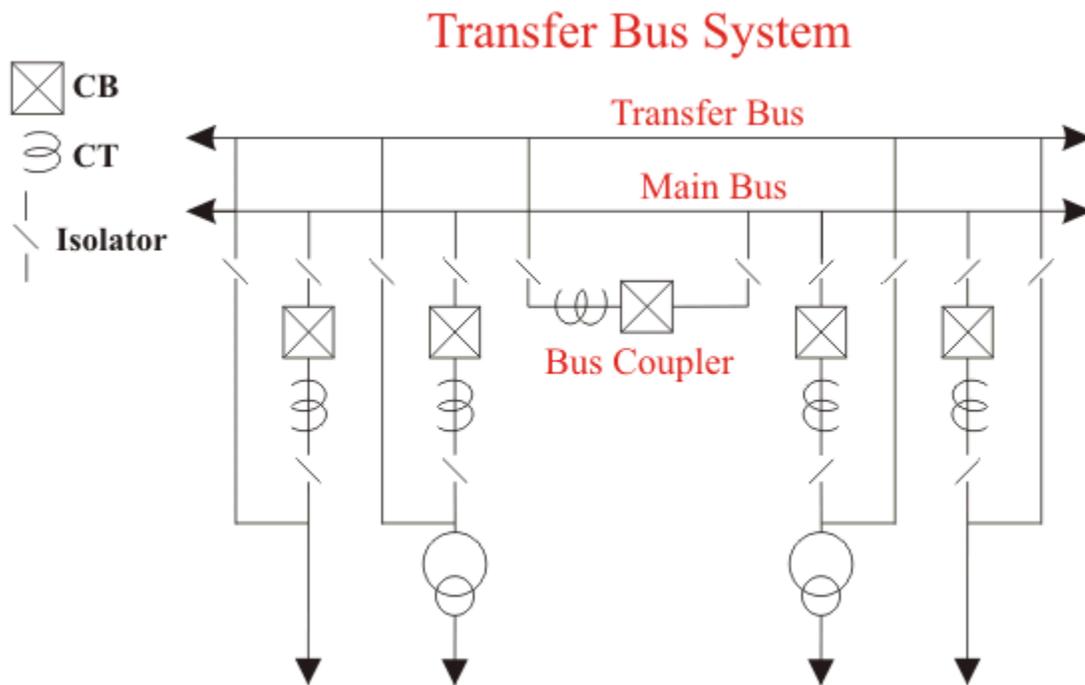
### **Advantages of Double Bus System**

Double Bus Bar Arrangement increases the flexibility of system.

### **Disadvantages of Double Bus System**

The arrangement does not permit breaker maintenance without interruption.

## MAIN AND TRANSFER BUS SYSTEM:



This is an alternative of double bus system. The main conception of Main and Transfer Bus System is, here every feeder line is directly connected through an isolator to a second bus called transfer bus. The said isolator in between transfer bus and feeder line is generally called bypass isolator. The main bus is as usual connected to each feeder through circuit breaker and associated isolators at both side of the breaker. There is one bus coupler by which couples transfer bus and main bus through a circuit breaker and associated isolators at both sides of the breaker. If necessary the transfer bus can be energized by main bus power by closing the transfer bus coupler isolators and then breaker. Then the power in transfer bus can directly be fed to the feeder line by closing the bypass isolator. If the main circuit breaker associated with feeder is switched off or isolated from system, the feeder can still be fed in this way by transferring it to transfer bus.

### **Switching Operation for Transferring a Feeder to Transfer Bus from Main Bus without Interruption of Power**

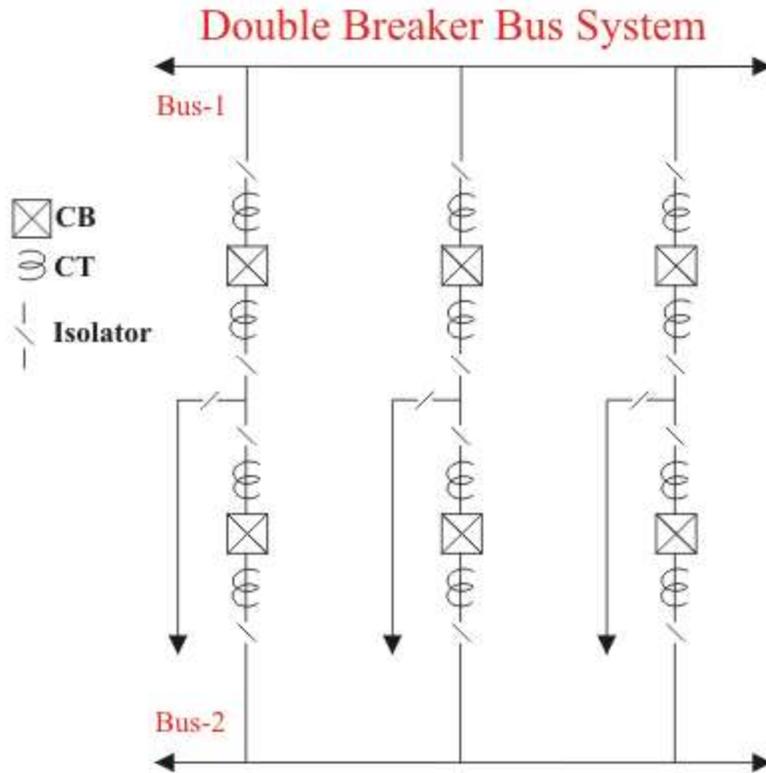
1. First close the isolators at both side of the bus coupler breaker.
2. Then close the bypass isolator of the feeder which is to be transferred to transfer bus.

3. Now energized the transfer bus by closing the bus coupler circuit breaker from remote.
4. After bus coupler breaker is closed, now the power from main bus flows to the feeder line through its main
5. Breaker as well as bus coupler breaker via transfer bus.
6. Now if main breaker of the feeder is switched off, total power flow will instantaneously shift to the bus coupler breaker and hence this breaker will serve the purpose of protection for the feeder.
7. At last the operating personnel open the isolators at both sides of the main circuit breaker to make it isolated from rest of the live system.

So, it can be concluded that in Main & Transfer Bus System the maintenance of circuit breaker is possible without any interruption of power. Because of this advantage the scheme is very popular for 33 KV and 11KV system.

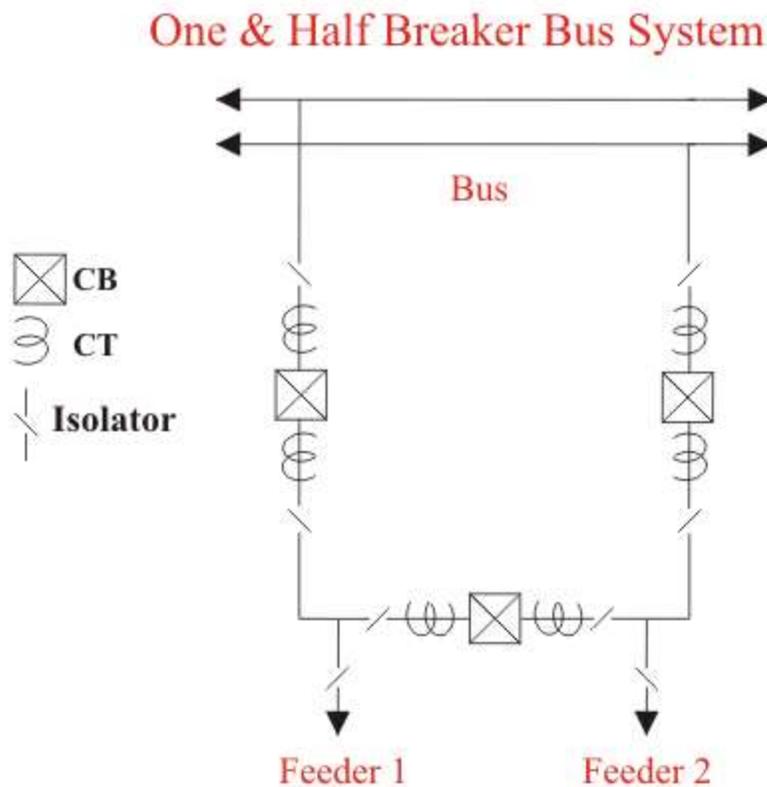
### **DOUBLE BREAKER BUS SYSTEM:**

In double breaker bus bar system two identical bus bars are used in such a way that any outgoing or incoming feeder can be taken from any of the bus similar to double bus bar system. Only difference is that here every feeder is connected to both of the buses in parallel through individual breaker instead only isolator as shown in the figure. By closing any of the breakers and its associated isolator one can put the feeder to respective bus. Both of the buses are energized and total feeders are divided into two groups, one group is fed from one bus and other from other bus similar to previous case. But any feeder at any time can be transferred from one bus to other. There is no need of bus coupler as because the operation is done by breakers instead of isolator. For transfer operation, one should first close the isolators and then the breaker associated with the bus to where the feeder would be transferred and then he or she opens the breaker and then isolators associated with the bus from where feeder is transferred.



**ONE AND A HALF BREAKER BUS SYSTEM:**

This is an improvement on the double breaker scheme to effect saving in the number of circuit breakers. For every two circuits only one spare breaker is provided. The protection is however



complicated since it must associate the central breaker with the feeder whose own breaker is taken out for maintenance. For the reasons given under double breaker scheme and because of the prohibitory costs of equipment even this scheme is not much popular. As shown in the figure that it is a simple design, two feeders are fed from two different buses through their associated breakers and these two feeders are coupled by a third breaker which is called tie breaker. Normally all the three breakers are closed and power is fed to both the circuits from two buses which are operated in parallel. The tie breaker acts as coupler for the two feeder circuits. During failure of any feeder breaker, the power is fed through the breaker of the second feeder and tie breaker, therefore each feeder breaker has to be rated to feed both the feeders, coupled by tie breaker.

**Advantages of One and A Half Breaker Bus System**

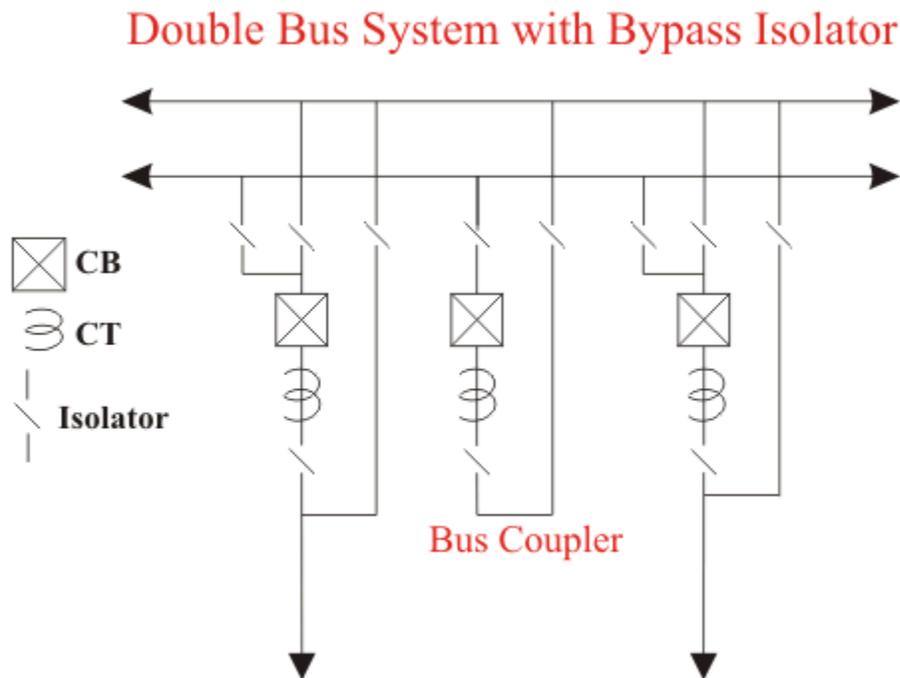
During any fault on any one of the buses, that faulty bus will be cleared instantly without interrupting any feeders in the system since all feeders will continue to feed from other healthy bus.

**Disadvantages of One and A Half Breaker Bus System**

This scheme is much expensive due to investment for third breaker.

**DOUBLE BUS SYSTEM WITH BYPASS ISOLATORS:**

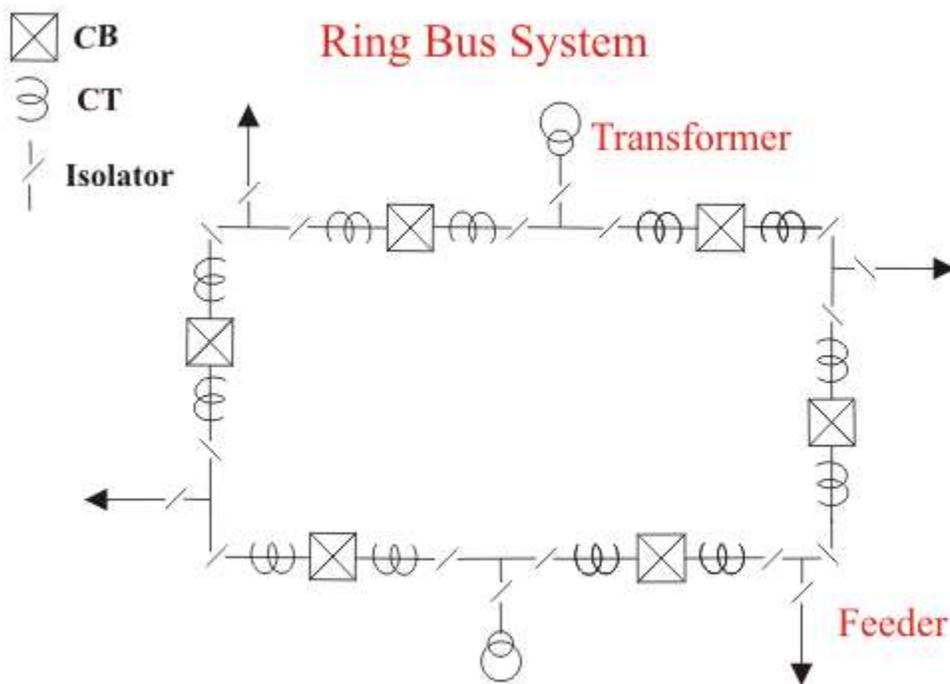
This is combination of the double bus system and main and transfer bus system. In Double Bus



System with Bypass Isolators either bus can act as main bus and second bus as transfer bus. It permits breaker maintenance without interruption of power which is not possible in double bus system but it provides all the advantages of double bus system. It however requires one additional isolator (bypass isolator) for each feeder circuit and introduces slight complication in system layout. Still this scheme is best for optimum economy of system and it is best optimum choice for 220 KV system.

**RING BUS SYSTEM:**

The schematic diagram of the system is given in the figure. It provides a double feed to each feeder circuit, opening one breaker under maintenance or otherwise does not affect supply to any feeder. But this system has two major disadvantages. One as it is closed circuit system it is next to impossible to extend in future and hence it is unsuitable for developing system. Secondly, during maintenance or any other reason if any one of the circuit breaker in ring loop is switched off reliability of system becomes very poor as because closed loop becomes opened. Since, at that moment for any tripping of any breaker in the open loop causes interruption in all the feeders between tripped breaker and open end of the loop.



**Key Diagram of 66/11 kV Sub-Station:**

Fig. 25.10 shows the key diagram of a typical 66/11 kV sub-station. The key diagram of this substation can be explained as under:

(i) There are two 66 kV incoming lines marked 'incoming 1' and 'incoming 2' connected to the bus-bars. Such an arrangement of two incoming lines is called a double circuit. Each incoming line is capable of supplying the rated sub-station load. Both these lines can be loaded simultaneously to share the sub-station load or any one line can be called upon to meet the entire load. The double circuit arrangement increases the reliability of the system. In case there is a breakdown of one incoming line, the continuity of supply can be maintained by the other line.

(ii) The sub-station has duplicate bus-bar system; one 'main bus-bar' and the other spare busbar.

The incoming lines

can be connected to either bus-bar with the help of a bus-coupler which consists of a circuit breaker and isolators. The advantage of double bus-bar system is that if repair is to be carried on one bus-bar, the supply need not be interrupted as the entire load can be transferred to the other bus.

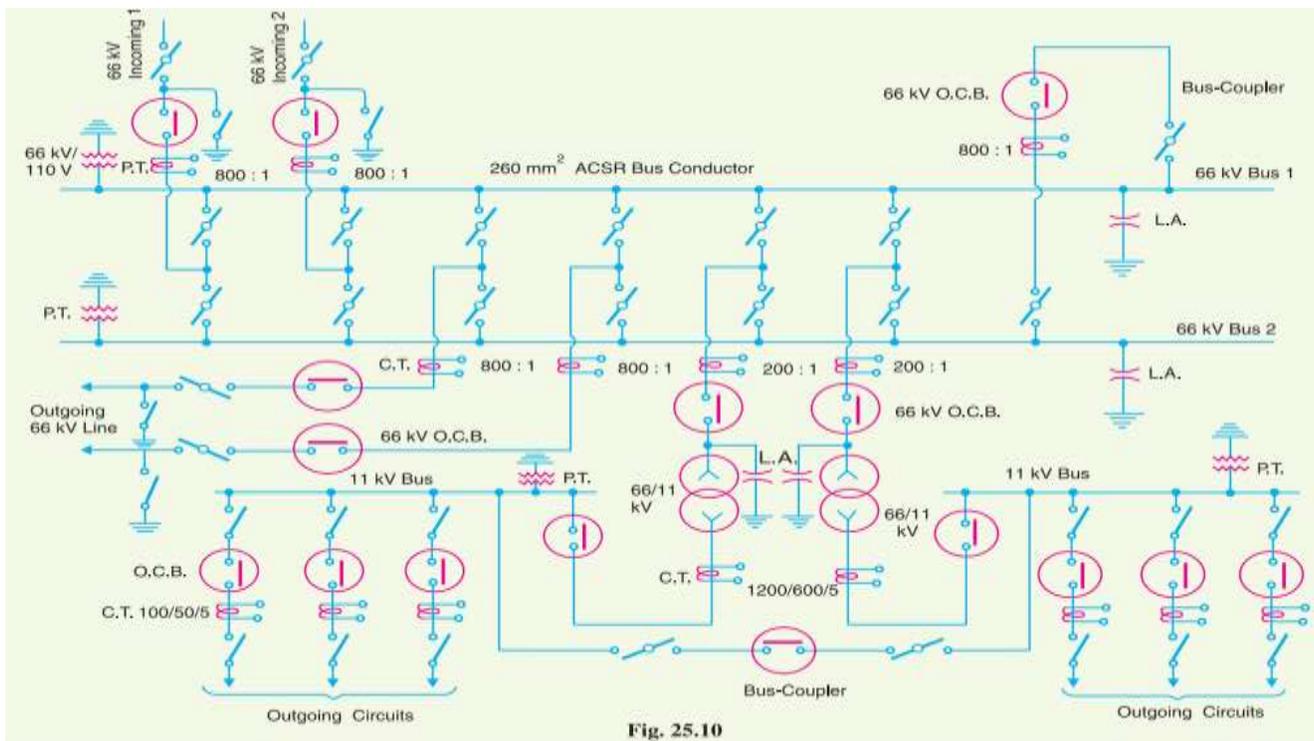
(iii) There is an arrangement in the sub-station by which the same 66 kV double circuit supply is going out *i.e.* 66 kV double circuit supply is passing through the sub-station. The outgoing 66 kV double circuit line can be made to act as incoming line.

(iv) There is also an arrangement to step down the incoming 66 kV supply to 11 kV by two units of 3-phase transformers; each transformer supplying to a separate bus-bar. Generally, one transformer supplies the entire sub-station load while the other transformer acts as a standby unit. If need arises, both the transformers can be called upon to share the sub-station load. The 11 kV outgoing lines feed to the distribution sub-stations located near consumers localities.

