LECTURE NOTES

on

POWER SYSTEMS-I

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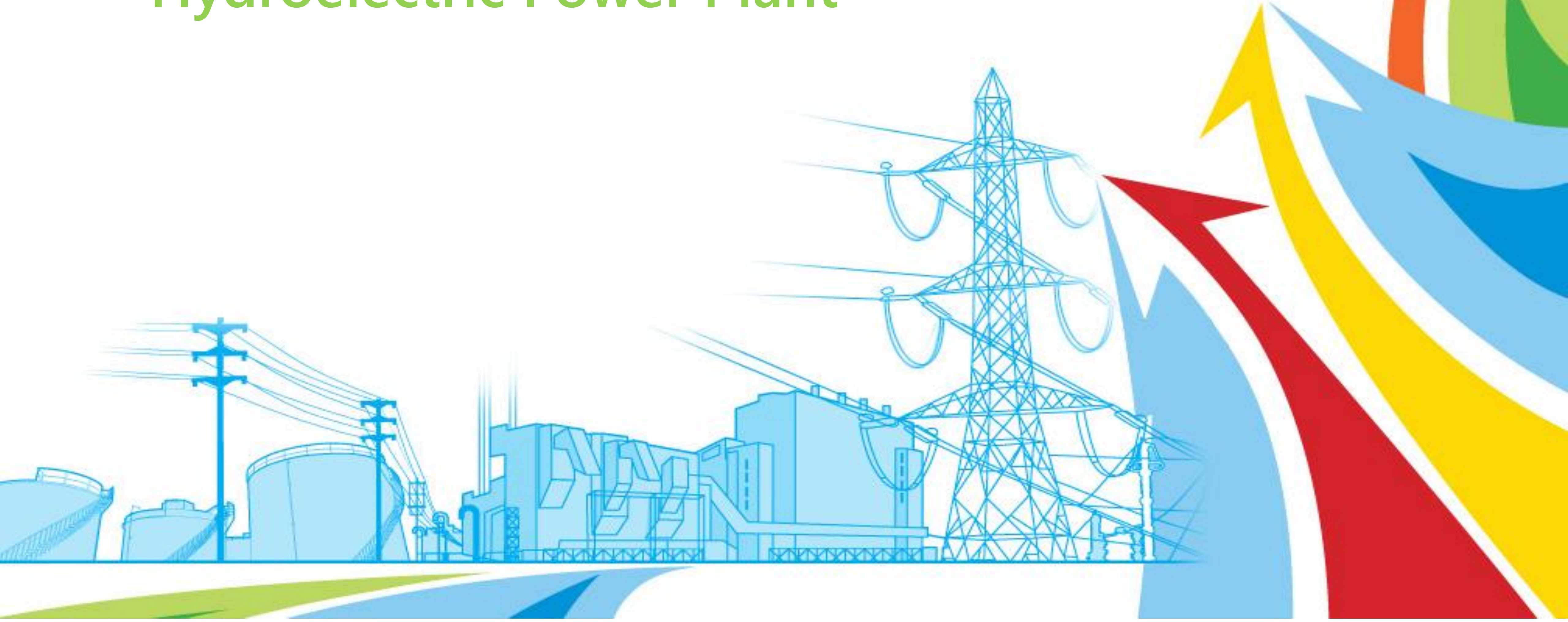
Unit - I

Electrical Power Generation and Distribution

-Hydroelectric Power Plant



Hydro Power

- A generating station which utilises the potential energy of water at a high level for the generation of electrical energy is known as a **hydro-electric power station.**
- Hydro-electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained.
- In a hydro-electric power station, water head is created by constructing a dam across a river or lake.
- From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e., product of head and flow of water) into mechanical energy at the turbine shaft.
- The turbine drives the alternator which converts mechanical energy into electrical energy.
- Hydro-electric power stations are becoming very popular because the reserves of fuels (i.e., coal and oil) are depleting day by day.
- They have the added importance for flood control, storage of water for irrigation and water for drinking purposes.

Hydro Power

Advantages

(*i*) It requires no fuel as water is used for the generation of electrical energy.

(*ii*) It is quite neat and clean as no smoke or ash is produced.