(v) Both incoming and outgoing lines are connected through circuit breakers having isolators on their either end. Whenever repair is to be carried over the line towers, the line is first switched off and then earthed.

(vi) The potential transformers (P.T.) and current transformers (C.T.) are suitably located for supply to metering and indicating instruments and relay circuits (not shown in the figure). The P.T. is connected right on the point where the line is terminated. The CTs are connected at the terminals of each circuit breaker.

(vii) The lightning arresters are connected near the transformer terminals (on H.T. side) to protect



them from lightning strokes.

(viii) There are other auxiliary components in the sub-station such as capacitor bank for power factor improvement, earth connections, local supply connections, d.c. supply connections etc. However, these have been omitted in the key diagram for the sake of simplicity.

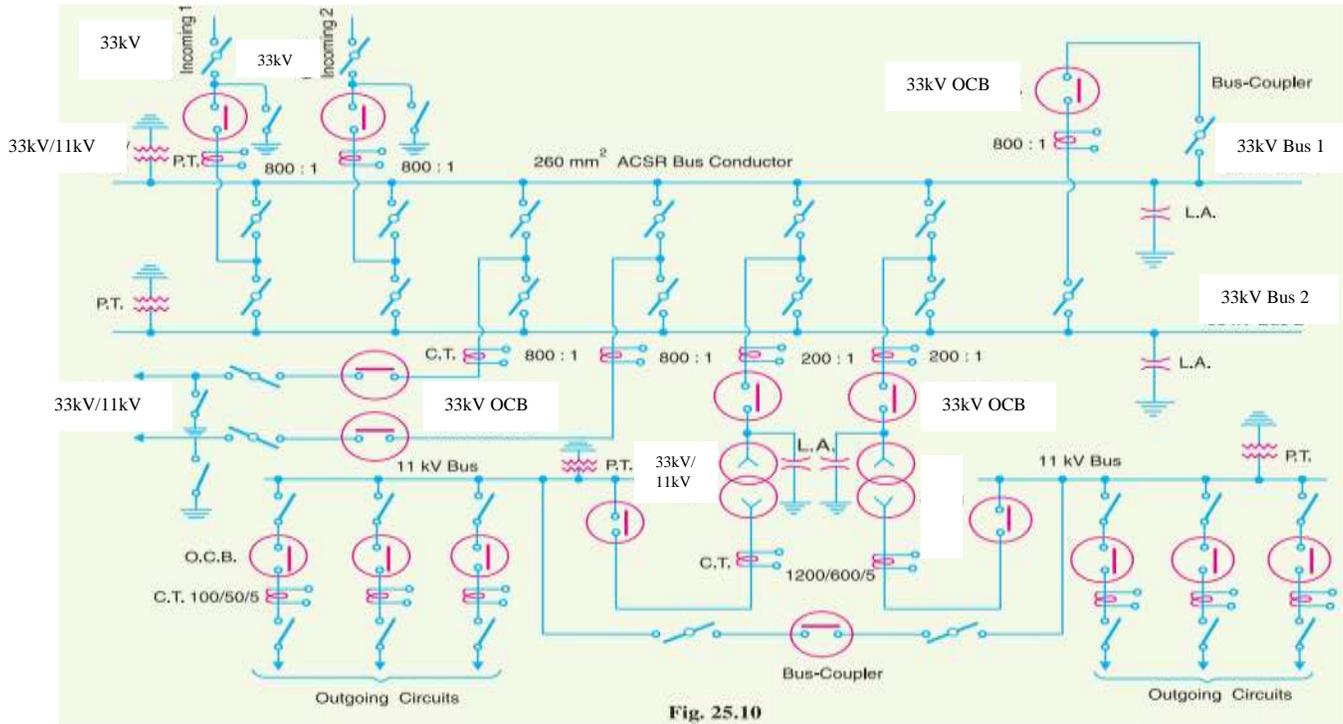


Fig. 25.10

## **GAS INSULATED SUBSTATION:**

### Introduction

Gas Insulated Substation uses sulfur hexafluoride (SF<sub>6</sub>) gas which has a superior dielectric properties used at moderate pressure for phase to phase and phase to ground insulation. In Gas Insulated Substation the high-voltage conductors, circuit breaker interrupters, switches, current transformers, voltage transformers and lightning arresters are encapsulated in SF<sub>6</sub> gas inside grounded metal enclosures.

### Why Gas Insulated Substations are used?

Gas Insulated Substations are used where there is space for providing the substation is expensive in large cities and towns. In normal substation the clearances between the phase to phase and phase to ground is very large. Due to this, large space is required for the normal or Air Insulated Substation (AIS). But the dielectric strength of SF<sub>6</sub> gas is higher compared to the air, the clearances required for phase to phase and phase to ground for all equipment's are quite lower. Hence, the overall size of each equipment and the complete substation is reduced to about 10% of the conventional air insulated substation.

### **Locations where Gas Insulated Substation is preferred:**

- Large cities and towns
- Underground stations
- Highly polluted and saline environment Indoor GIS occupies very little space
- Substations and power stations located Off shore
- Mountains and valley regions

### Explanation:

The SF<sub>6</sub> Gas Insulated Substation (GIS) contains the same compartments as in the conventional outdoor substations. All the live parts are enclosed in metal housings filled with SF<sub>6</sub> gas. The live parts are supported on cast resin insulators. Some of the insulators are designed as barriers between neighboring modules such that the gas does not pass through them.

The entire installation is sub divided into compartments which are gas tight with respect to each other. Thereby the gas monitoring system of each compartment can be independent and simpler.

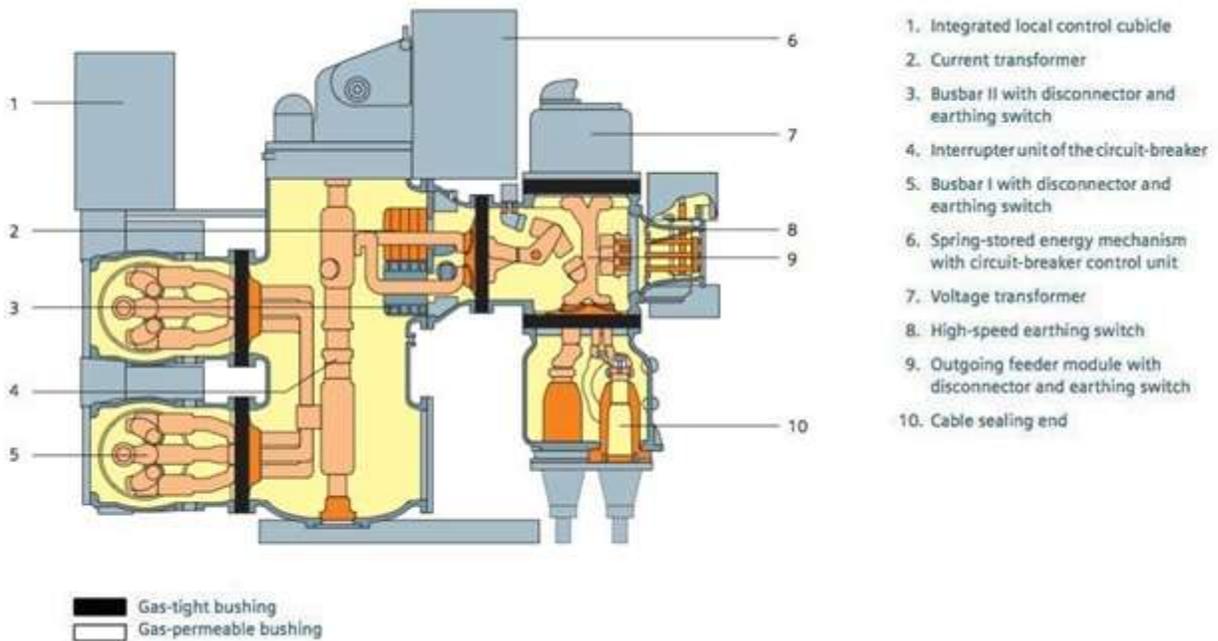
The enclosures are of non-magnetic materials such as aluminum or stainless steel and are earthed. The gas tightness is provided with static 'O' seals placed between the machined flanges. The 'O'- rings are placed in the grooves. 'O'-seals are important to ensure gas tight performance of Gas Insulated Substation.

Gas Insulated Substation has gas monitoring system. Gas inside each compartment should have a pressure of about  $3\text{kg/cm}^2$ . The gas density in each compartment is monitored. If the pressure drops slightly, the gas is automatically trapped up. With further gas leakage, the low pressure alarm is sounded or automatic tripping or lock-out occurs.

### **Properties of Gas Insulated Substation (GIS)**

1. SF<sub>6</sub> is non-toxic.
2. Maintains atomic and molecular properties even at high voltages.
3. High cooling properties.
4. Superior arc quenching properties.

SF<sub>6</sub> has superior dielectric properties compared to other gases thereby provide favorable insulation for the phase to phase and phase to ground moderation.



### Advantages of GIS

1. It occupies very less space (1/10th) compared to ordinary substations. Hence these Gas Insulated Substations (GIS) are most preferred where area for substation is small (eg: Cities)
2. Most reliable compared to Air Insulated Substations, number of outages due to the fault is less
3. Low maintenance requirements due to expedient design and protection against external elements.
4. It Can be assembled at the shop and modules can be commissioned in the plant easily
5. Under scheduled maintenance, SF<sub>6</sub> neither ages nor depletes. There is no need to top up the gas levels throughout the equipment lifetime (approx 40 years).
6. The maintenance of GIS is free.
7. GIS has no risk for fire and explosion due to leakage of oil.
8. They generate no noise and have no radio interference.

## **Disadvantages of GIS**

1. Cost is higher compared to Air Insulated Substation or conventional substation.
2. Procurement of SF6 gas and supply of gas to the site is problematic
3. Normally this type of substations are indoor type and requires separate building
4. Maintaining Cleanliness is very important. Dust or moisture inside the compartment causes the flash overs
5. When fault occurs internally, the outage period will be very long. The damage effect will also be severe.

## **DIFFERENT TYPES OF GAS INSULATED SUBSTATIONS:**

According to metal enclosed switchgears GIS are classified as

### **Isolated phase GIS**

In this configuration, each phase of the bay is assembled separately. That is, for each phase, one pole of circuit breaker, a single pole of electrical isolator, one phase assembly of current transformer are assembled together. This type of GIS requires larger bay width as compared to other gas insulated switchgear system.



### **Integrated 3 Phase GIS**

In this configuration all three phase of circuit breaker, 3 phases of disconnections and three phase current transformer are encapsulated in an individual metal enclosure. The arrangement forms a three phase module for the element. The size of this type of module is one third of the isolated phase GIS.



### **Hybrid GIS System**

It is a suitable combination of isolated phase and three phase common elements. Here three phase common bus bar system simplifies the connection from the bus bar. The isolated phase equipment prevents phase to phase faults. This is an optimum design considering, both facts in mind, i.e. space requirement and maintenance facility.



### **Compact GIS**

In this GIS or gas insulated switchgear system than one functional element are encapsulate in a single metal enclosure. For example, in some design, a three phase circuit breaker, current transformer, earth switches, even other feeder elements are covered together in a single metal capsule.



### **Highly Integrated System**

This design was introduced in the year of 2000, where, total substation equipment's are encapsulated together in single enclosure housing. This single unit gas insulated substation has gained user appreciation as it is a complete solution for an outdoor substation, in a single unit. As such, only equipment (HIS) is substitute of a total outdoor switch yard.



### **CONSTRUCTIONAL ASPECTS OF GIS**

The GIS equipment is usually of modular construction. The enclosures for GIS equipment are fabricated using carbon steel and alloy steel, or cast using aluminum. Various components such as bus bars, circuit breakers, voltage transformer, current transformer, isolator, etc. are contained in earthed enclosures filled with SF<sub>6</sub> gas and segregated by gas-tight insulating cones. The costly aluminum enclosures are preferred as they are light-weight and entail low production costs. The entire installation is subdivided into compartments which are gas-tight which connect each other. Thereby the gas-monitoring system of each compartment can be independent and simple. The gas tightness is presided by static 'O' seals placed between machined flanges. The 'O' rings are placed in the grooves such that after assembly the 'O' rings get squeezed by about 20%. As per guideline followed by specter energies, the gas compartments of the three phases are fully segregated. Each gas compartment, within a phase, provided with a gas service connection to which a vacuum pump, gas refilling tank, or a gas recuperating plant can be connected. Protective items, such as absorber and bursting disks, are provided for proper functioning of the SF<sub>6</sub> gas system. In addition to above, to monitor the pressure and temperature of gas, densimeters are provided in compartments of each phase. This meter also gives alarm for loss of gas. SF<sub>6</sub> gas leakage rate is normally less than or equal to one percent per annum.

## **INSTALLATION**

Installing a GIS high voltage substation can be faster than installing its metal-clad AIS counterpart. This is largely due to the fact that GIS systems are significantly smaller and weigh less (despite the gas weighing more than air). Provided the technician doesn't need to handle the gas itself, GIS substations are quicker to install. AIS systems need bus-bar connections and boots on the switchgear. The average installation time is reduced by approximately 30% with a GIS installation (when no gas-handling is required). GIS systems also take up less space than AIS. The physical footprint of a GIS is about 35% less than AIS.

## **OPERATION**

GIS systems are significantly easier to care for on a regular basis as they offer front instead of rear access. They also contain their own integrated testing instruments.

Arc flashes are rare in GIS because all the interior elements are insulated, with only the cable compartment being accessible. As the parts are fully insulated, no cables or linkage can come in contact with the live parts.

## **MAINTENANCE**

As discussed in point one, GIS switchyards require significantly less maintenance. On average, GIS systems need only be visually inspected every four years or more, depending on the specific manufacturer recommendation for your device. GIS drives only need to be re-greased after about 20 years (again, this varies between manufacturers).

AIS systems should be visually inspected every year to two years (again, based on the specific manufacturer recommendation). When inspected, all compartments must be checked, unlike GIS where the individual compartments and elements are fully insulated and can be monitored. On average, an AIS breaker will need about four hours of maintenance for each two-year period.

In terms of maintenance, AIS systems require significantly more effort, especially due to the thoroughness of the inspections. Inspections include having a technician torque, draw-out, clean, lubricate and vacuum the unit. They also need to be checked for visual signs of copper corrosion,

something that doesn't occur in GIS due to the units being sealed. That sealing also protects the components from environmental damage.

**Comparison of AIS and GIS**

<b>S.No</b>	<b>Particulars</b>	<b>AIS</b>	<b>GIS</b>
1	Area requirement	More	Less
2	Maintenance cost	More	Less
3	Installation cost	More	Less
4	Concrete work to do	More	Less
5	Flashovers and Breakdown occurs	Frequently	Rarely
6	Voltage rating	Low	High
7	Visualization spark	Visible	Not visible
8	Repair and Replacement cost of equipment	Low	High

# GAS INSULATED SUBSTATION

# GAS INSULATED SUBSTATION

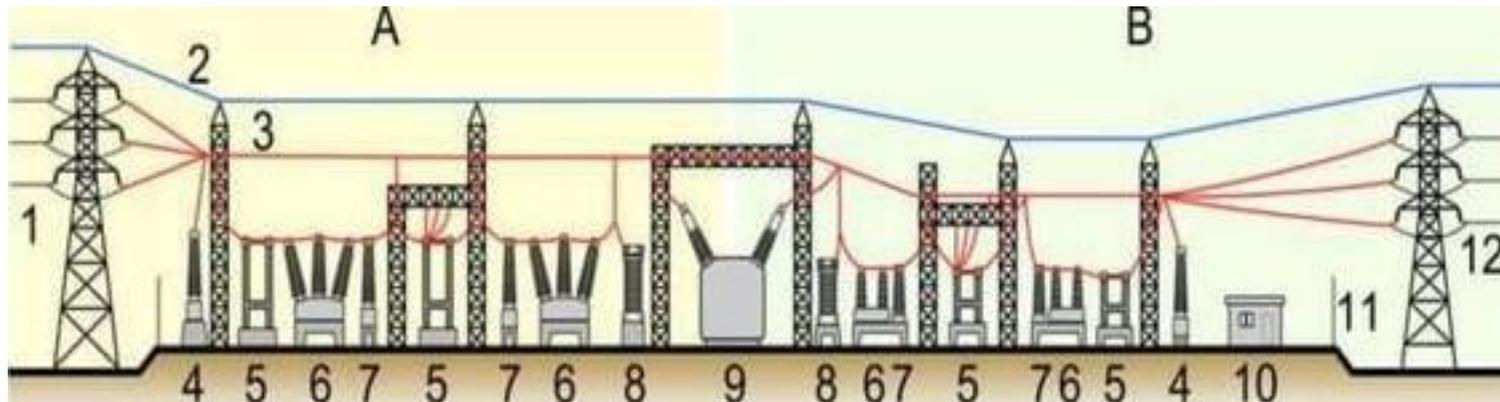


# Contents:

- Substation
- Conventional substations (AIS)
- Limitations of AIS
- The need for GIS
- Introduction to GIS
- Properties of SF<sub>6</sub>
- GIS assembly
- Advantages of GIS
- Design features
- Drawbacks
- SF<sub>6</sub> — Environmental concerns
- SFP /N<sub>2</sub> mixtures
- Future trends in GIS
- Conclusion.

# Substation:

- An assembly of apparatus installed to control transmission and distribution of electric power.



A:Primary power lines' side B:Secondary power lines' side

- 1.Primary power lines
- 2.Ground wire
- 3.Overhead lines
- 4.Transformer for measurement of electric voltage
- 5.Disconnect switch
- 6.Circuit breaker
- 7.Current transformer
- 8.Lightning arrester
- 9.Main transformer
- 10.Control building
- 11.Security fence
- 12.Secondary power lines

# Air Insulated Substation (AIS):

- Air used as a dielectric.
- Normally used for outdoor substations.
- In very few cases used for indoor substations.
- Easy to expand (in case that space is not an issue)
- Excellent overview, simple handling and easy access.

# Limitations of AIS:

- Large dimensions due to statutory clearances and poor dielectric strength of air.
- Insulation deterioration with ambient conditions and susceptibility to pollutants.
- Wastage of space
- Life of steel structures degrades.
- Seismic instability.
- Large planning & execution time.
- Regular maintenance of the substation required.

# The need for GIS

- Non availability of sufficient space.
- Difficult climatic and seismic conditions at site.
- Urban site (high rise building).
- High altitudes.
- Limitations of AIS.