(*iii*) It requires very small running charges because water is the source of energy which is available free of cost.

(*iv*) It is comparatively simple in construction and requires less maintenance.

(*v*) It does not require a long starting time like a steam power station. In fact, such plants can be put into service instantly.

(*vi*) It is robust and has a longer life.

(*vii*) Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

(*viii*) Although such plants require the attention of highly skilled persons at the time of construction, yet for operation, a few experienced persons may do the job well.

Disadvantages

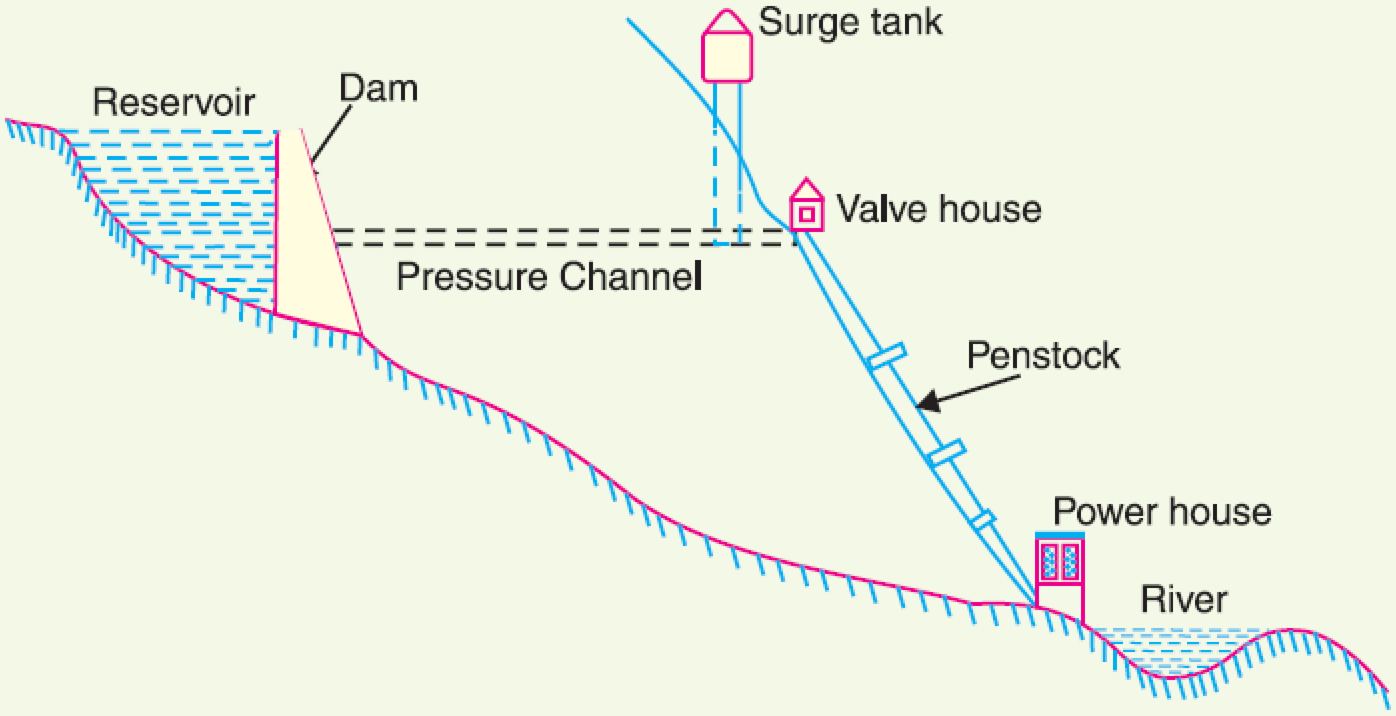
(*i*) It involves high capital cost due to construction of dam.

(*ii*) There is uncertainty about the availability of huge amount of water due to dependence on weather conditions.

(*iii*) Skilled and experienced hands are required to build the plant.

(*iv*) It requires high cost of transmission lines as the plant is located in hilly areas which are quite away from the consumers.

Layout

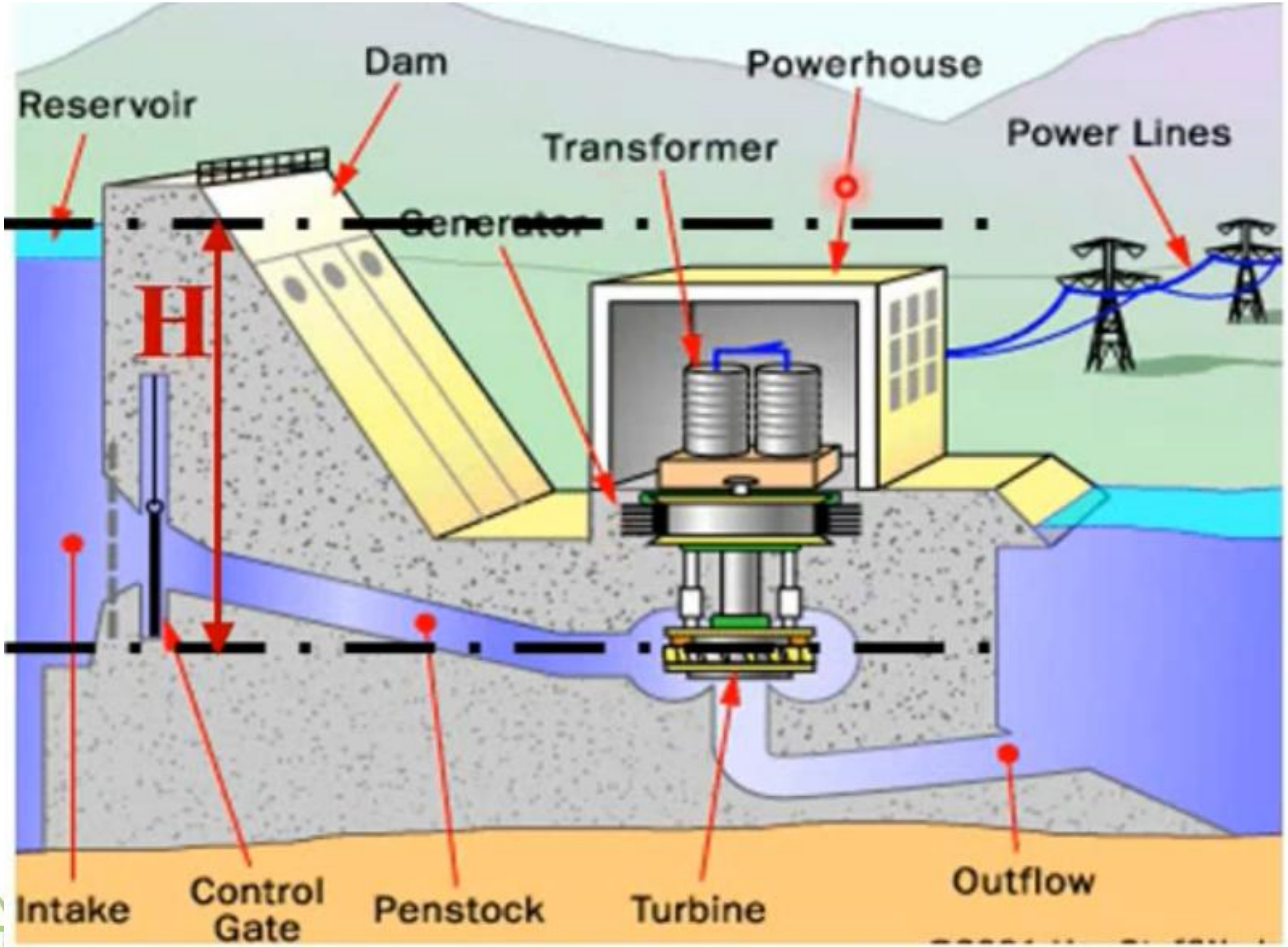


Schematic arrangement of a Hydro-electric plant

Layout

Bhakra Dam

Layout


Dam
Powerhouse
Reservoir
Transformer
Power Lines
Generator
H
Intake
Control
Gate
Penstock
Turbine
Outflow

Selection of Site

(*i*) *Availability of water.* Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water, such plants should be built at a place (*e.g.*, river, canal) where adequate water is available at a good head.