# Gas Insulated Substation:

## Introduction:

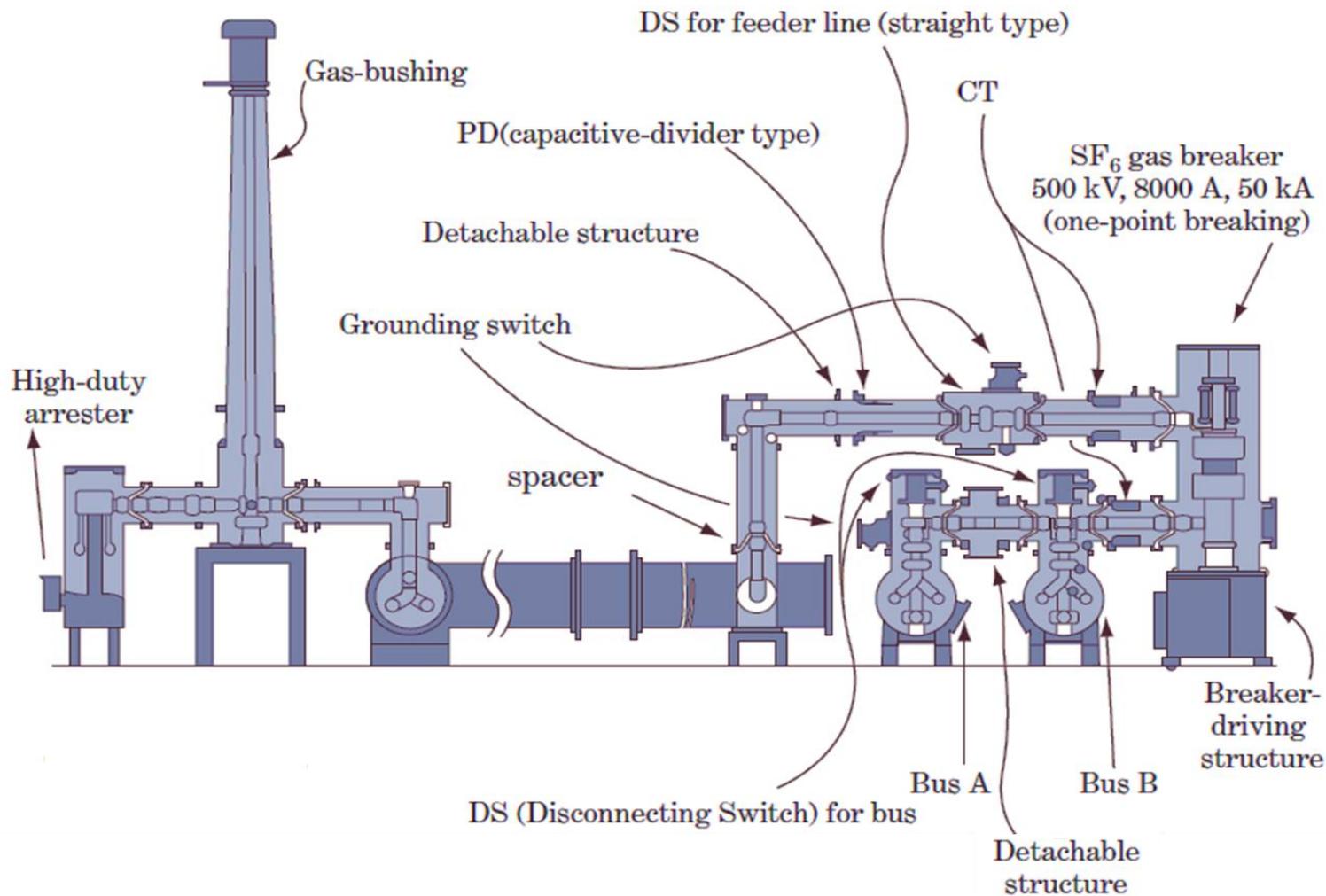
- Compact, multi-component assembly.
- Enclosed in a ground metallic housing.  
Sulphur Hexafluoride (SF<sub>6</sub>) gas – the primary insulating medium.  
(SF<sub>6</sub>) gas- superior dielectric properties used at moderate pressure for phase to phase and phase to ground insulation
- Preferred for voltage ratings of 72.5 kV, 145 kV, 300 kV and 420 kV and above.
- Various equipment's like Circuit Breakers, Bus-Bars, Isolators, Load Break Switches, Current Transformers, Voltage Transformers, Earthing Switches, etc. housed in metal enclosed modules filled with SF<sub>6</sub> gas.

# Properties of SF<sub>6</sub>:

- Non-toxic, very stable chemically.
- Man-made.
- Lifetime — Very long (800 to 3200 years!).
- Insulating properties 3-times that of air.
- Colorless & heavier than air.
- Almost water insoluble.
- ” Non inflammable.

# Gas insulated substation

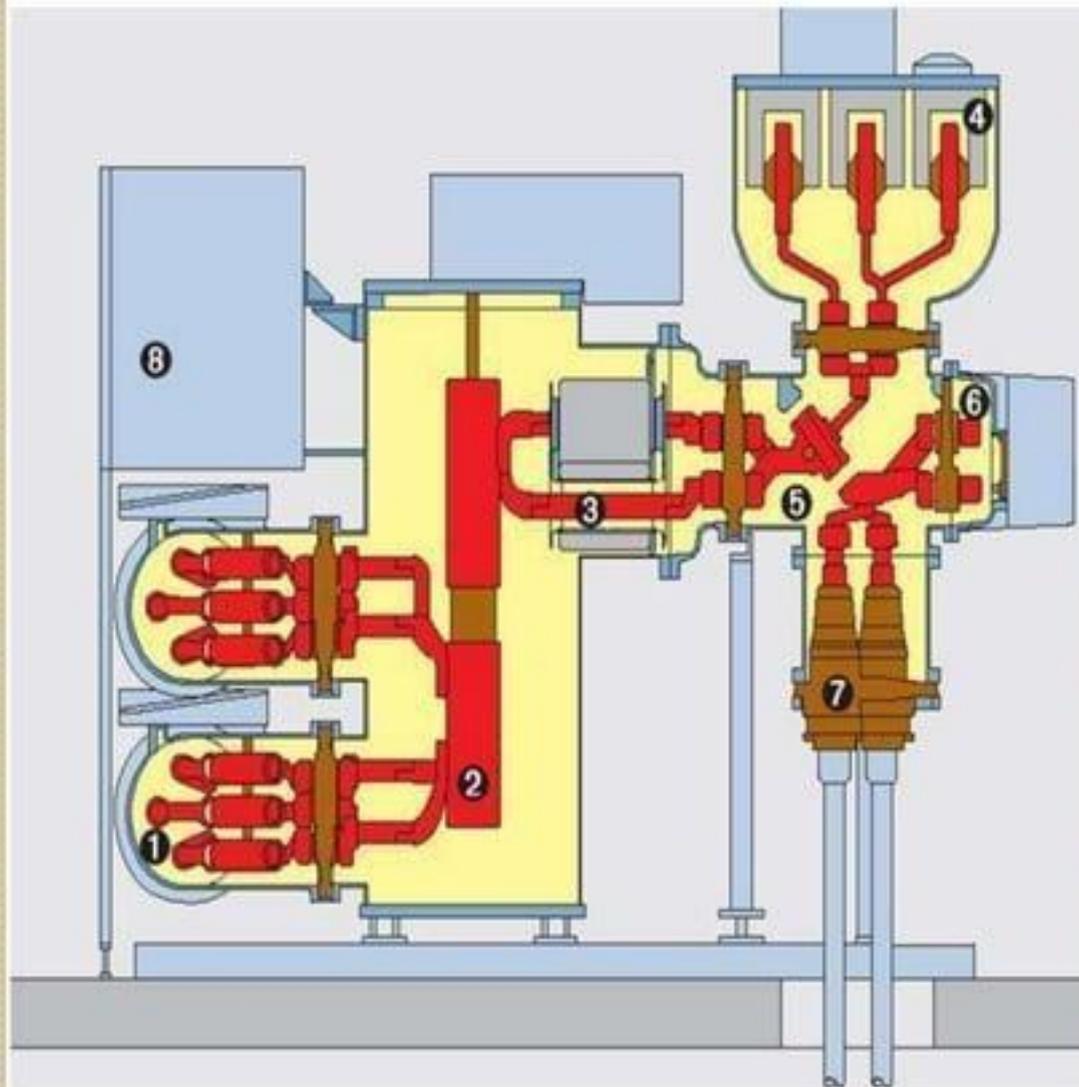




# GIS Assembly

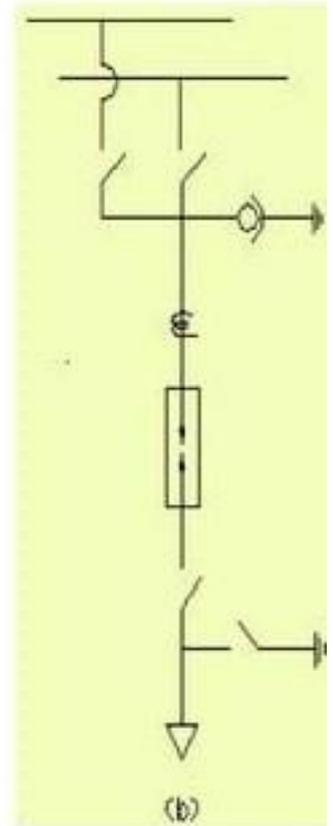
## ***ESSENTIAL PARTS OF GIS:***

1. Bus bar
2. Circuit Breaker
3. Disconnecter (line or bus)
4. Earthing switch (line or bus)
5. Current transformer (feeder / bus)
6. Voltage transformer (feeder/ bus)
7. Feeder Disconnecter
8. Feeder Earthing switch
9. Lightning / Surge Arrested
10. Cable termination
11. Control Panel.



- 1** Busbar with combined disconnect and earthing switch
- 2** Circuit breaker
- 3** Current transformer
- 4** Voltage transformer
- 5** Line disconnect with earthing switch
- 6** Make-safe earthing switch
- 7** Cable sealing end
- 8** Control cubicle

**Fig: essential parts of Gas insulated substation**

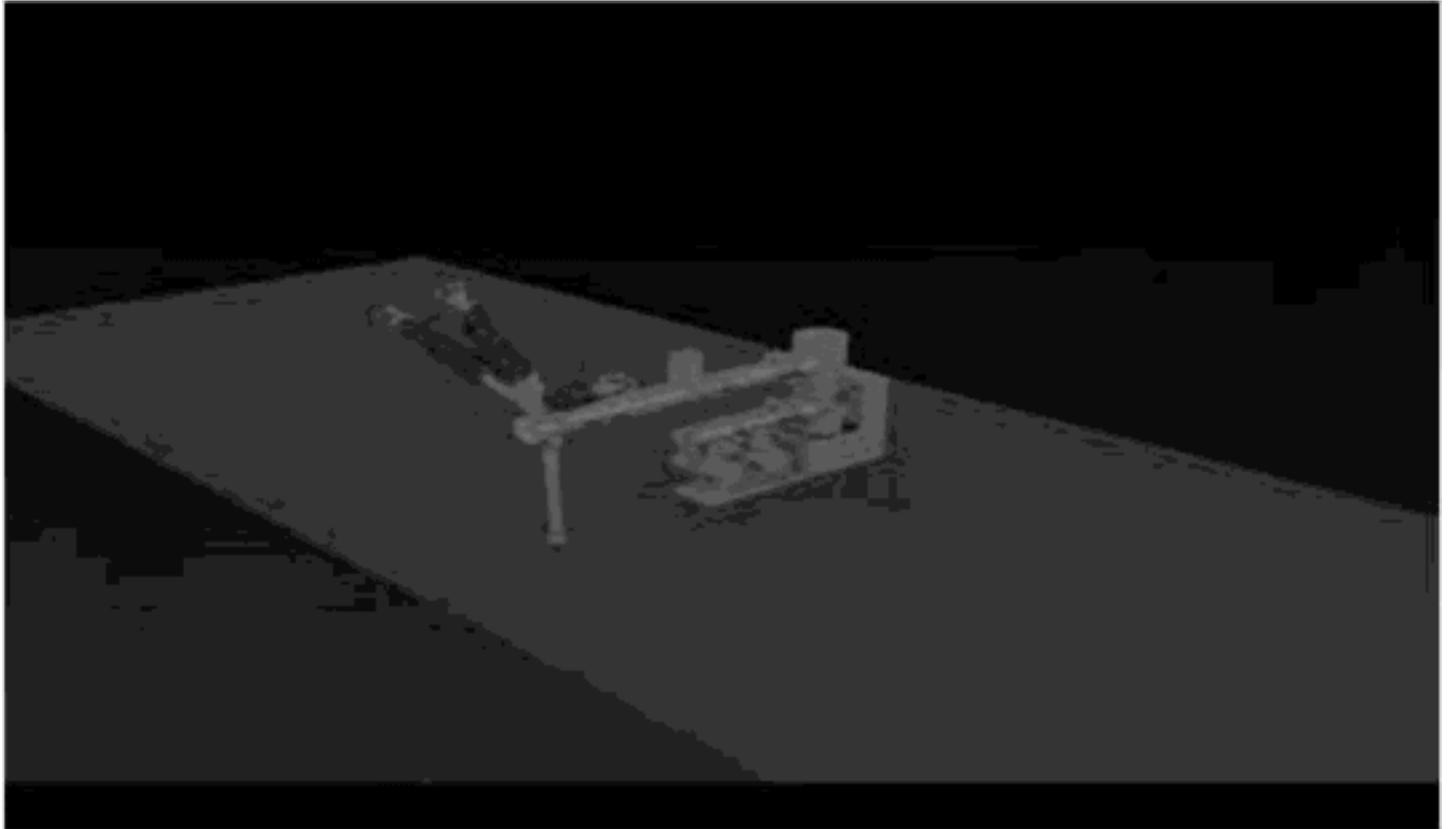


6KV Gas Insulated substation with 3-phase double busbar



Fig: Gas insulated substation with double bus arrangement

# GIS assembly:



# Advantages

- Occupies very less space (1/10th) compared to ordinary substations.
- Hence, most preferred where area for substation is small (eg: Cities)
- Most reliable compared to Air Insulated Substations.
- Number of outages due to the fault is less
- Maintenance Free.
- Can be assembled at workshop and modules can be commissioned in the plant easily.



# GIS vs AIS

Life cycle assessment



# Design Challenges:

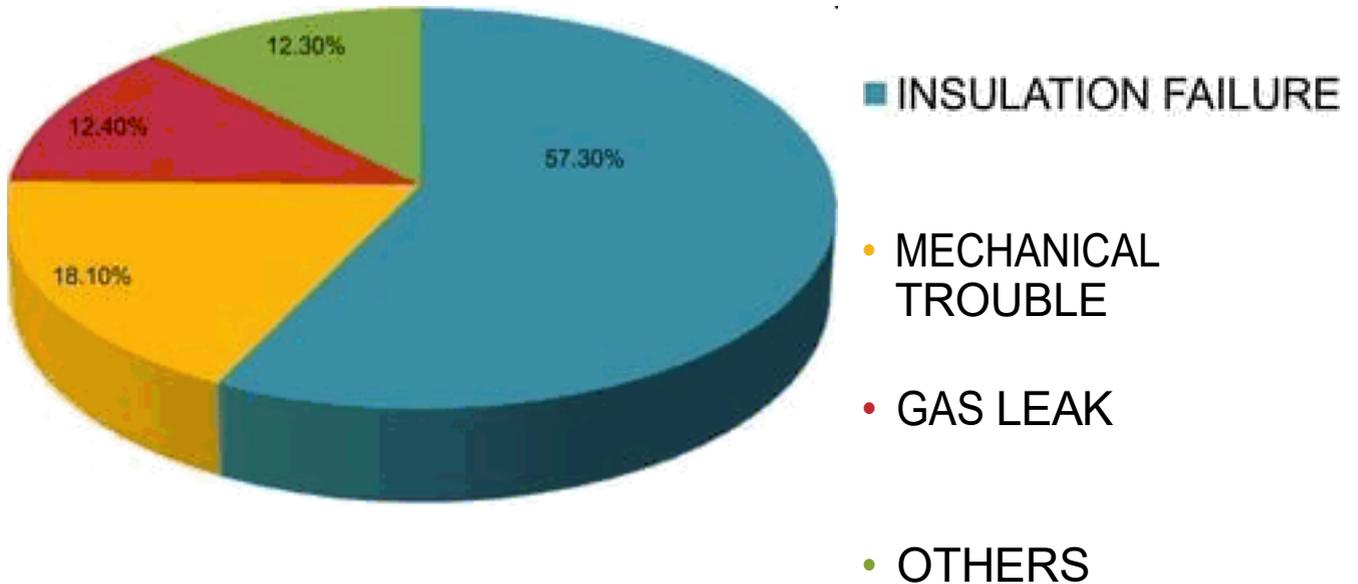
## 1. Safety:

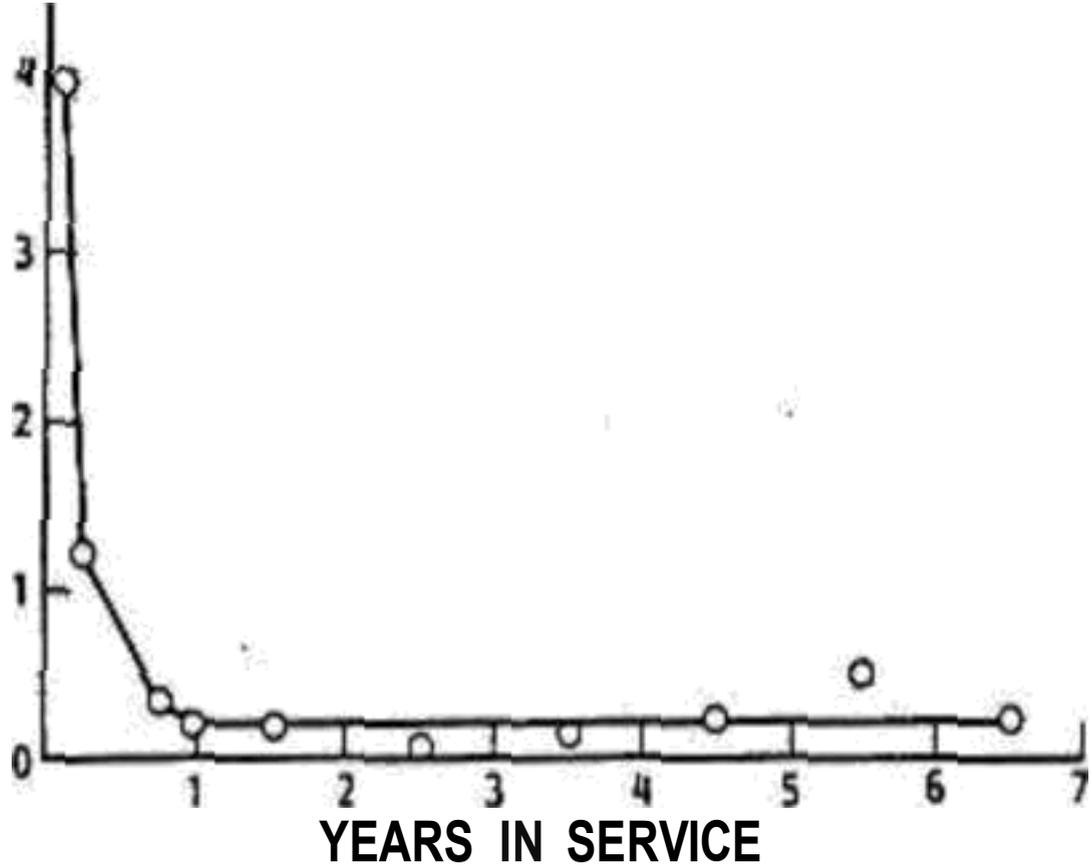
- Optimizing operating electrical stresses to safe levels by better inter electrode spacing.
- Increasing the gas volume and the thermal inertia of the system to enhance cooling and retain Insulation strength.

## 2. High reliability:

- Superior contact systems for Circuit Breakers And Disconnectors.
- Multi-contact and friction free surfaces incorporated for long operating cycles.
- Rugged, time proven operating drives used.