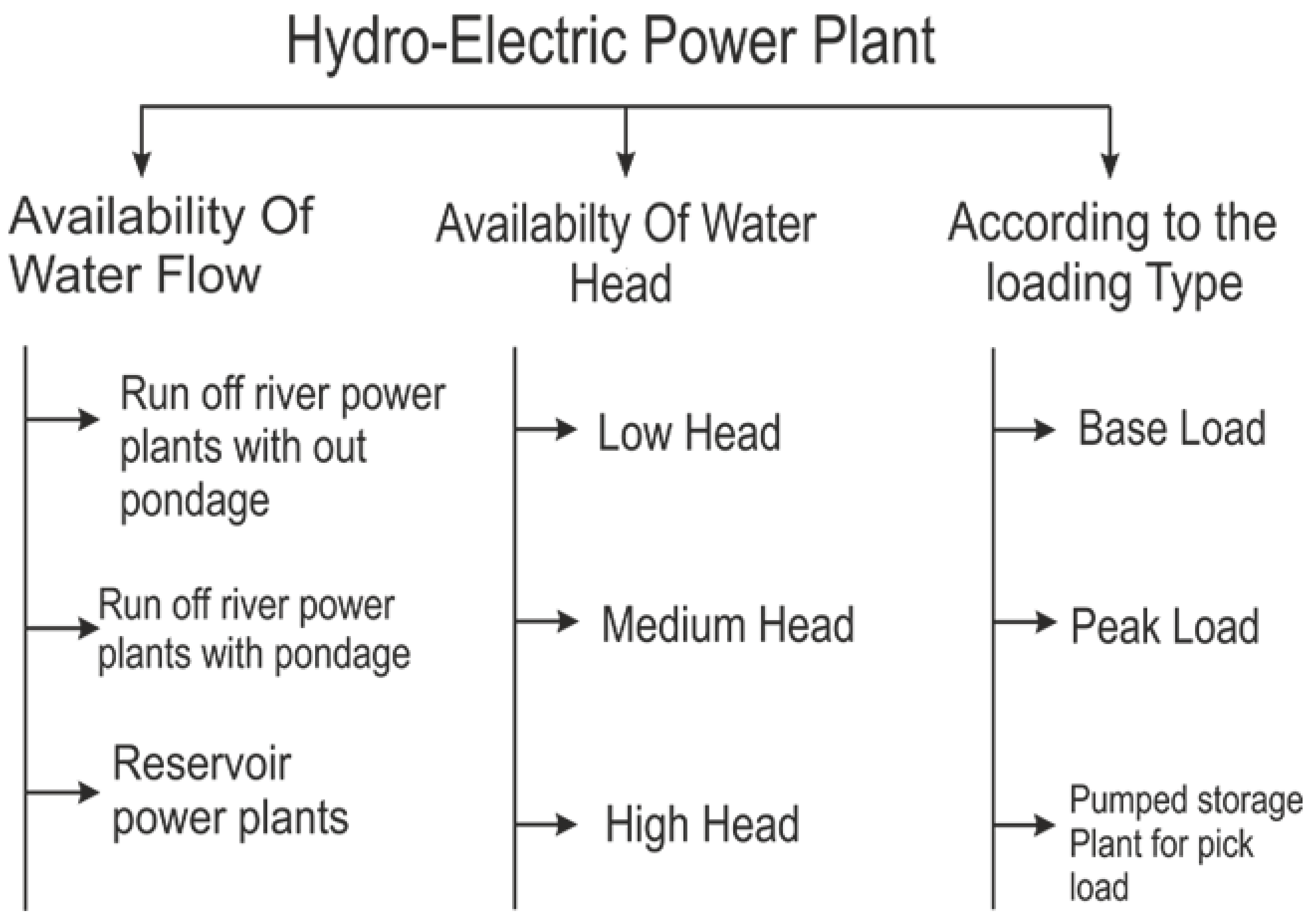
(*ii*) *Storage of water.* There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year. The storage helps in equalising the flow of water so that any excess quantity of water at a certain period of the year can be made available during times of very low flow in the river. This leads to the conclusion that site selected for a hydro-electric plant should provide adequate facilities for erecting a dam and storage of water.

(*iii*) *Cost and type of land.* The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstand the weight of heavy equipment to be installed.

(*iv*) *Transportation facilities.* The site selected for a hydro-electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported.

It is clear from the above mentioned factors that ideal choice of site for such a plant is near a river in hilly areas where dam can be conveniently built and large reservoirs can be obtained.

Classification



Working of Hydro Power Plant

- Although a hydro-electric power station simply involves the conversion of hydraulic energy into electrical energy, yet it embraces many arrangements for proper working and efficiency.
- The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir.
- A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the penstock.
- The valve house contains main sluice valves and automatic isolating valves.
- The former controls the water flow to the power house and the latter cuts off supply of water when the penstock bursts.

Working of Hydro Power Plant

- From the valve house, water is taken to water turbine through a huge steel pipe known as *penstock.*
- *The water turbine converts hydraulic energy* into mechanical energy.
- The turbine drives the alternator which converts mechanical energy into electrical energy.
- A surge tank (open from top) is built just before the valve house and protects the penstock from bursting in case the turbine gates suddenly close due to electrical load being thrown off.
- When the gates close, there is a sudden stopping of water at the lower end of the penstock and consequently the penstock can burst like a paper log.
- The surge tank absorbs this pressure swing by increase in its level of water.
- The governor opens or closes the turbine gates in accordance with the changes in electrical load. If the electrical load increases, the governor opens the turbine gates to allow more water and *vice-versa.*

Description of Main Components

The constituents of a hydro-electric plant are

(1)Hydraulic structures

(2) Water turbines and

(3) Electrical Equipment

Description of Main Components

1. Hydraulic structures. Hydraulic structures in a hydro-electric power station include dam, spillways, headworks, surge tank, penstock and accessory works.

(i) Dam. A dam is a barrier which stores water and creates water head.

- Dams are built of concrete or stone masonary, earth or rock fill.
- The type and arrangement depends upon the topography of the site.
- A masonary dam may be built in a narrow canyon.
- An earth dam may be best suited for a wide valley.
- The type of dam also depends upon the foundation conditions, local materials and transportation available, occurrence of earthquakes and other hazards.

Description of Main Components

narrow canyon

earth dam

Description of Main Components

Spillways.

- There are times when the river flow exceeds the storage capacity of the reservoir.
- Such a situation arises during heavy rainfall in the catchment area.
- In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spillways are used.
- Spillways are constructed of concrete piers on the top of the dam.
- Gates are provided between these piers and surplus water is discharged over the crest of the dam by opening these gates.
- A spillway is a structure used to provide the controlled release of water from a dam
- Spillways ensure that water does not damage parts of the structure

Spillways

Description of Main Components

Headworks.

- The headworks consists of the diversion structures at the head of an intake.
- They generally include booms and racks for diverting floating debris, sluices for by-passing debris and sediments and valves for controlling the flow of water to the turbine.
- The flow of water into and through headworks should be as smooth as possible to avoid head loss and cavitation.

Headworks

Description of Main Components

Surge tank.

- *Open conduits* leading water to the turbine require no protection.
- However, when closed conduits are used, protection becomes necessary to limit
- the abnormal pressure in the conduit.
- For this reason, closed conduits are always provided with a surge tank.
- A surge tank is a small reservoir or tank (open at the top) in which water level
- rises or falls to reduce the pressure swings in the conduit.
- A surge tank is located near the beginning of the conduit.
- When the turbine is running at a steady load, there are no surges in the flow of water through the conduit *i.e., the quantity of water flowing in the conduit is just sufficient to meet the* turbine requirements.
- However, when the load on the turbine decreases, the governor closes the gates of turbine, reducing water supply to the turbine.