# GIS Failure Statistics:





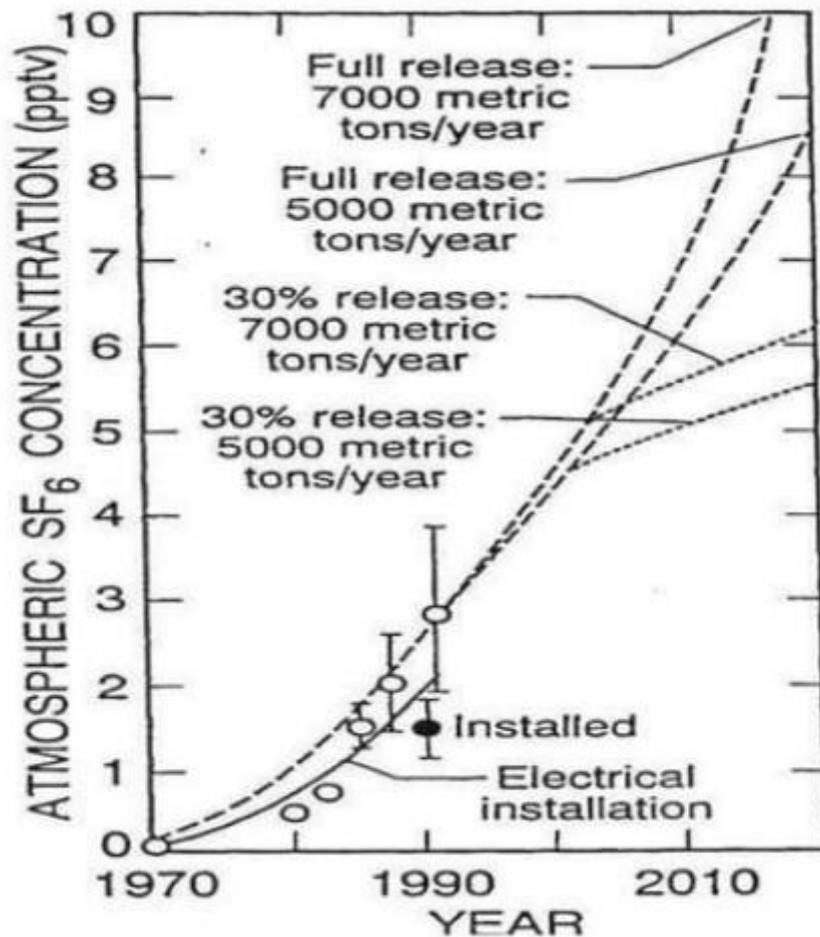
In-service fault rate (Faults/station-year) vs. years in service for North American 21

# Main Drawbacks:

- High cost compared to conventional Substation (AIS).
- Excessive damage in case of internal fault.
- Diagnosis of internal fault and rectifying takes very long time (high outage time).
- SF6 gas pressure must be monitored in each compartment.
- Reduction in the pressure of the SF6 gas in any module results in flash over and faults.
- SF6 causes ozone depletion and global warming.

# SF6 — Environmental Concerns:

- Currently, 80% used by Electrical Power industry.
- Other Uses — micro-electronics: Al & Mg production.
- 7000 metric tons/yr in 1993.
- Reached 10,000 metric tons/yr by 2010.
- Two areas of Health and Environmental impact:
  - Through its normal use in a work place — Arcing byproducts.
  - Global Environmental impact - Ozone depletion and Global warming.



# SF6/N2 Mixtures for GIS?

- SF6 gas – specifically mentioned in Kyoto protocol.
- Small quantities of SF6 in N2 can improve dielectric strength drastically.
- All of the dielectric strength of SF6, nearly, can be achieved by adding less than 20% SF6 into N2.
- SF6/N2 mixtures less susceptible to effects of field non uniformity than pure SF6.
- Thus mitigating the effects of particles and surface protrusions.

# Future trends:

- Compact design of switch gear by using three phase modules.
- Use of vacuum circuit breaker cells in the medium high voltage GIS.
- Optimization of GIS design to allow easier maintenance.
- Development of DC GIS for incorporating into expanding national/international HVDC systems.
- Search for replacement gases for SF<sub>6</sub>.
- The most promising - an 80%/20% N<sub>2</sub>/SF<sub>6</sub> mixture.
- Replacement of existing AIS by GIS will accelerate especially near urban centers.

# CONCLUSION:

- GIS — necessary for Extra HV & Ultra HV
- Some important areas to be studied include:
  - More conservative design.
  - Improved gas handling.
  - Decomposition product management techniques.
- Achieving & maintaining high levels of availability require — more integrated approach to quality control by both users and manufactures.



**SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES.  
(AUTONOMOUS)  
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING  
NBA ACCREDITED**

**Course Outcomes:**

**Learning Outcomes**

After completing these topics, students will be able to:

1. **Explain the structure and operation of air insulated substations**, including indoor and outdoor configurations used in distribution networks.
2. **Interpret the layout of a 33/11 kV substation** and identify the function and placement of each substation component.
3. **Differentiate various bus bar arrangements** and evaluate their advantages, disadvantages, and applications in electrical power systems.
4. **Describe the constructional features and working of Gas Insulated Substations (GIS)** including the use of SF<sub>6</sub> gas as insulation.

**BOOK/NPTEL LINK REFERENCE FOR UNIT -3**

1. V. K. Mehta and Rohit Mehta, Principles of Power System, S. Chand, 4th Edition, 2005.
2. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1985.
3. NPTEL – Power Plant Engineering  
<https://nptel.ac.in/courses/112105123>
4. NPTEL – Energy Resources and Technology  
<https://nptel.ac.in/courses/103103206>

**Case Study:**

**Compare AIS and GIS substations** and determine their suitability for urban, industrial, and high-voltage applications.

Date: - 02-03-2026.

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K. VEERANJINEYULU.

## Assignment

\* Difference between air insulated and gas insulated substations.

5/8

GIS substation	AIS substation.
① Less space required (10%)	① More space required.
② enclosed in building	② open area.
③ Less sensitive to pollution salt, sand and snow.	③ More sensitive.
④ Initial cost is high	④ Initial cost is low.
⑤ operation and maintenance cost is less then comparatively AIS.	⑤ operation and maintenance cost is high the comparatively GIS.
⑥ Installation time is less	⑥ Installation time is more.
⑦ NO arc and flashess	⑦ arc and flashess are common.
⑧ Need less maintenance	⑧ Need Regular maintenance.
⑨ Insulating medium as sulphur Hexafluoride ( $SF_6$ ) gas.	⑨ Insulating medium as air.
⑩ Mostly indoor or underground installation.	⑩ Mostly outdoor installation.
⑪ very low fault rate	⑪ fault rate is higher due to pollution & moisture.
⑫ Expansion is difficult.	⑫ Expansion is easy.
⑬ Reliability is very high	⑬ Reliability is moderate.

## Advantages of GIS:

- ① Requires very less space.
- ② suitable for urban & industrial areas.
- ③ High reliability and long life
- ④ Minimal maintenance.

## Disadvantages of GIS:

- ① High installation cost.
- ② SF<sub>6</sub> gas is harmful to the environment.

## Advantages of AIS:

- ① simple construction.
- ② easy to repair and expand.
- ③ lower cost.

## Disadvantages of AIS:

- ① Requires large land area.
- ② affected by weather, dust, pollution.

## Applications:

**GIS:** cities, underground substations, metro rail, space-limited areas.

**AIS:** Rural areas, power plants, where land is available.

## GIS Substations in India:-

- ① Telangana/Hyderabad: 765/400 kV GIS at Nizamabad and Maheshwaram: 400V GIS.
- ② Gujarat: 220/66kV GIS at Borejodi.
- ③ Goa: 220/33kV GIS at Saligao.
- ④ Kerala: 400kV GIS in Kottayam.
- ⑤ Maharashtra: India's first 765 kV GIS in Pune.

## GIS Substations in Foreign Countries:

- ① Germany: 380 kV GIS substation in Buhl (Transnet BW).
- ② France: RTE is deploying 245 kV SF<sub>6</sub>-free GIS.
- ③ Japan: As the originator of the technology in the 1960s, Japan extensively uses GIS in high-density urban areas and seismic zones.
- ④ Singapore: ABB has deployed GIS substations to strengthen the power grid.

2/3/20

# ASSIGNMENT - 3

①. Comparison between Air insulated substation (AIS) and Gas Insulated Substation (GIS)?

## Air Insulated Substation (AIS) :-

- \* Air insulated substation (AIS) is electrical equipment is open to the atmosphere, and air acts as the insulation.
- \* The Construction of AIS is in open type equipment installed in yard.
- \* It requires very large space.
- \* The initial cost is low.
- \* The maintenance of AIS is high (exposed to environment).
- \* Reliability is lower in polluted area.
- \* The AIS installation consumes more time.
- \* It causes less environmental effect.
- \* The flexibility for extension is easy to expand.
- \* The life span is about around 25-35 years.
- \* It consists of large land area needed for construction.
- \* It chooses the rural areas to construct.
- \* The fault is due to more dust, moisture and animals.
- \* The operating voltage range is 11 kv to 765 kv.

\* The impact is high due to weather effect.

### Components used in AIS :-

Bus bars, circuit breakers, Isolators, current transformer, potential transformers, lightning arresters, power transformer.

### Working Principle :-

- \* Air acts as insulation between conductors.
- \* Large physical distance is required to avoid flashover.

### Voltage and Power levels in AIS :-

- \* The Voltage range is 11 kV to 765 kV.
- \* The common transmission Voltage is 132 kV, 220 kV, 400 kV.
- \* The power handling Capacity is 10 MVA to 2000+ MVA.
- \* It is used for transmission and distribution.

### Advantages of AIS :-

- \* Low installation cost.
- \* Simple construction.
- \* Easy fault detection.
- \* Easy expansion.

### Dis-advantages of AIS :-

- \* Requires large land.
- \* More maintenance.
- \* Environmental effects reduce reliability.

## Gas Insulated Substation (GIS) :-

- \* Gas insulated substation (GIS) is an electrical component enclosed in metal chambers filled with  $\text{SF}_6$  gas (sulphur hexa fluoride) for insulation.
- \* The construction of GIS is in completely enclosed metal chambers.
- \* It requires the very compact (about  $\frac{1}{10}$ th of AIS) area.
- \* The initial cost is very high.
- \* The maintenance of GIS is low (sealed system).
- \* The reliability is very high.
- \* The GIS installation consumes less time (modular design).
- \* The environmental effect of GIS is  $\text{SF}_6$  gas handling.
- \* Required (green house gas).
- \* The flexibility of extension is difficult and costly.
- \* Fault occurrence in GIS is very less.
- \* The life span is around 30-50 years.
- \* It requires very small land area.
- \* It chooses the urban or indoor locations only.
- \* The operating voltage range is 33 kV to 1200 kV.
- \* There is no weather effect almost no impact.

## Components used in GIS :-

- \* GIS Components is metal enclosed.
- \* The Components are circuit breakers, busbars, disconnectors, earthing switch, instrument transform.

## Working Principle :-

- \*  $SF_6$  gas high di-electric strength (about 2-3 times higher than air).
- \* Equipment Spacing is very small, making the Substation Compact.

## Voltage and Power levels :-

- \* The Voltage range is 33kV to 1200 kV.
- \* The Common transmission voltage is 220 kV, 400kV, 765
- \* It is used for high-voltage transmission, especially in cities.

## Advantages of GIS :-

- \* Requires very small space.
- \* very high reliability.
- \* less maintenance.
- \* safe and compact.

## Dis-advantages of GIS :-

- \* It is very expensive
- \* Complex design.
- \*  $SF_6$  gas handling required.
- \* Expansion is difficult.

## Gas Installations (In India) :-

Delhi - Dwarka.

Bihar - Kishanganj.

Punjab - Chandigarh.

Maharashtra - Padghe & Pune.

Karnataka - Bidadi & Yelahanka.

Assam - Haflong.

Uttar Pradesh - Varanasi.

## AIS Installations (In India) :-

Bihar - Patna & Gaya.

Jharkhand - Ranchi.

Punjab - Amritsar.

Karnataka - Bangalore.

West Bengal - Durgapur.

Maharashtra - Aurangabad.

2/3/2026

## **UNIT-IV: DISTRIBUTION SYSTEMS:**

**(09)**

*Classification of Distribution systems, A.C Distribution, Overhead versus Underground system, Connection schemes of Distribution system, Requirements of Distribution system, Design considerations in Distribution system.*

### **UNDERGROUND CABLES:**

*Types of cables, construction, types of insulating materials, calculation of insulation resistance, stress in insulation and power factor of cable. Capacitance of single and 3-Core belted Cables. Grading of cables: capacitance grading and inter sheath grading.*

### **Unit 4 Objectives :**

- 1. Understand the structure and classification of electrical distribution systems**, including radial, ring main, and interconnected systems used in modern power distribution networks.
- 2. Explain the operating principles of A.C distribution systems** and analyze the advantages and disadvantages of **overhead and underground distribution systems**.
- 3. Study various connection schemes and configurations of distribution systems**, including feeder, distributor, and service mains used in practical power supply networks.
- 4. Analyze the requirements and design considerations of distribution systems**, such as voltage regulation, reliability, efficiency, and load balancing.
- 5. Understand the construction and electrical characteristics of underground cables**, including insulation materials, capacitance, insulation resistance, grading of cables, and stress distribution in cable insulation.

The distribution system is the electrical system between the sub-station fed by the transmission system and the consumers meters. It generally consists of **feeders**, **distributors** and the **service mains**. Fig. 12.1 shows the single line diagram of a typical low tension Electric Power Distribution System.

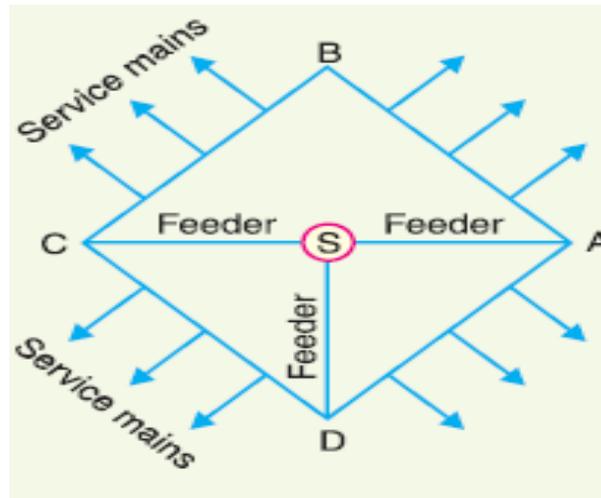


Fig. 12.1

1. **Feeders:** A feeder is a conductor which connects the sub-station (or localised generating station) to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.
2. **Distributor:** A distributor is a conductor from which tappings are taken for supply to the consumers. In Fig. 12.1, AB, BC, CD and DA are the distributors. The current through a distributor is not constant because tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is  $\pm 6\%$  of rated value at the consumers terminals.
3. **Service mains:** A service main is generally a small cable which connects the distributor to the consumers terminals.

#### **Classification of Distribution systems:**

Distribution systems are primarily classified based on the nature of the current, the type of construction, and the scheme of connection. These

systems are essential for delivering electric power locally from substations to consumers, with modern infrastructure almost universally adopting AC for its simplicity and economic efficiency.

## **Classification of Distribution Systems**

### **Nature of Current:**

- **AC Distribution System:** The most common method, utilizing primary and secondary distribution levels to manage voltage efficiently.
- **DC Distribution System:** Used for specific applications (e.g., battery charging) and can be configured as 2-wire or 3-wire systems.

### **Type of Construction:**

- **Overhead System:** Widely used due to its flexibility and significantly lower initial cost (5 to 10 times cheaper than underground).
- **Underground System:** Preferred in areas where overhead lines are prohibited or impractical, offering higher safety despite higher installation costs.

### **Scheme of Connection:**

- **Radial System:** The simplest and lowest-cost configuration where feeders radiate from a substation.
- **Ring Main System:** Provides better reliability as the distributor is fed at more than one point, forming a loop.
- **Interconnected System:** A more complex, highly reliable network where multiple substations are linked to provide power from various sources.

### **A.C Distribution:**

The AC Distribution System is the electrical system between the step-down substation fed by the transmission system and the consumers meters. The AC Distribution System is classified into

1. Primary distribution system and
2. Secondary distribution system.

## 1.Primary distribution system:

- It is that part of AC Distribution System which operates at voltages somewhat higher than general utilisation and handles large blocks of electrical energy than the average low-voltage consumer uses.
- The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed.
- The most commonly used primary distribution voltages are 11 kV, 6.6 kV and 3.3 kV.
- Due to economic considerations, primary distribution is carried out by 3-phase, 3-wire system.

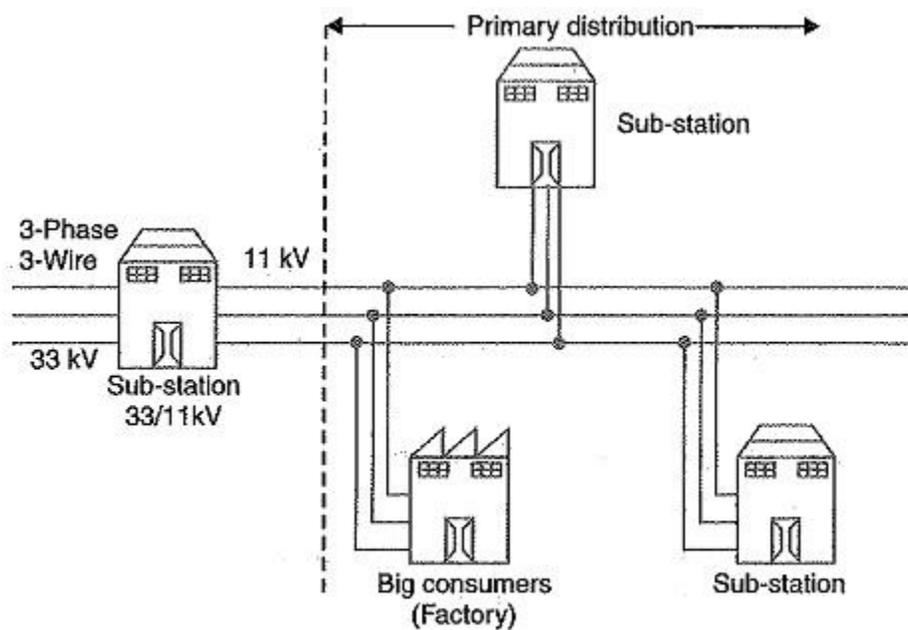


Fig. 12.2

Fig. 12.2 shows a typical primary distribution system. Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation, voltage is stepped down to 11 kV with the help of step-down transformer. Power is supplied to various substations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution.

## 2.Secondary distribution system:

It is that part of AC Distribution System which includes the range of voltages at which the ultimate consumer utilises the electrical energy.

The secondary distribution employs 400/230 V, 3-phase, 4-wire system.

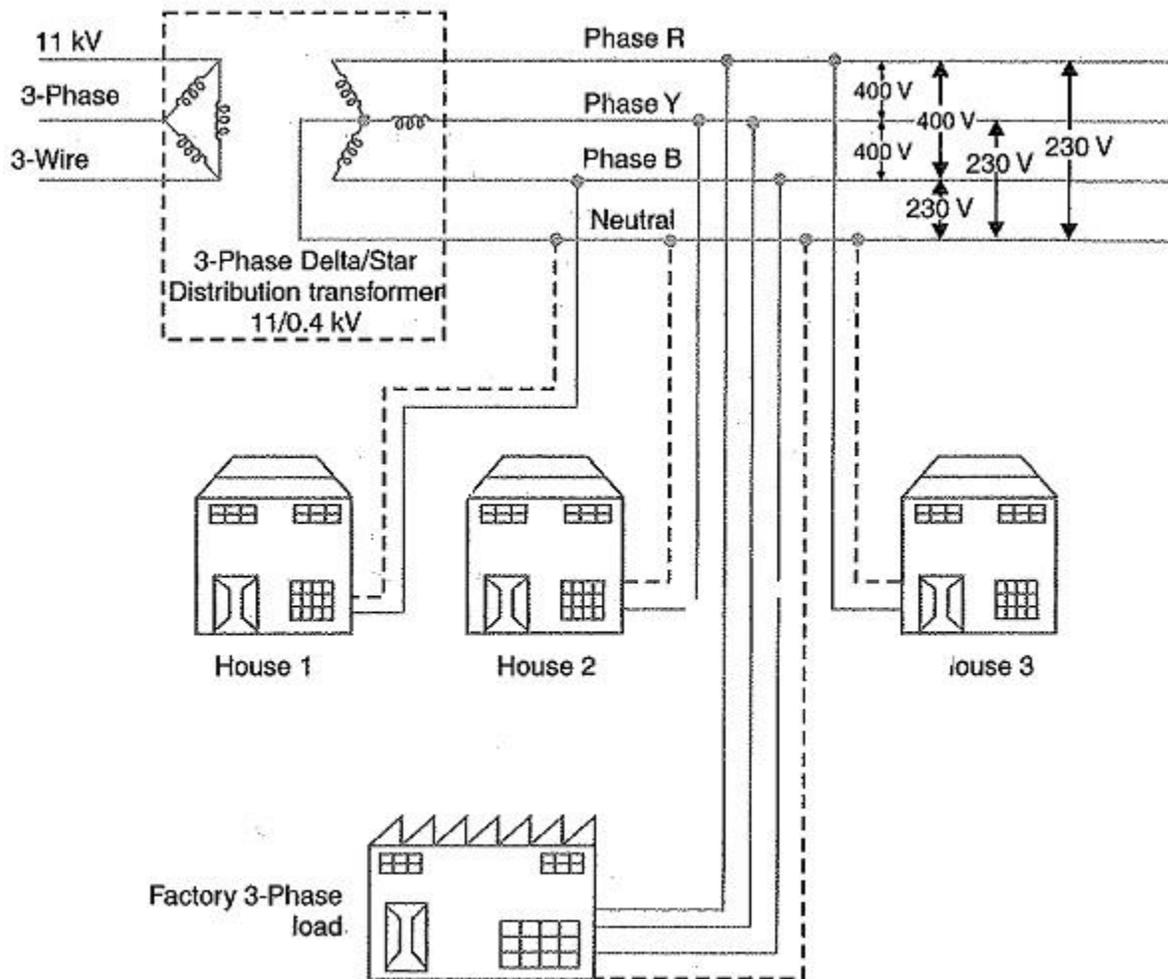


Fig. 12.3

Fig. 12.3 shows a typical secondary distribution system. The primary distribution circuit delivers power to various substations, called distribution substations.

The substations are situated near the consumers localities and contain step-down transformers.

At each distribution substation, the voltage is stepped down to 400 V and power is delivered by 3-phase,4-wire a.c. system. The voltage between any two phases is 400 V and between any phase and neutral is 230 V.

The single-phase domestic loads are connected between any one phase and the neutral, whereas 3-phase 400 V motor loads are connected across 3- phase lines directly.

### **Overhead versus Underground system:**

**Electrical power** is produced at the **power generating plants** which are located far away from the load centers. Therefore, we need to transport the electrical power generated at the power generating plant to the points of utilization or load points. For this purpose, two major systems of conductors are developed called **transmission system and distribution system**.

Both transmission and distribution systems are further classified into two types namely,

- Overhead system
- Underground system

In the **overhead system** of transmission and distribution, the **overhead line wires** supported by poles are used for power transportation; while in the **underground system, insulated underground cables** are employed for the transportation of electric power.



Overhead Lines

Versus



Underground Cables

Let's start with the basics of overhead lines and underground cables so it becomes easier to understand the differences between them.

#### **What is Overhead Line?**

**Overhead lines** or **overhead transmission lines** are the bare conductors supported on poles and towers. In overhead system, the line conductors are

hanged in air with the help of transmission line supports installed at a certain distance.

An overhead line consists of conductors, supports, line insulators, cross arms, and many other auxiliary components. The conductors are the bare metallic conductors that carry electric power from the sending end to the utilization end. The supports may be poles or steel towers that keep the line conductors at a suitable level above the ground. Since the conductor and support both are conductors of electricity, therefore insulators are used to insulate the line conductors from the support and hence from the ground which may otherwise cause fault and danger for living beings.

The cross-arm is the part of an overhead line which provides housing and support to the line insulators. Other auxiliary component of an overhead line are lightning arrestors, anti-climbing wires, phase and danger plates, stay rod, etc.

Due to some technical and economic reasons, the overhead lines are extensively used in power transmission and distribution.

### **What is Underground Cable?**

**Underground cables** or **undergrounds lines** are the insulated electric cables which are buried under the earth surface for the transmission and distribution of electric power. However, the power transmission using underground cables is relatively more expensive method, hence it is less frequently used method.

Mostly, the underground cables are used in such cases where it is possible to install overhead lines.

A typical underground cable consists of one or more (two, three or four) central cores of stranded conductors (copper or aluminium) and these are insulated from each other by paper or varnished cambric or impregnated paper.

In order to protect this insulation against moisture and mechanical damages, a metallic sheath of lead or alloy of aluminium is provided around it. Finally, an insulation cover is provided.

The type of underground cable used for power transmission and distribution depends on the voltage and service requirements.

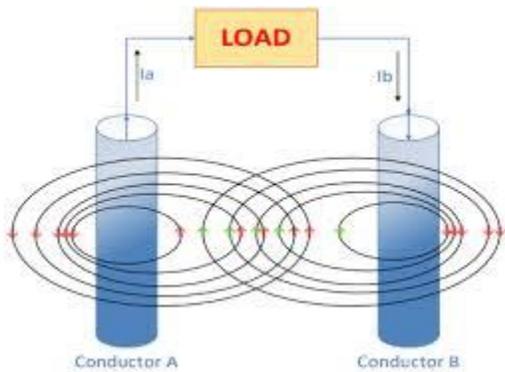
## Difference between Overhead Lines and Underground Cables

Since overhead lines and underground cables both are used in the electric power transmission and distribution. However, there are several differences between overhead lines and underground cables that are given in the following table

<b>Basis of Difference</b>	<b>Overhead Lines</b>	<b>Underground Cables</b>
Definition	An overhead line is the one that uses bare conductors supported on a pole or tower for power transmission and distribution.	An underground cable is an insulated cable which is buried under the earth surface for power transmission and distribution.
Type of conductor	Overhead lines use bare conductor.	Undergrounds cables use insulated conductor.
Size of conductor	The size of conductor used in overhead lines is comparatively smaller.	The size of conductor used in underground cables is relatively larger.
Voltage rating	Overhead lines have higher voltage rating, near about 765 kV.	Undergrounds cables have comparatively lower voltage rating. It is typically limited to 66 kV.
Current carrying capacity	The current carrying capacity of overhead lines is comparatively more.	Underground cables have lesser current carrying capacity.

Insulation	Overhead lines require less insulation. Usually, at the contact points of the support.	Underground cables need more insulation. It is because, the whole conductor is required coated with the insulation sheath.
Interference with communication lines	Overhead lines causes interference to the nearby communication lines.	Underground cables do not cause interference to the communication lines as these are buried under the earth surface.
Safety for living being	Overhead lines are not much safer for the living beings.	Underground cables are safest for living beings.
Fault detection and clearance	In case of overhead lines, the detection and clearance of fault is easy.	It is very difficult to detect and clear the fault in underground cables.
Line cost	Overhead lines are relatively less expensive.	Underground cables are comparatively expensive.
Maintenance cost	Overhead lines have high maintenance cost.	For the underground cables, the maintenance cost is comparatively low.
Extra connection	In case of overhead lines, it is very to join an extra connection.	It is not easy to make an extra connection in case of underground cables.
Reliability	Overhead lines are less reliable.	The reliability of underground cables is high.

Risk of explosion	In case of overhead line, the risk of explosion or fire is more.	Underground cables reduce the risk of explosion or fire.
Layout flexibility	The layout of overhead lines is highly flexible.	The underground cables possess less flexibility in the layout.
Effect environmental conditions	Overhead lines get easily affected by the adverse environmental conditions like lightning, thunderstorm, wind storm, moisture, etc.	Underground cables are less affected by the environmental attacks.
Corona discharge	The corona discharge occurs in the overhead lines.	No corona discharge takes place in the underground cables.
Proximity effect	Overhead lines remain unaffected from the proximity effect.	The proximity effect influences the underground cables.
Applications	Overhead lines are used in electric power transmission and distribution over large distances.	Underground cables are used in power transmission and distribution over short and moderate distances.



When the conductors carry the high alternating voltage then the currents are non-uniformly distributed on the cross-section area of the conductor. This effect is called proximity effect.

The proximity effect can be reduced by using the ACSR (Aluminum Core Steel Reinforced) conductor. In ACSR conductor the steel is placed at the centre of the conductor and the aluminium conductor is positioned around steel wire.

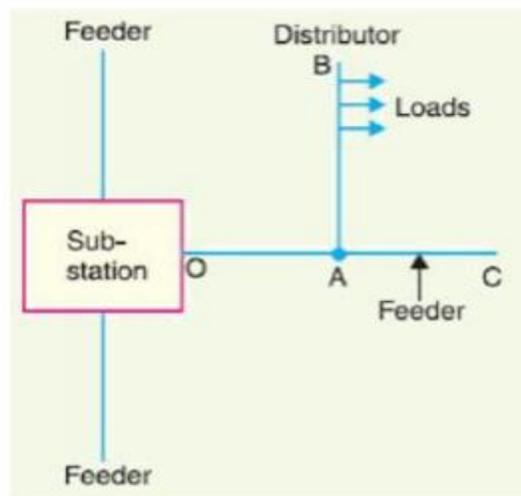
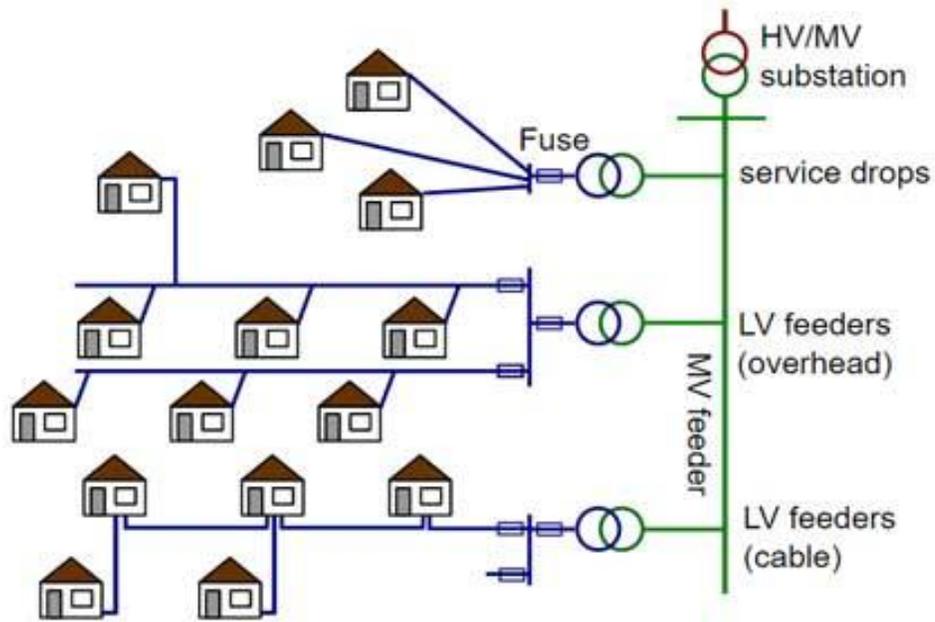
### ***Connection schemes of Distribution system:***

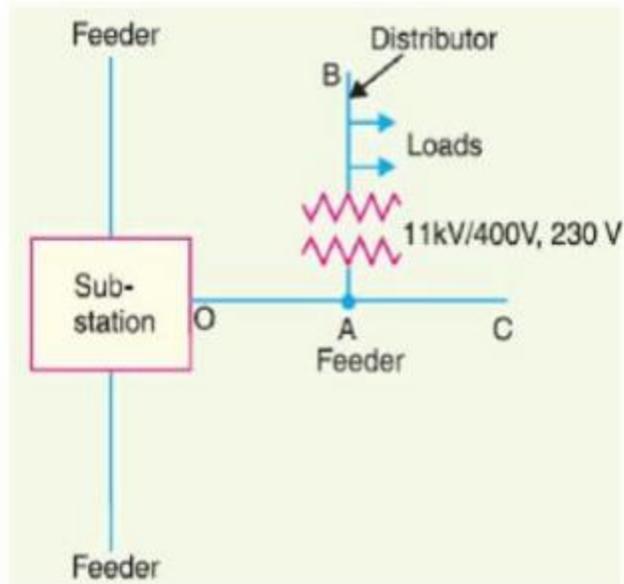
An **electric power distribution system** can be classified based on the configuration of its feeder connection schemes, also known as distribution topologies. The four most commonly used configurations are:

- Radial distribution system
- Parallel feeders distribution
- Ring main distribution system
- Interconnected distribution

#### **Radial distribution system**

This system is used only when the substation or generating station is located at the centre of the consumer zone. In this system, different feeders radiate from a substation or a generating station and feed the distributors at one end. Thus, the main **characteristic of a radial distribution system** is that the power flow is in only one direction. Single line diagram of a typical radial distribution system is as shown in the figure below. It is the simplest system and has the lowest initial cost.





### Key Characteristics:

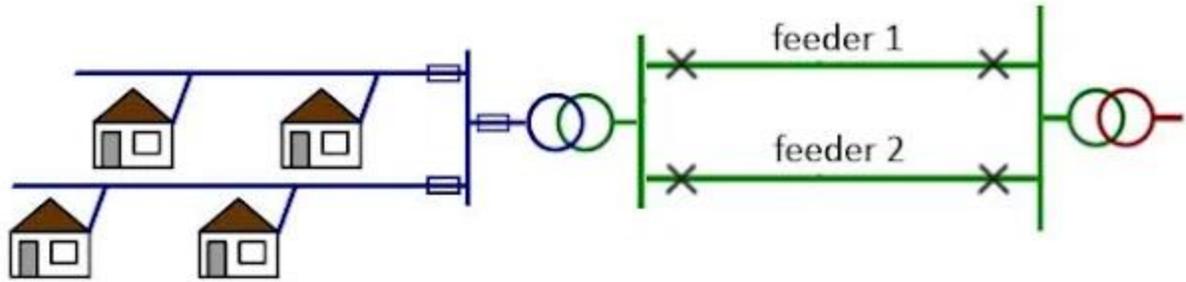
- Power flows in one direction only
- Simplest and least expensive configuration
- Low initial cost

### Drawbacks:

- Low reliability – a fault in the feeder will result in supply failure to associated consumers as there won't be any alternative feeder to feed distributors
- Maintenance leads to service interruption

### Parallel feeders distribution system

The above-mentioned disadvantage of a radial system can be minimized by introducing parallel feeders. The initial cost of this system is much more as the number of feeders is doubled. Such system may be used where reliability of the supply is important or for load sharing where the load is higher.



### Key Characteristics:

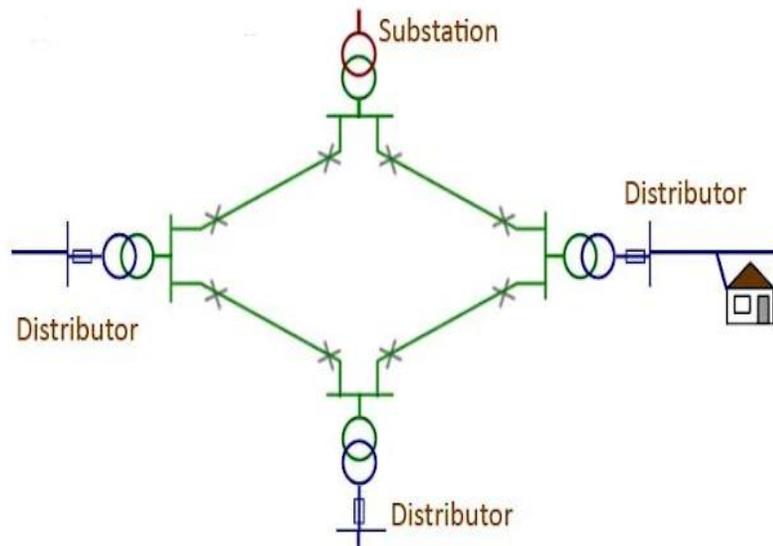
- Improved reliability
- Better load-sharing in high-demand areas

### Drawbacks:

- High initial cost due to doubling of feeders

### Ring main distribution system

A similar level of system reliability to that of the parallel feeders can be achieved by using **ring distribution system**. Here, each distribution transformer is fed with two feeders but in different paths. The feeders in this system form a loop which starts from the substation bus-bars, runs through the load area feeding distribution transformers and returns to the substation bus-bars. The following figure shows a typical single line diagram of a ring main distribution system.



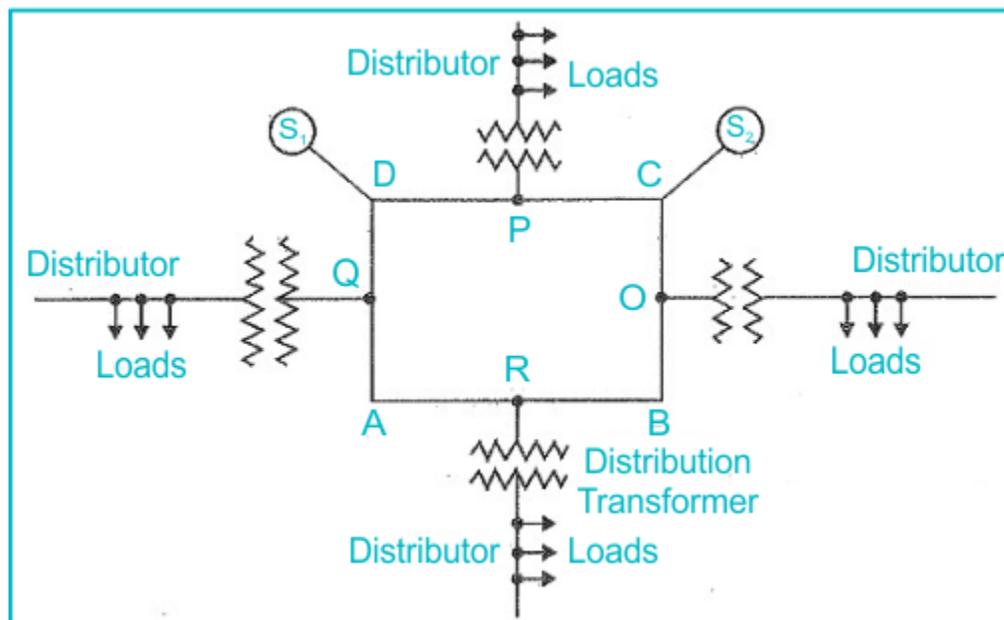
Ring main distribution system is the most preferred due to its following advantages.

### Advantages of ring main distribution system

- There are fewer voltage fluctuations at consumer's terminal.
- The system is very reliable as each distribution transformer is fed with two feeders. That means, in the event of a fault in any section of the feeder, the continuity of the supply is ensured from the alternative path.

### Interconnected distribution system

When a ring main feeder is energized by two or more substations or generating stations, it is called as an interconnected distribution system. This system ensures reliability in an event of transmission failure. Also, any area fed from one generating stations during peak load hours can be fed from the other generating station or substation for meeting power requirements from increased load.



### Key Characteristics:

- Redundant power sources in case of failure
- Load sharing between substations during peak demand
- Highly suitable for dense metro areas

## Summary Comparison

Distribution Type	Reliability	Cost	Power Flow	Best For
Radial	Low	Low	One-directional	Small towns, rural areas
Parallel Feeders	Moderate	High	One-directional	High-load, industrial zones
Ring Main	High	Moderate	Bidirectional	Urban & residential areas
Interconnected	Very High	Very High	Multi-directional	Metropolitan grids

## ***Requirements of Distribution system***

Ref:<https://ieeexplore.ieee.org/document/9538547>

### **Requirements of a Distribution System:**

The primary requirements of an electrical distribution system centre on providing high-quality, safe, and cost-effective power to consumers. A well-designed system must balance these technical and economic factors to ensure reliable operation.

#### **1. Core Technical Requirements**

**Proper Voltage Regulation:** Voltage variations at the consumer's terminals must be kept within strict permissible limits.