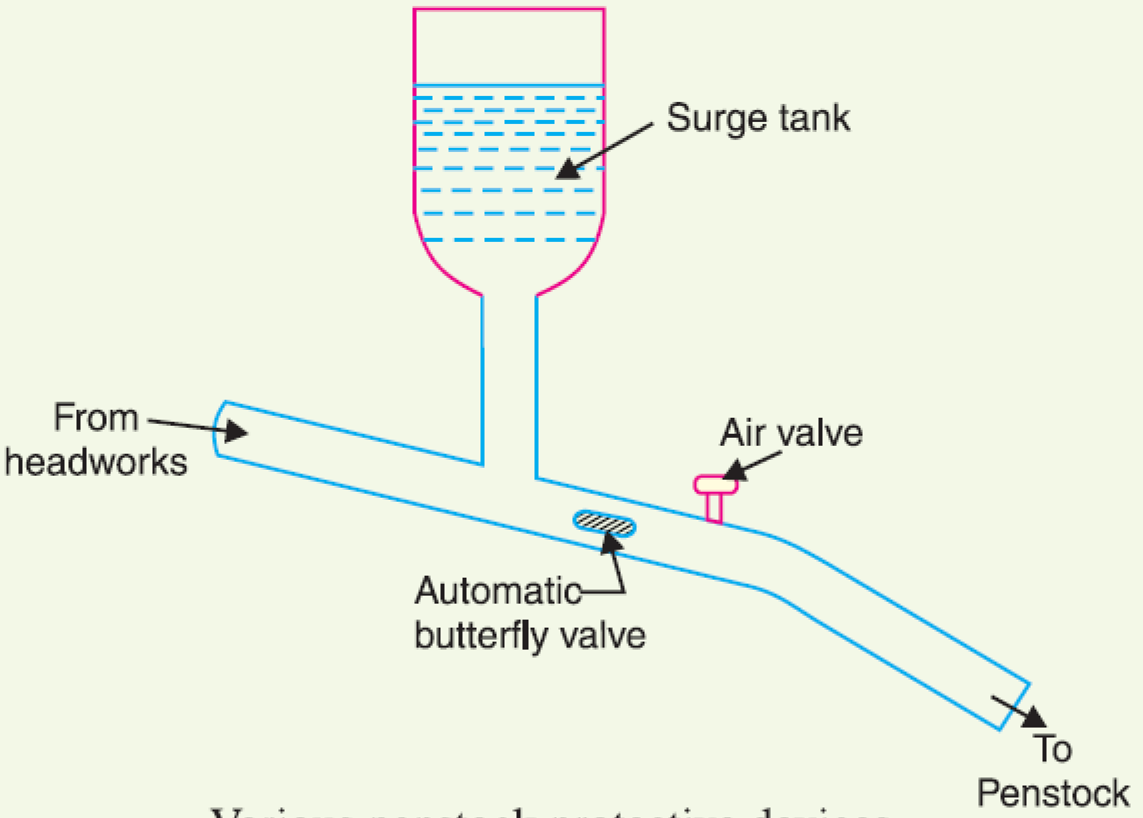
Description of Main Components

Surge tank.

- The excess water at the lower end of the conduit rushes back to the surge tank and increases its water level.
- Thus the conduit is prevented from bursting.
- On the other hand, when load on the turbine increases, additional water is drawn from the surge tank to meet the increased load requirement.
- Hence, a surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and acts as a reservoir during increase of load on the turbine.

Surge Tank

Description of Main Components



Various penstock protective devices

Description of Main Components - Penstocks

- Penstocks are open or closed conduits which carry water to the turbines.
- They are generally made of reinforced concrete or steel.
- Concrete penstocks are suitable for low heads (< 30 m) as greater pressure causes rapid deterioration of concrete.
- The steel penstocks can be designed for any head; the thickness of the penstock increases with the head or working pressure.
- Various devices such as automatic butterfly valve, air valve and surge tank are provided for the protection of penstocks.
- Automatic butterfly valve shuts off water flow through thepenstock promptly if it ruptures. Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure.
- When water runs out of a penstock faster than it enters, a vacuum is created which may cause the penstock to collapse.
- Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air pressure.