In India, the statutory limit for voltage variation is typically  $\pm 6\%$  of the rated value.

Low voltage causes revenue loss and can burn out motors, while high voltage can permanently damage lamps and other appliances.

**Reliability:** The system must provide continuous and uninterrupted power. High reliability is achieved through:

Interconnected systems that allow multiple paths for power flow.

Automatic control systems to handle faults and switching.

Reserve facilities to manage unexpected outages or maintenance.

**Availability of Power on Demand:** Electricity cannot be easily stored on a large scale; therefore, the system must be capable of meeting consumer load demands instantly at any time.

## **2. Safety and Operational Requirements**

**Safety:** The system must not present hazards to the public or maintenance personnel. This involves proper insulation, grounding, and the use of protective devices like circuit breakers and fuses.

**Adequate Capacity:** Feeders and distributors must have sufficient current-carrying capacity to handle peak loads without overheating or overloading.

**Efficiency:** Power losses (such as

losses) should be minimized to improve overall system efficiency and reduce operational costs.

## **3. Design and Economic Considerations**

**Economy:** The design must minimize initial investment, including installation and material costs (e.g., conductor size), while also reducing long-term maintenance expenses.

**Flexibility and Extensibility:** A good system is adaptable to future load growth and can be easily modified or expanded without major overhauls.

**Simplicity:** Simple designs facilitate easier maintenance and faster fault detection, reducing potential downtime

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the good Requirements of a Distribution System are:

### **1. Proper voltage**

## **2. Availability of power on demand**

### **3. Reliability**

#### **1. Proper voltage:**

One important Requirements of a Distribution System is that voltage variations at consumer's terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits. The statutory limit of voltage variations is  $\pm 6\%$  of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

#### **2. Availability of power on demand:**

Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the Requirements of a Distribution System must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

#### **3. Reliability:**

Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by

- **interconnected system**
- **reliable automatic control system**

- **providing additional reserve facilities.**

### **Design Considerations in Distribution System:**

Design Considerations:

**Voltage Regulation:** Ensuring voltage at consumers' terminals remains within of the nominal value, essential for equipment performance.

**Reliability & Continuity:** Designing with redundancy (e.g., ring main systems) to minimize outages and improve service.

**Load Estimation & Forecasting:** Analysing current loads and projecting future growth to size components properly (transformers, feeders).

**System Configuration:** Choosing between radial, ring main, or interconnected networks based on reliability needs.

**Equipment Location:** Placing substations and transformers at the load center to minimize cable lengths, reduce voltage drops, and decrease power losses.

**Safety and Protection:** Installing adequate circuit breakers, relays, and proper grounding to protect against faults and overloads.

**Cost Efficiency:** Balancing initial capital investment (material, construction) with operational expenses (losses, maintenance).

**Environmental Factors:** Considering overhead vs. underground, and environmental impacts on equipment.

#### **Component Considerations:**

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers.

##### **1.Feeders:**

- A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant.
- It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

##### **2.Distributors:**

- A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals ( $\pm 6\%$  of rated value).
- The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

### 3.Service Mains:

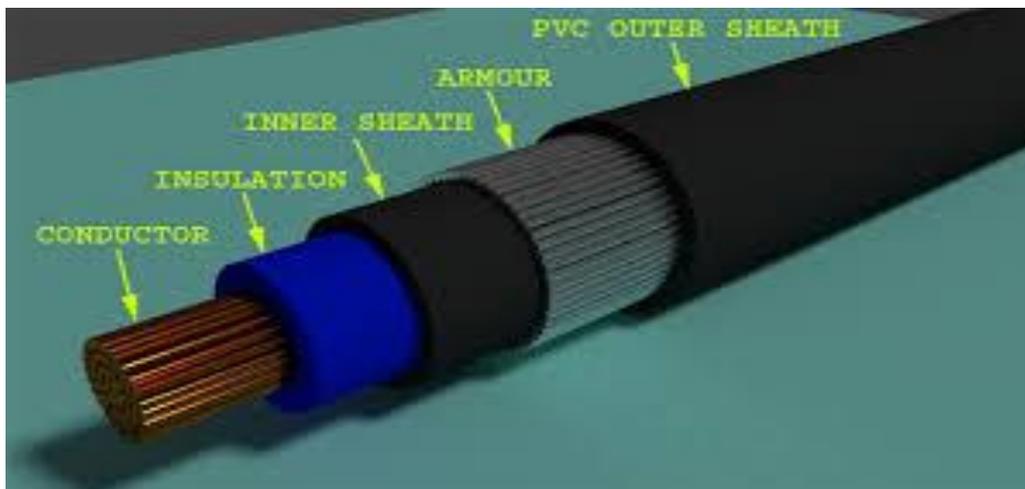
Designed for economic cable sizing connecting the distributor to the consumer.

## **UNIT-4(Part-B) Syllabus**

### **UNDERGROUND CABLES:**

***Types of cables, construction, types of insulating materials, calculation of insulation resistance, stress in insulation and power factor of cable. Capacitance of single and 3-Core belted Cables. Grading of cables: capacitance grading and inter sheath grading.***

### **Types of cables:**



## Classification of underground cables

The **classification of Underground cables** can be done on the basis of several criteria. Various aspects are taken into account while classification and these include:

- A. Number of conductors in the cable
- B. Voltage rating of the cable
- C. Construction of cable
- D. Type and thickness of insulation used
- E. Installation and Laying of the cables

### ➤ **Classification based upon number of conductors in the cable**

- 1. Single core cable
- 2. Three core cable

Typically, an Underground cable has either one, three or four cores. These cables are of course, constructed accordingly.

Underground cables are usually employed to deliver 3 phase power. A 3 cored cable is preferred up to 66 kV. Beyond that, insulation required for the cable is too much. For higher voltages, 3 cored constructions become too bulky, and hence, even with some limitations we employ single cored cables.

### ➤ **Classification based upon voltage rating of the cable**

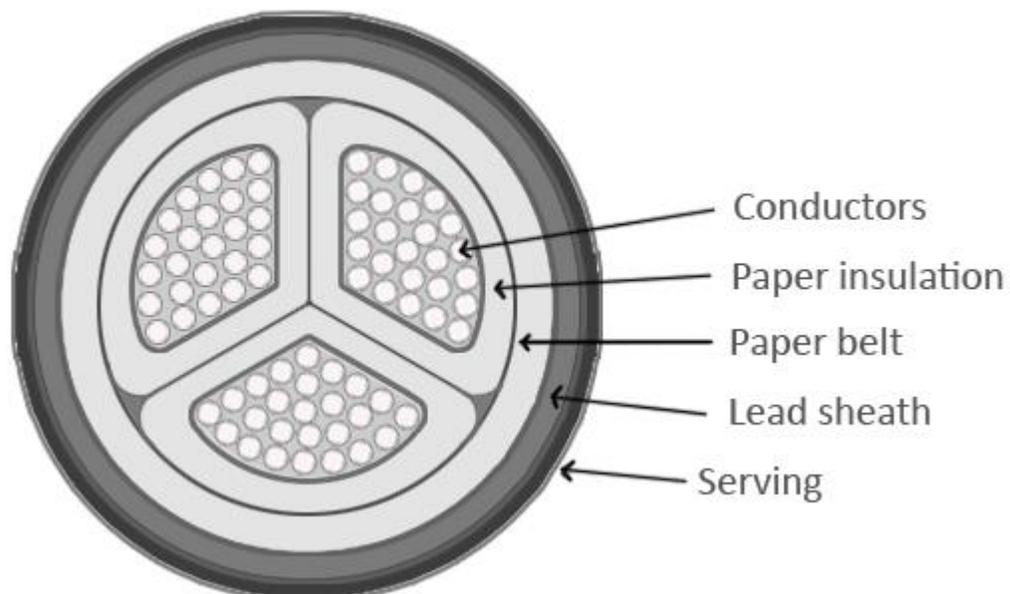
- 1. **Low tension cables:** These have a maximum voltage handling capacity of 1000 V (1 kV)
- 2. **High tension cables:** These have a maximum voltage handling capacity of 11 kV.
- 3. **Super tension cables:** These have a maximum voltage handling capacity of 33 kV.

4. **Extra hightension cables:** These have a maximum voltage handling capacity of 66 kV.
5. **Extra super voltage cables:** These are used for applications with voltage requirement above 132 kV.

➤ **Classification based upon construction of the cable**

**1. Belted cable**

- In such cables, the conductors (usually three) are bunched together and then bounded with an insulating paper 'belt'.
- In such cables, each conductor is insulated using paper impregnated with a suitable dielectric.
- The gaps between the conductors and the insulating paper belt are filled with a fibrous dielectric material such as Jute or Hessian.
- This provides flexibility as well as a circular shape. As we discussed earlier (in Construction of Cables), the jute layer is then covered by a metallic sheath and armouring for protection.
- One particular speciality of this cable is that its shape may not be perfectly circular. It is kept non-circular to use the available space more effectively.



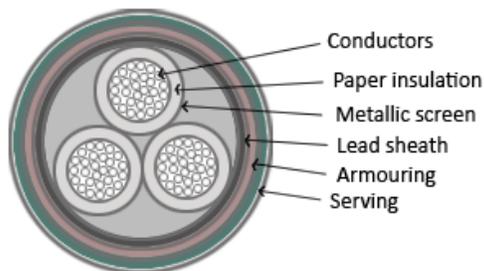
There are **some limitations** of such construction. Since the electric field is tangential, the insulation provided is stressed.

- As a result, the dielectric strength falls over time. Hence, such construction isn't preferred for voltage levels above 11 kV.

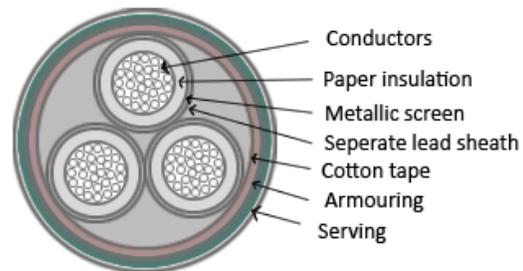
## 2. Screened cable

### H-Type Cables:

- It was first designed by M. Hochstadter. The three cores are individually insulated with paper and then covered by a metallic screen / cover. These metallic covers are perforated. As a result, such construction allows the three metallic screens to touch each other. These three metallic covers are then grouped together in a metallic tape usually made of copper. A lead sheath surrounds this construction. The metallic covers and the sheath are grounded.
- The obvious advantage is the electric stresses are radial, not tangential and hence of lesser magnitudes. Also, the metallic covers improve the heat dissipation.



H-type cable



S.L. type cable

### S.L Type Cables:

- It is similar to the H type cables, with the difference that each of the three cores has its own lead sheath. With this provision, the need for the overall sheath used previously is eliminated. The advantage of such a construction is that the

chances of a core-to-core breakdown are greatly minimized. Also, the flexibility of the cable is improved.

- The limitations are severe. Such construction is limited for voltages up to 66kV only. The individual sheaths are thinner, and if there are constructional defects, moisture may enter the cable and reduce its dielectric strength.

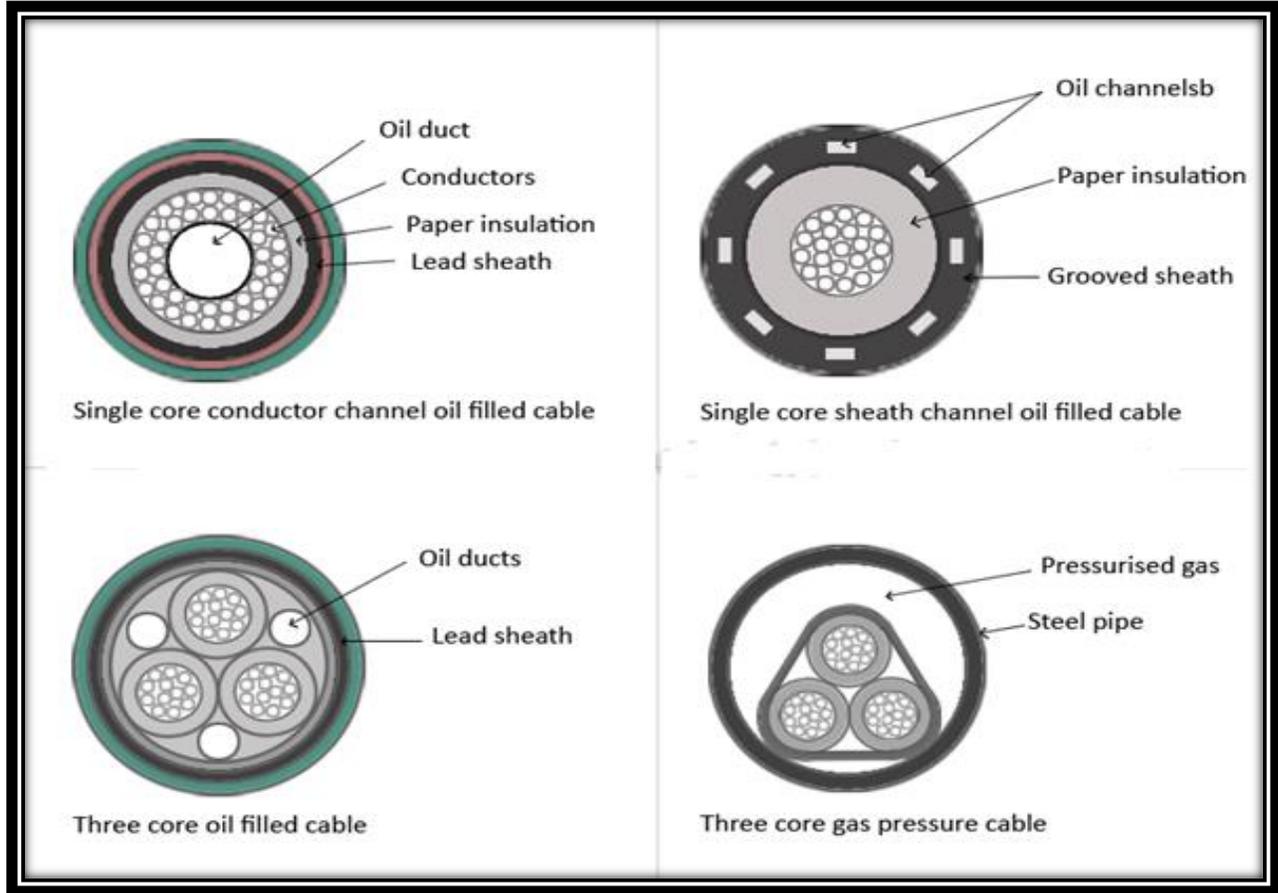
### **H.S.L. Type Cables:**

This type of cable is combination of H type and S.L. type cable. In these cables each core is insulated with impregnated paper and provided with separate lead sheaths.

### **3. Pressure cables**

For voltages beyond 66 kV, the electrostatic stresses in the cables exceed the acceptable values and solid cables become unreliable. This occurs mainly because voids are created when voltages exceed 66 kV. Hence, instead of solid cables, we use Pressure cables. Typically, such cables are either oil filled or gas filled.

- **Oil Filled Cables:** Oil is circulated under suitable pressure through ducts provided for such purpose. This oil supply and pressure are maintained through reservoirs kept at proper distances. The oil used is the same that is employed for impregnation of paper insulators.
- **Gas Filled Cables:** Pressurized gas (usually dry nitrogen) is circulated around cables in an air-tight steel pipe. Such cables are cable of carrying higher values of load current and can operate at higher values of voltage. But the overall cost is more.



**Classification based upon insulation of the cable**

Various insulating materials used in cable construction are Rubber, Paper, PVC, XLPE (Cross linked Polyethene) etc. Such classification is based upon operating temperature limitations. Following are some insulating materials used and their maximum operating temperatures.

Insulation material	Max.operating temperature
PVC TYPE A	75°C
PVC TYPE B	85°C

PVC TYPE C	85°C
XLPE	90°C
RUBBER	90°C
RUBBER – EPR IE-2, EPR IE-3, EPR IE-4, SILICON IE-5	150°C

### **Classification based upon installation and laying of the cable**

**Direct Buried:** As the name suggests, the conductors are buried underground in a trench without additional accessories. Sometimes cooling pipes are added if required. Once the cables are installed, there's no visible sign above the ground.

**Trough:** Concrete troughs are dug and cables are installed in them. They're visible on the surface. Maintenance is easier.

**Tunnels:** Sometimes, tunnels are dug up for this purpose. Such construction is mainly employed if a river needs to be crossed or if the intended power distribution is to a major city. Maintenance and future expansion is easier, but initial cost is higher.

**Gas Insulated Lines:** This is a relatively new technology. For cables operating at higher voltages and currents, and handling high power, such gas insulated line construction is safer. It is being employed nowadays for advanced projects.

### **Calculation of Insulation Resistance of Underground Cables**

#### **Concept of Insulation Resistance**

When a potential difference is applied between the **conductor and metallic sheath**, a small leakage current flows through the insulation. According to **Ohm's law**:

$$R = \frac{V}{I}$$

Where

- $R$  = Insulation resistance ( $\Omega$ )
- $V$  = Applied voltage (V)
- $I$  = Leakage current through insulation (A)

For underground cables, insulation forms a **cylindrical layer** between conductor and sheath.

### **Derivation of Insulation Resistance of a Single-Core Cable**

**Consider a cable with:**

- $r_1$  = radius of conductor
- $r_2$  = inner radius of sheath
- $l$  = length of cable
- $\rho$  = resistivity of insulation material

#### **Step 1: Consider a thin cylindrical layer**

Take a cylindrical shell of thickness  $dr$  at radius  $r$ .

Area for current flow:

$$A = 2\pi r l$$

Resistance of thin layer:

$$dR = \frac{\rho dr}{A}$$

Substitute  $A$ :

$$dR = \frac{\rho dr}{2\pi r l}$$

#### **Step 2: Integrate from conductor to sheath**

$$R = \int_{r_1}^{r_2} \frac{\rho}{2\pi l} \frac{dr}{r}$$

$$R = \frac{\rho}{2\pi l} \int_{r_1}^{r_2} \frac{dr}{r}$$

$$R = \frac{\rho}{2\pi l} \ln \left( \frac{r_2}{r_1} \right)$$

### Final Formula

$$R = \frac{\rho}{2\pi l} \ln \left( \frac{r_2}{r_1} \right)$$

Where

- $R$  = insulation resistance ( $\Omega$ )
- $\rho$  = resistivity of insulation ( $\Omega\cdot\text{m}$ )
- $l$  = length of cable (m)
- $r_1$  = conductor radius (m)
- $r_2$  = sheath radius (m)

### Important Observations

1. **Insulation resistance is inversely proportional to cable length**

$$R \propto \frac{1}{l}$$

Longer cable  $\rightarrow$  lower insulation resistance.

2. **Insulation resistance increases with insulation thickness**

$$R \propto \ln \left( \frac{r_2}{r_1} \right)$$

More insulation thickness  $\rightarrow$  higher resistance.

### 3. Better insulating materials have high resistivity

**Example resistivity values:**

Insulating Material	Resistivity ( $\Omega\cdot m$ )
Rubber	$10^{13}$
PVC	$10^{12}$
Impregnated Paper	$10^{11}$

#### **Insulation Resistance of a 3-Core Cable**

For a **3-core cable**, insulation exists:

1. Between **each conductor and sheath**
2. Between **conductors**

Equivalent resistance is calculated using **parallel resistance network**.

Approximate relation:

$$R_{phase} = \frac{3}{2}R$$

Where

$R$  = insulation resistance of one core to sheath.

#### **Example Problem**

**Given**

Length of cable  $l = 1000\ m$

Conductor radius  $r_1 = 1\ cm = 0.01\ m$

Sheath radius  $r_2 = 3\ cm = 0.03\ m$

Resistivity of insulation

$$\rho = 5 \times 10^{12}\ \Omega m$$

**Solution**

$$R = \frac{\rho}{2\pi l} \ln \left( \frac{r_2}{r_1} \right)$$
$$R = \frac{5 \times 10^{12}}{2\pi \times 1000} \ln \left( \frac{0.03}{0.01} \right)$$
$$\ln(3) = 1.0986$$
$$R = \frac{5 \times 10^{12}}{6283.18} \times 1.0986$$
$$R \approx 8.74 \times 10^8 \Omega$$
$$R \approx 874 M\Omega$$

### **Applications**

Insulation resistance calculation is used in:

- Underground cable design
- High voltage cable insulation testing
- Preventing leakage currents
- Ensuring safety and reliability in power systems

### **Reference Books:**

1. Power System Engineering
2. Electrical Power Systems
3. A Course in Electrical Power
4. Principles of Power System.

## **Outcomes:**

After completion of this unit, students will be able to:

1. **Classify and explain different types of electrical distribution systems** and evaluate their suitability for various power distribution applications.
2. **Compare overhead and underground distribution systems** based on cost, reliability, maintenance, and operational performance.
3. **Analyze different connection schemes of distribution systems** and understand their role in efficient power delivery.
4. **Evaluate the electrical properties of underground cables**, including insulation resistance, capacitance, dielectric stress, and power factor.
5. **Apply cable grading techniques such as capacitance grading and inter-sheath grading** to reduce electric stress and improve cable performance in high-voltage applications.

## **TEXT BOOKS:**

1. S. N. Singh, Electric Power Generation, Transmission and Distribution, PHI Learning Pvt Ltd, New Delhi, 2nd Edition, 2010
2. J. B. Gupta, Transmission and Distribution of Electrical Power, S. K. Kataria and sons, 10th Edition, 2012.

## **REFERENCE BOOKS:**

1. J. Nagarath & D.P. Kothari, Power System Engineering, McGraw-Hill Education, 3rd Edition, 2019.
2. C. L. Wadhwa, Generation, Distribution and Utilization of Electrical Energy, New Age International Publishers, 6th Edition, 2018.
3. V. K. Mehta and Rohit Mehta, Principles of Power System, S. Chand, 4th Edition, 2005.
4. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1985.
5. Handbook of switchgear, BHEL, McGraw-Hill Education, 2007.

## **REFERENCE WEBSITE:**

1. <https://nptel.ac.in/courses/108102047>

## **ASSIGNMENT TOPICS:**

1. Explain the Ring Main Distribution System used in smart cities?
2. Explain the reason for Underground cable failures in coastal areas?



**SREENIVASA INSTITUTE OF TECHNOLOGY AND MANAGEMENT STUDIES.  
(AUTONOMOUS)  
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING  
NBA ACCREDITED**

**UNIT-V: ECONOMIC ASPECTS & TARIFF:**

**(09)**

Economic Aspects – load curve, load duration and integrated load duration curves, discussion on economic aspects: connected load, maximum demand, demand factor, load factor, diversity factor, plant capacity factor and plant use factor, base and peak load plants.

Tariff Methods– Costs of generation and their division into fixed, semi-fixed and running costs, desirable characteristics of a tariff method, tariff methods: simple rate, flat rate, block-rate, two- part, three–part, and power factor tariff methods, Time of Day (TOD) tariff and Time of Use (TOU) tariff.

**OBJECTIVE:**

1. To understand load curves, load duration curves, and integrated load duration curves for analyzing power demand patterns.
2. To evaluate economic parameters such as connected load, maximum demand, demand factor, and load factor in power systems.
3. To analyze diversity factor, plant capacity factor, and plant use factor for efficient system operation.
4. To distinguish between base load and peak load plants and their economic significance.
5. To study cost components and various tariff methods including TOD and TOU tariffs for effective pricing of electrical energy.

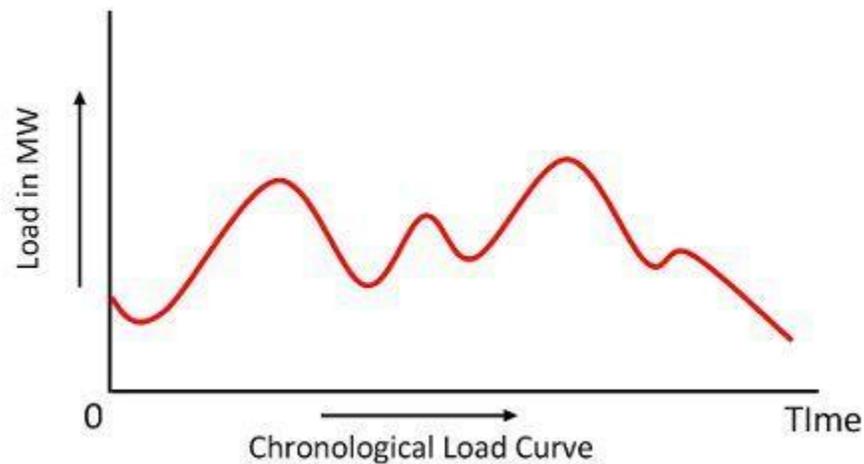


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## LOAD CURVE

**Definition:** Load curve or chronological curve is the graphical representation of load (in kW or MW) in proper time sequence and the time in hours. It shows the variation of load on the power station. When the load curve is plotted for 24 hours a day, then it is called daily load curve. If the one year is considered then, it is called annual load curve.

The load curve of the power system is not same all the day. It differs from day to day and season to season. The load curve is mainly classified into two types, i.e., the summer load curve and the winter load curve.



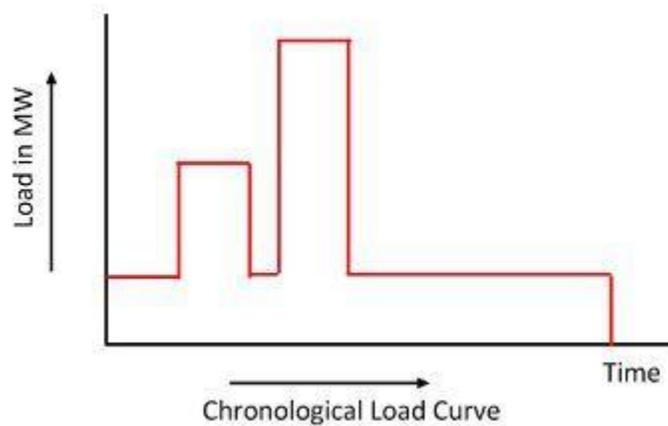
**Practical Load Curve**

The following are the information obtained from load curves.

1. Load duration curve determines the load variation during different hours of the day.
2. It indicates the peak load which determines the maximum demand on the power station.

3. The area under the load curve gives the total energy generated in the period under consideration.
4. The area under the curve divided by the total numbers of hours gives the load.
5. The ratio of the area under the load curve of the total area of the rectangle in which it is contained gives the load factor.

The ideal load curve is flat, but practically it is far from flat. For a flat load curve, the load factor will be higher. Higher load factor means the more uniform load pattern with fewer variations in load.



**Ideal Load Curve**

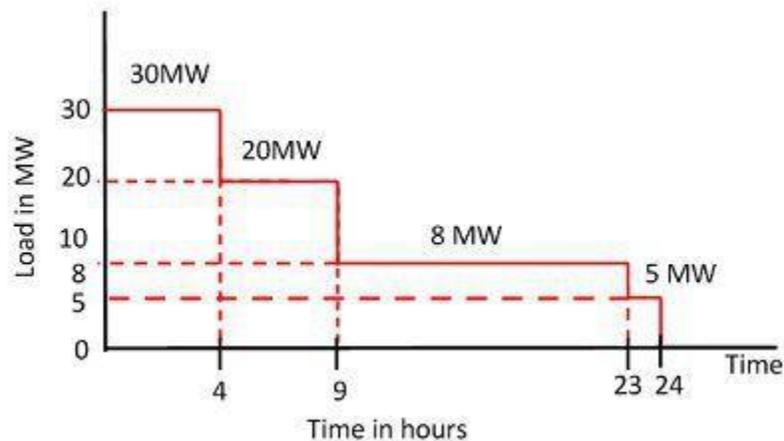
### **Utility of Load Curve**

The following are the utility of the load curve.

1. Load curve decides the installed capacity of a power station.
2. It is helpful in choosing the most economical sizes of the various generating units.
3. The load curve estimates the generating cost.
4. It decides the operating schedules of the power station, i.e., the sequence in which the different generating units should run.

### **LOAD DURATION CURVE**

**Definition:** The load duration curve is defined as the curve between the load and time in which the ordinates representing the load, plotted in the order of decreasing magnitude, i.e., with the greatest load at the left, lesser loads towards the right and the lowest loads at the time extreme right. The load duration curve is shown in the figure below.



Load Duration Curve

This curve represents the same data as that of the load curve. The load duration curve is constructed by selecting the maximum peak points and connecting them by a curve. The load duration curve plotting for 24 hours of a day is called the daily load duration curve. Similarly, the load duration curve plotted for a year is called the annual load curve.

$$\text{Average Demand} = \frac{\text{kWh (or MWh) consumed in a given period of time}}{\text{hours in the time period}}$$

$$\text{Average Demand} = \frac{\text{area under the load duration curve}}{\text{base of the load duration curve}}$$

#### Procedure for Plotting the Load Duration Curve

1. From the data available from the load curve determines the maximum load and the duration for which it occurs.
2. Now take the next load and the total time during which this and the previous load occurs.

3. Plots the loads against the time during which it occurs.

The load duration curves can be drawn for any duration of time, for example, a day or a month or a year. The whole duration is taken as 100%.

**Example:** Consider the daily load curve data of the power system.

Time	Load in MW
6.00 am to 8.00am	8
8.00 am to 1.00 noon	20
1.00 noon to 2.00 noon	5
12.30 noon to 6.00 pm	30
6.00 pm to 6.00 am	8

**Solution:** The data available from the load curve are tabulated as follows. Here the total time is 24 hours or 100%.

Load in MW	Hours in a day	Time in percentage
30	4	$4/5 \times 100 = 16.67\%$
20	4+5	$9/24 \times 100 = 37.5\%$
8	2+4+5+12 = 23	$23/24 \times 100 = 95.83\%$
5	4+5+2+12+1 = 24	$24/24 \times 100 = 100\%$

1. The load duration curve gives the minimum load present throughout the specified period.

2. It authorises the selection of base load and peak load power plants.
3. Any point on the load duration curve represents the total duration in hours for the corresponding load and all loads of greater values.
4. The area under the load duration curve represents the energy associated with the load duration curve.
5. The average demand during some specified time periods such as a day or a month can be obtained from the load duration curve.

### **INTEGRATED LOAD DURATION CURVE (ILDC)**

In power system planning and operation, understanding load variation over time is essential. Two important tools are:

- Load Curve
- Load Duration Curve (LDC)
- Integrated Load Duration Curve (ILDC)

A Load Duration Curve is obtained by arranging load values in descending order of magnitude against time.

#### Characteristics

- Does not follow chronological order
- Shows how long a particular load level persists
- Helps classify:
  - Base load
  - Intermediate load
  - Peak load

Need for Integrated Load Duration Curve:

- To calculate total energy consumption, we use ILDC.

### **Integrated Load Duration Curve (ILDC)**

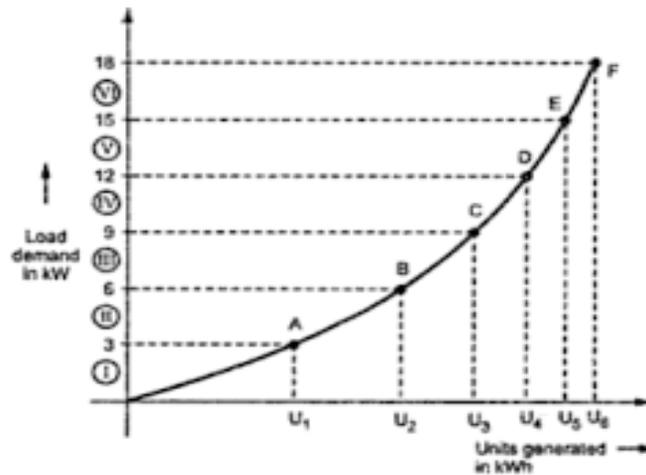
The Integrated Load Duration Curve is the cumulative sum (integral) of load over time, representing energy (MWh).

## 5. Mathematical Expression

$$E = \int_0^T P(t) dt$$

Where:

- (E) = Energy (MWh)
- (P(t)) = Load (MW)
- (T) = Total duration (hours)



## Relationship Between LDC and ILDC

Aspect	LDC	ILDC
Quantity	Power (MW)	Energy (MWh)

<b>Aspect</b>	<b>LDC</b>	<b>ILDC</b>
Curve Nature	Decreasing	Increasing
Meaning	Load variation	Energy accumulation
Area	Represents energy	Direct value

## **Applications**

### 1. Power Plant Scheduling

- Determines:
  - Base load plant operation
  - Peak load plant usage

### 2. Energy Estimation

- Direct calculation of total energy demand

### 3. Economic Operation

- Helps in merit order dispatch

### 4. Capacity Planning

- Determines required:
  - Installed capacity
  - Reserve margin

### 5. Tariff Design

- Useful in energy billing and pricing

## **Advantages**

- Simple representation of energy
- Helps in long-term planning

- Useful for economic analysis

### **Limitations**

- Time sequence is lost (like LDC)
- Does not show real-time fluctuations
- Less useful for transient analysis.

Connected load:

A consumer, for example, a domestic consumer, may have several appliances rated at different wattages.

The sum of these ratings is his/her connected load.

Connected load is the sum of the ratings (W, kW, or MW) of the apparatus installed on a consumer's premises.

### **Maximum demand:**

It is the maximum load used by a consumer at any time. It can be less than or equal to the connected load. The maximum demand is usually measured in units of kilowatts (kW) or megawatts (MW) by a maximum demand indicator.

### **Demand factor:**

The ratio of the maximum demand to the connected load is called the 'demand factor'.

$$\text{Demand Factor (DF)} = \frac{\text{Maximum Demand}}{\text{Connected Load}}$$

**Note:** Maximum demand and the connected load are to be expressed in the same units (W, kW, or MW).

### **Average load:**

If the number of kWh supplied by a station in one day is divided by 24 hours, then the value obtained is known as the daily average load.

$$\text{Average load} = \frac{\text{Energy Generated in kWh}}{\text{Time}}$$

For daily Average load *time* = 24 hrs

For monthly Average load *time* = 30 × 24 hrs

For yearly Average load *time* = 365 × 24 hrs

### **Load factor:**

The ratio of the average demand to the maximum demand is called the load factor.

$$\text{Load Factor (LF)} = \frac{\text{Average Demand}}{\text{Max. Demand}} \text{ or } \frac{\text{Energy Generated in kWh}}{\text{Max. Demand} \times \text{Time}}$$

The load factor may be a daily load factor, a monthly load factor, or an annual load factor, if the time period is considered in a day or a month or a year, respectively. Load factor is always less than one because average load is smaller than the maximum demand.

It plays a key role in determining the overall cost per unit generated. Higher the load factor of the power station, lesser will be the cost per unit generated.

### **Diversity factor:**

Diversity factor is the ratio of the sum of the maximum demands of a group of consumers to the simultaneous maximum demand of the group of consumers.

$$\text{Diversity Factor} = \frac{\text{sum of individual max. demand}}{\text{simultaneous max. demand}}$$

A power system supplies load to various types of consumers whose maximum demands generally do not occur at the same time. Therefore, the maximum demand on the power system is always less than the sum of individual maximum demands of the consumers.

A high diversity factor implied that with a smaller maximum demand on the station, it is possible to cater to the needs of several consumers with varying maximum demands occurring at different hours of the day. The lesser the

maximum demand, the lesser will be the capital investment on the generators. This helps in reducing the overall cost of the units (kWh) generated.

Thus, a higher diversity factor and a higher load factor are the desirable characteristics of the load on a power station. The load factor can be improved by encouraging the consumers to use power during off-peak hours with certain incentives like offering a reduction in the cost of energy consumed during off-peak hours.

**Plant capacity:**

It is the capacity or power for which a plant or station is designed. It should be slightly more than the maximum demand. It is equal to the sum of the ratings of all the generators in a power station.

**Plant capacity factor:**

It is the ratio of the average demand on the station to the maximum installed capacity of the station.

$$\text{Plant Capacity Factor (PCF)} = \frac{\text{Average Demand}}{\text{Max. installed capacity}}$$

or

$$\text{capacity factor} = \text{Load factor} \times \text{utilization factor}$$

$$\text{Reserve capacity} = \text{plant capacity} - \text{maximum demand}$$

**Utilization factor (or plant-use factor):**

It is the ratio of kWh generated to the product of the plant capacity and the number of hours for which the plant was in operation.

$$\text{Plant Use Factor (PUF)} = \frac{\text{Energy Generated in kWh}}{\text{Plant Capacity} \times \text{Time of use}}$$

**Firm power:** It is the power that should always be available even under emergency.

**Prime power:** It is the maximum power (may be thermal or hydraulic or mechanical) continuously available for conversion into electric power.

**Dump power:** This is the term usually used in hydro-electric plants and it represents the power in excess of the load requirements. It is made available by surplus water.

**Spill power:** It is the power that is produced during floods in a hydro-power station.

**Cold reserve:** It is the reserve-generating capacity that is not in operation, but can be made available for service.

**Hot reserve:** It is the reserve-generating capacity that is in operation, but not in service.

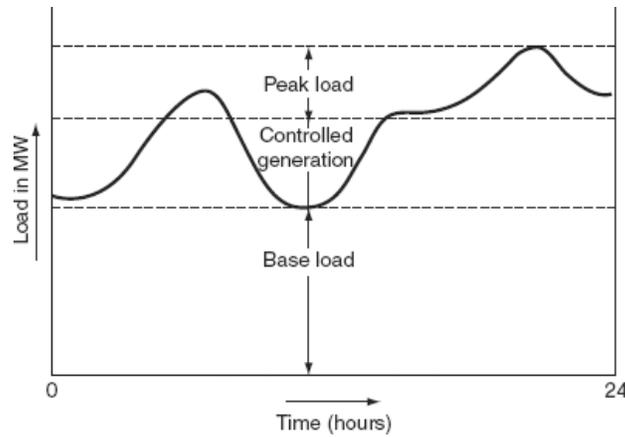
**Spinning reserve:** It is the reserve-generating capacity that is connected to bus bars and is ready to take the load.

### **Base Load and Peak Load**

In a power system, there may be several types of generating stations such as hydro-electric stations, fossil-fuel-fired stations, nuclear stations, and gas-turbine-driven generating stations. Of these stations, some act as base-load stations, while others act as peak load stations.

**Base load:** It is the unvarying load that occurs almost during the whole day on the station.

**Peak load:** It is the various peak demands of load over and above the base load of the station.



*Daily load curve*

To have a clear idea of 'base-load' and 'peak load', let us consider a power system, the daily load curve of which is depicted in above fig.

Base-load stations run at 100% capacity on a 24-hour basis. Nuclear reactors are ideally suited for this purpose.

Intermediate or controlled-power generation stations normally are not fully loaded. Hydro-electric stations are the best choice for this purpose.

Peak load stations operate during the peak load hours only. Since the gas-turbine-driven generators can pick up the load very quickly, they are best suited to serve as peak load stations. Where available, pumped-storage hydro-electric plants can be operated as peak load stations.

A base-load station operates at a high-load factor, whereas the peak load plant operates at a low-load factor. So, the base-load station should have low operating costs.

### **Example Problems 1**

A generating station has a maximum demand of 35 MW and has a connected load of 60 MW. The annual generation of units is  $24 \times 10^7$  kWh. Calculate the load factor and the demand factor.

#### **Solution:**

No. of units generated annually =  $24 \times 10^7$  kWh

$$\begin{aligned} \text{No. of hours in a year (assuming 365 days in a year)} &= 365 \times 24 \\ &= 8,760 \text{ hours} \end{aligned}$$

$$\begin{aligned} \therefore \text{Average load on the station} \\ &= \frac{24 \times 10^7}{8,760} = 27,397.26 \text{ kW} = 27.39726 \text{ MW} \end{aligned}$$

$$\begin{aligned} \therefore \text{Load Factor} \\ &= \frac{\text{average load}}{\text{max. demand}} = \frac{27.39726(\text{MW})}{35(\text{MW})} = 0.7828 \text{ or } 78.28\% \end{aligned}$$

$$\begin{aligned} \text{Demand factor} \\ &= \frac{\text{max. demand}}{\text{connected load}} = \frac{35(\text{MW})}{60(\text{MW})} = 0.583 \text{ or } 58.3\% \end{aligned}$$

## Example Problems 2

A generating station supplies four feeders with the maximum demands (in MW) of 16, 10, 12, and 7 MW. The overall maximum demand on the station is 20 MW and the annual load factor is 45%. Calculate the diversity factor and the number of units generated annually.

### Solution:

$$\text{Sum of maximum demands} = 16 + 10 + 12 + 7 = 45 \text{ MW}$$

$$\text{Simultaneous maximum demand} = 20 \text{ MW}$$

$$\begin{aligned} \therefore \text{Diversity factor} \\ &= \frac{\text{sum of max. demands}}{\text{simultaneous max. demand}} = \frac{45}{20} = 2.25 \end{aligned}$$

$$\begin{aligned} \text{Average demand} &= (\text{maximum demand}) \times (\text{load factor}) \\ &= 20 \times 0.45 = 9 \text{ MW} \end{aligned}$$

$$\therefore \text{No. of units generated annually} = 9 \times 8,760 = 78,840 \text{ MWh}$$

### Alternatively,

$$\begin{aligned} \text{Annual load factor} \\ &= \frac{\text{No. of units generated annually}}{(\text{Max. demand}) \times 8,760} \end{aligned}$$

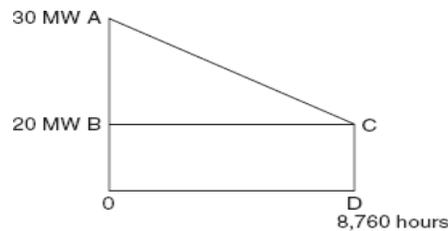
i.e,

$$0.45 = \frac{\text{No. of units generated annually}}{20 \times 8,760}$$

so that the number of units generated annually =  $0.45 \times 20 \times 8,760$  MWh  
= 78,840 MWh

### Example Problems 3

The yearly load-duration curve of a power plant is a straight line in fig. The maximum load is 30 MW and the minimum load is 20 MW. The capacity of the plant is 35MW. Calculate the plant capacity factor, the load factor, and the utilization factor.



*Load-duration curve*

#### Solution:

No. of units generated per year = Area  $OACD$  = Area  $OBCD$  + Area  $BAC$

$$= 20 \times 8,760 + \frac{1}{2} (30 - 20) \times 8,760$$

$$= 8,760 \left( 20 + \frac{1}{2} \times 10 \right)$$

$$= 8,760 \times 25 = 2,19,000 \text{ MWh}$$

∴ Average annual load

$$= \frac{\text{no. of units generated per year}}{8,760} = \frac{2,19,000}{8,760} = 25 \text{ MW}$$

∴ Load factor

$$= \frac{\text{average annual load}}{\text{maximum load}} = \frac{25}{30} = 0.833$$

Plant capacity factor

$$= \frac{\text{Average annual load}}{\text{Rated plant capacity}} = \frac{25}{35} = 0.714$$

Utilization factor

$$= \frac{\text{Average annual load}}{\text{Rated plant capacity}} = \frac{25}{35} = 0.714$$

**Alternatively,**

Utilization factor

$$= \frac{\text{capacity factor}}{\text{load factor}} = \frac{0.714}{0.833} = 0.857$$

### **Example Problems 4**

Calculate the total annual energy generated, if the maximum demand on a power station is 120 MW and the annual load factor is 50%.

**Solution:**

Maximum demand on a power station = 120 MW

Annual load factor = 50%

Load factor

$$= \frac{\text{energy generated/annum}}{\text{maximum demand} \times \text{hours in a year}}$$

$$\begin{aligned} \therefore \text{Energy generated/annum} &= \text{maximum demand} \times \text{LF} \times \text{hours in a year} \\ &= (120 \times 10^3) \times (0.5) \times (24 \times 365) \text{ kWh} \\ &= 525.6 \times 10^6 \text{ kWh} \end{aligned}$$

### **Example Problems 5**

Determine the demand factor and the load factor of a generating station, which has a connected load of 50 MW and a maximum demand of 25 MW, the units generated being  $40 \times 10^6$ /annum.

**Solution:**

Connected load = 50 MW

Maximum demand = 25 MW

Units generated =  $40 \times 10^6$ /annum

Demand factor

$$= \frac{\text{maximum demand}}{\text{connected load}} = \frac{25}{50} = 0.5$$

Average demand

$$= \frac{\text{units generated/annum}}{\text{hours in a year}} = \frac{40 \times 10^6}{8,760} = 4,566.21 \text{ kW}$$

Load factor

$$= \frac{\text{average demand}}{\text{maximum demand}} = \frac{4566.21}{25 \times 10^3} = 18.26\%$$

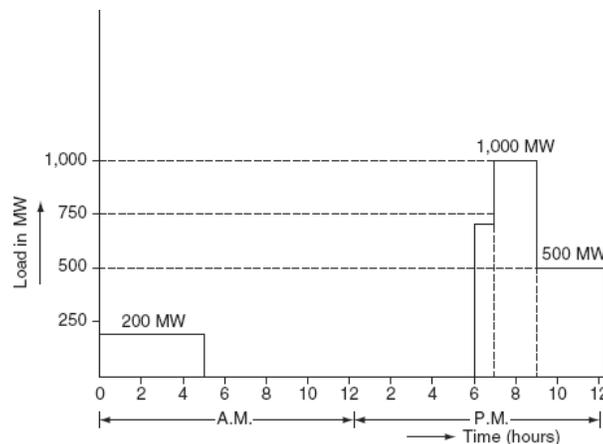
### Example Problems 6

A consumer has a connected load of 12 lamps each of 100 W at his/ her premises. His/ her load demand is as follows:

From midnight to 5 A.M.	:	200 W.
5 A.M. to 6 P.M.	:	no load.
6 P.M. to 7 P.M.	:	700 W.
7 P.M. to 9 P.M.	:	1,000 W.
9 P.M. to midnight	:	500 W.

Draw the load curve and calculate the (i) energy consumption during 24 hours, (ii) demand factor, (iii) average load, (iv) maximum demand, and (v) load factor.

**Solution:**



*Load curve*

From Fig. 1.6,

- Electrical energy consumption during the day = area of load curve
 
$$= 200 \times 5 + 700 \times 1 + 1,000 \times 2 + 500 \times 3$$

$$= 5,200 \text{ Wh}$$

$$= 5.2 \text{ kWh}$$

2. Average load

$$= \frac{\text{energy consumed during a day}}{24} = \frac{5,200}{24} = 216.7 \text{ W}$$

3. Demand factor

$$= \frac{1,000}{12 \times 100} = 0.83$$

4. Maximum demand = 1,000 W

5. Load factor

$$= \frac{\text{average load}}{\text{maximum demand}} = \frac{216.7}{1,000} = 0.2167 = 21.7\%$$

**Tariff Methods– Costs of generation and their division into fixed, semi-fixed and running costs, desirable characteristics of a tariff method, tariff methods: simple rate, flat rate, block-rate, two- part, three-part, and power factor tariff methods, Time of Day (TOD) tariff and Time of Use (TOU) tariff**

**(i) Fixed cost:**

It is the cost which is independent of maximum demand and units generated. The fixed cost is due to the annual cost of central organization, interest on capital cost of land and salaries of high officials. The annual expenditure on the central organization and salaries of high officials is fixed since it has to be met whether the plant has high or low maximum demand or it generates less or more units. Further, the capital investment on the land is fixed and hence the amount of interest is also fixed.

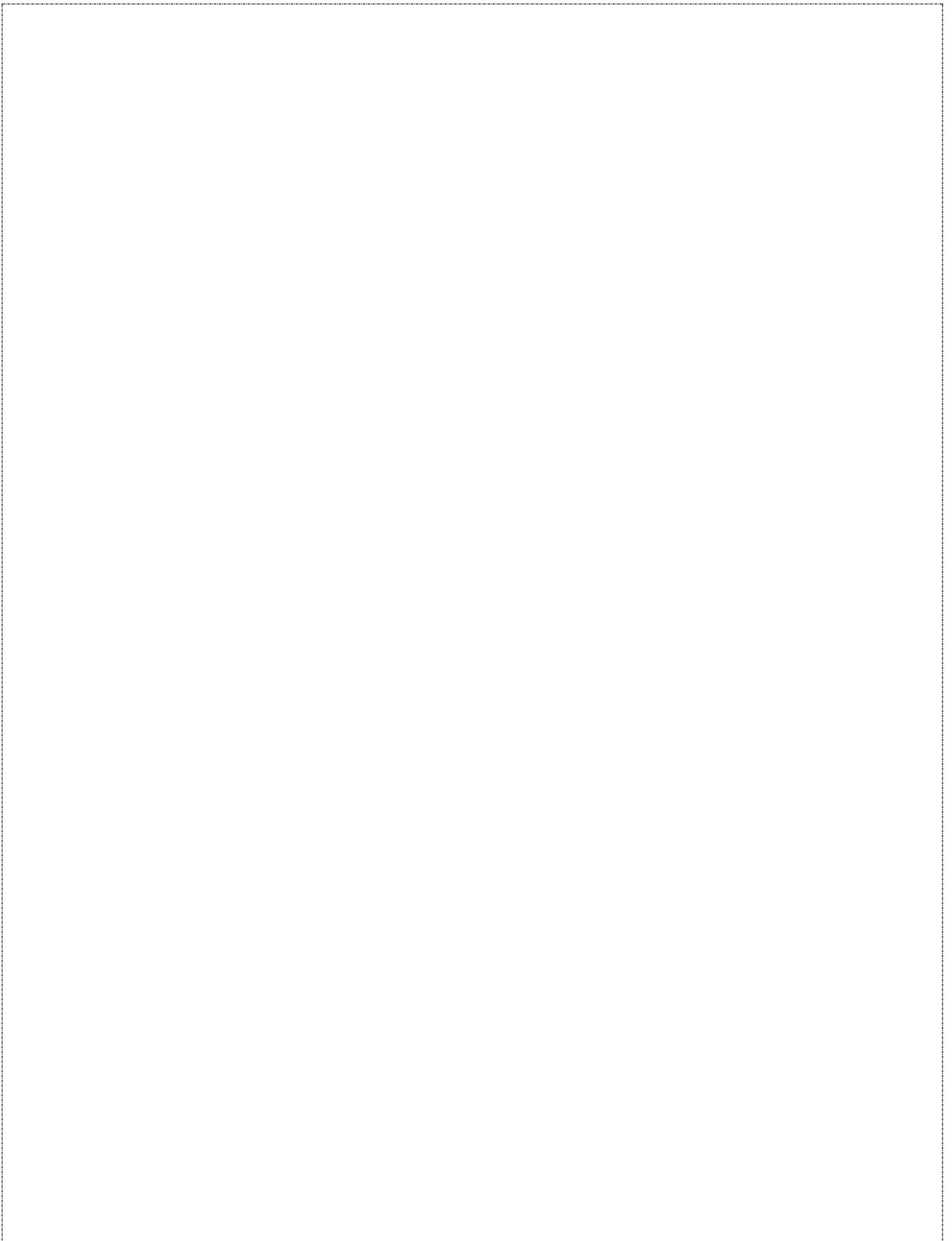
**(ii) Semi-fixed cost.**

It is the cost which depends upon maximum demand but is independent of units generated. The semi- fixed cost is directly proportional to the maximum demand on power station and is on account of annual interest and depreciation

on capital investment of building and equipment, taxes, salaries of management and clerical staff. The maximum demand on the power station determines its size and cost of installation. The greater the maximum demand on a power station, the greater is its size and cost of installation. Further, the taxes and clerical staff depend upon the size of the plant and hence upon maximum demand.

**(iii) Running cost:**

It is the cost which depends only upon the number of units generated. The running cost is on account of annual cost of fuel, lubricating oil, maintenance, repairs and salaries of operating staff. Since these charges depend upon the energy output, the running cost is directly proportional to the number of units generated by the station. In other words, if the power station generates more units, it will have higher running cost and vice-versa.



## UNIT-V

**Tariff Methods– Costs of generation and their division into fixed, semi-fixed and running costs, desirable characteristics of a tariff method, tariff methods: simple rate, flat rate, block-rate, two- part, three–part, and power factor tariff methods, Time of Day (TOD) tariff and Time of Use (TOU) tariff**

# Tariff

- The rate at which electrical energy is supplied to a consumer is known as tariff.
- Although tariff should include the total cost of producing and supplying electrical energy plus the profit, yet it cannot be the same for all types of consumers. It is because the cost of producing electrical energy depends to a considerable extent upon the magnitude of electrical energy consumed by the user and his load conditions.
- Therefore, in all fairness, due consideration has to be given to different types of consumers (e.g., industrial, domestic and commercial) while fixing the tariff. This makes the problem of suitable rate making highly complicated.

# Objectives of tariff

Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items :

- (i) Recovery of cost of producing electrical energy at the power station.
- (ii) Recovery of cost on the capital investment in transmission and distribution systems.
- (iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.
- (iv) A suitable profit on the capital investment.

# Desirable Characteristics of a Tariff

- A tariff must have the following desirable characteristics :

**(i) Proper return** : The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

**(ii) Fairness** : The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal (i.e., non variable) should be charged at a lower\* rate than the one whose load conditions change appreciably from the ideal.

**iii) Simplicity** : The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

**(iv) Reasonable profit** : The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. Therefore, the investment is relatively safe due to non-competition in the market. This calls for the profit to be restricted to 8% or so per annum.

**(v) Attractive** : The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy. Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

# Types of Tariff

- There are several types of tariff.

However, the following are the commonly used types of tariff :

## **1. Simple tariff:**

- When there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff.
- In this type of tariff, the price charged per unit is constant i.e., it does not vary with increase or decrease in number of units consumed.
- The consumption of electrical energy at the consumer's terminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers

# Disadvantages of Simple Tariff:

- (i) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed\* charges.
  
- (ii) The cost per unit delivered is high.
  
- (iii) It does not encourage the use of electricity.

## 2.Flat rate tariff:

- When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.
- In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.
- For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less† (say 55 paise per kWh) for power load.
- The different classes of consumers are made taking into account their diversity and load factors.
- The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

### Disadvantages are

(i) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

(ii) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced

# 3. Block rate tariff.

- When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff.
- In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block.
- The price per unit in the first block is the highest\*\* and it is progressively reduced for the succeeding blocks of energy.
- For example, the first 30 units may be charged at the rate of 60 paise per unit ; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

## **The advantage of such a tariff is that**

- The consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced.
- However, its principal defect is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

## 4. Two-part tariff:

- When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.
- In two-part tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.
- Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e.,

- Total charges = Rs ( $b \times \text{kW} + c \times \text{kWh}$ )

where,  $b$  = charge per kW of maximum demand

$c$  = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

### **Advantages**

- (i) It is easily understood by the consumers.
- (ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

### **Disadvantages**

- (i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.
- (ii) There is always error in assessing the maximum demand of the consumer.

## 5. Maximum demand tariff:

- It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.
- This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value.
- This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (e.g., residential consumer) as a separate maximum demand meter is required

# 6. Power factor tariff:

- The tariff in which power factor of the consumer's load is taken into consideration is known as power factor tariff.
- In an a.c. system, power factor plays an important role. A low\* power factor increases the rating of station equipment and line losses. Therefore, a consumer having low power factor must be penalised.
- The following are the important types of power factor tariff :
  - (i) **kVA maximum demand tariff** : It is a modified form of two-part tariff. In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW. As kVA is inversely proportional to power factor, therefore, a consumer having low power factor has to contribute more towards the fixed charges.
    - This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.
  - (ii) **Sliding scale tariff** : This is also known as average power factor tariff. In this case, an average power factor, say 0.8 lagging, is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.
  - (iii) **kW and kVAR tariff** : In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

## 7.Three-part tariff.

- When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a three-part tariff. i.e.,
- Total charge = Rs  $(a + b \times \text{kW} + c \times \text{kWh})$

where

a = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues

b = charge per kW of maximum demand

c = charge per kWh of energy consumed

It may be seen that by adding fixed charge or consumer's charge (i.e., a) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split into three components. This type of tariff is generally applied to big consumers

# 8. Time of Day (ToD) Tariff

- The **Time of Day (ToD)** tariff by the distribution licensees to its consumers is as approved by the Appropriate Commission for that particular category of consumer.
- In most of the States the ToD tariff is applicable for Commercial and Industrial consumers. In some of the States ToD Tariff is applicable for other e.g. domestic and agricultural consumers also.
- Ministry of Power has issued the **Electricity (Rights of Consumers) Amendment Rules, 2023** wherein the rule for Time of Day (ToD) Tariff has also been specified. The main features of these Rules are:
- ToD tariff for Commercial and Industrial consumers having maximum demand more than 10kW shall be made effective from a date not later than 1st April, 2024 and for other consumers except agricultural consumers, the ToD tariff shall be made effective not later than 1st April, 2025.
- ToD tariff shall be made effective immediately after installation of smart meters for the consumers.

## 8. Time of Day (ToD) Tariff

- ToD tariff, during the peak period of the day, for Commercial and Industrial consumers shall not be less than 1.20 times the normal tariff and for other consumers it shall not be less than 1.10 times the normal tariff.
- Tariff for solar hours, of the day, to be specified by the State Commission shall be at least twenty percent (20%) less than the normal tariff for that category of consumers.
- ToD tariff shall be applicable on energy charge component of the normal tariff.

# 8. Time of Day (ToD) Tariff

## Advantages of ToD

- The ToD tariff comprising separate tariffs for peak hours, solar hours and normal hours, sends price signals to consumers to manage their load in accordance with the Tariff.
- Since, the tariff during the solar hours will be at least 20% less than the normal tariff, the consumer can shift consumption during solar hours when power cost is less and can be benefitted.
- With awareness and effective utilisation of ToD tariff mechanism, consumers can reduce their expenditure on electricity consumption.

- It optimizes generation capacity, helps utilities in maintaining load-generation balance and in reducing financial burden for arranging costly power to meet peak load, which ultimately would be beneficial to the end consumers.
- It also improves the management of renewable generation fluctuations and incentivises more consumption during the periods of Renewable Energy generation, thereby providing benefits to consumers with availability of reliable and cleaner power at reasonable rates.

# Power Factor:

- The cosine of angle between voltage and current in an a.c. circuit is known as power factor.
- In an a.c. circuit, there is generally a phase difference  $\varphi$  between voltage and current.
- The term  $\cos \varphi$  is called the power factor of the circuit.
- If the circuit is inductive, the current lags behind the voltage and the power factor is referred to as lagging.
- However, in a capacitive circuit, current leads the voltage and power factor is said to be leading

**OUTCOMES:**

- Analyze load curves and evaluate system demand characteristics for efficient planning.
- Calculate and interpret demand factor, load factor, diversity factor, and plant factors for power systems.
- Assess the economic performance of power plants using cost classifications and operational parameters.
- Compare various tariff methods and determine their suitability for different types of consumers.
- Evaluate TOD and TOU tariffs for improving load management and reducing peak demand.

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3. V. K. Mehta and Rohit Mehta, Principles of Power System, S. Chand, 4th Edition, 2005.
4. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1985.
5. Handbook of switchgear, BHEL, McGraw-Hill Education, 2007.

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