Description of Main Components

Description of Main Components

Description of Main Components

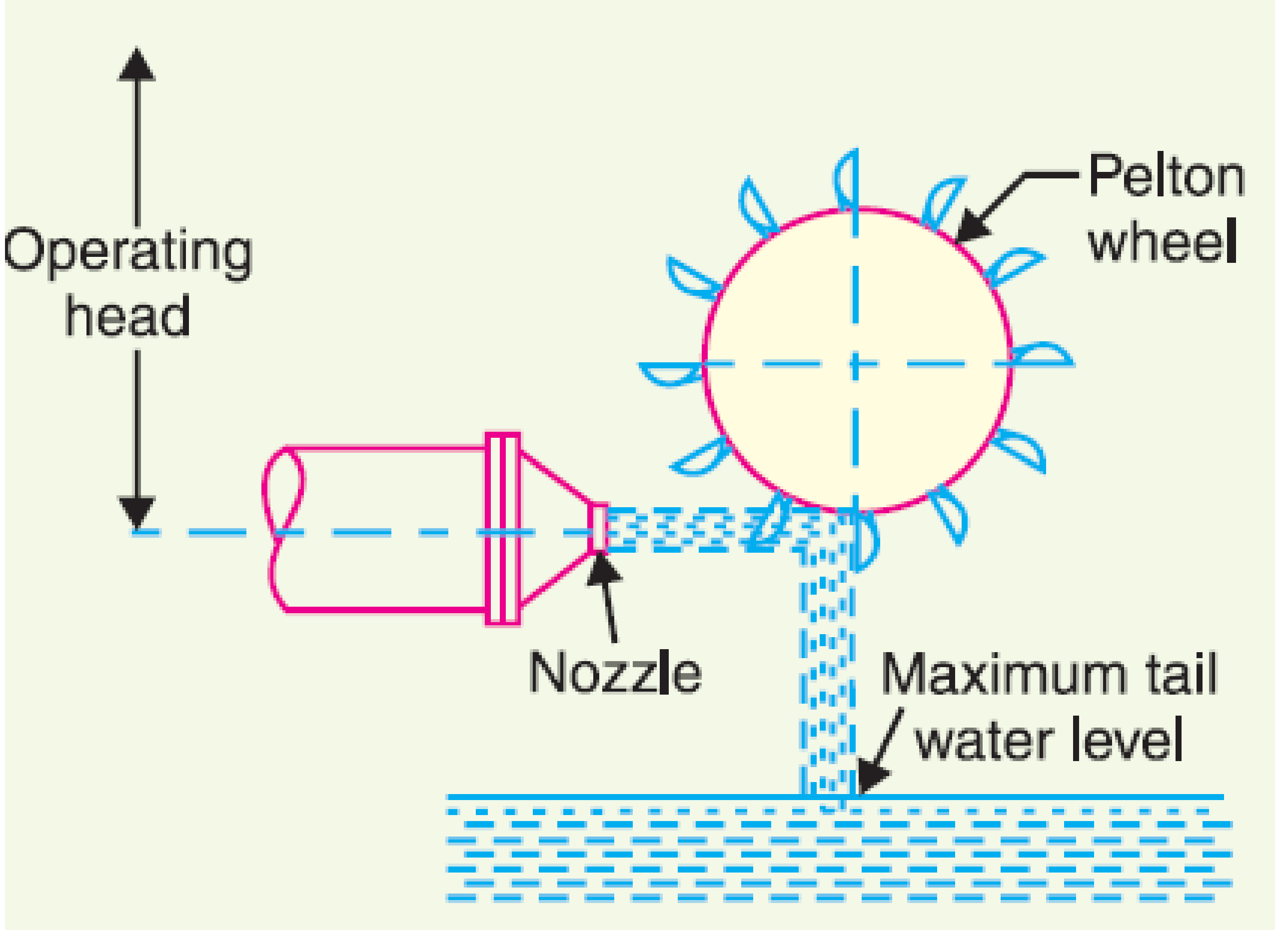
2. Water turbines. Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are :

(i) Impulse turbines (ii) Reaction turbines

(i) Impulse turbines.

- Such turbines are used for high heads.
- In an impulse turbine, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel.
- The example of this type of turbine is the Pelton wheel
- It consists of a wheel fitted with elliptical buckets along its periphery.
- The force of water jet striking the buckets on the wheel drives the turbine.
- The quantity of water jet falling on the turbine is controlled by means of a needle or spear placed in the tip of the nozzle.
- The movement of the needle is controlled by the governor.
- If the load on the turbine decreases, the governor pushes the needle into the nozzle, thereby reducing the quantity of water striking the buckets.
- Reverse action takes place if the load on the turbine increases.

Description of Main Components



Description of Main Components

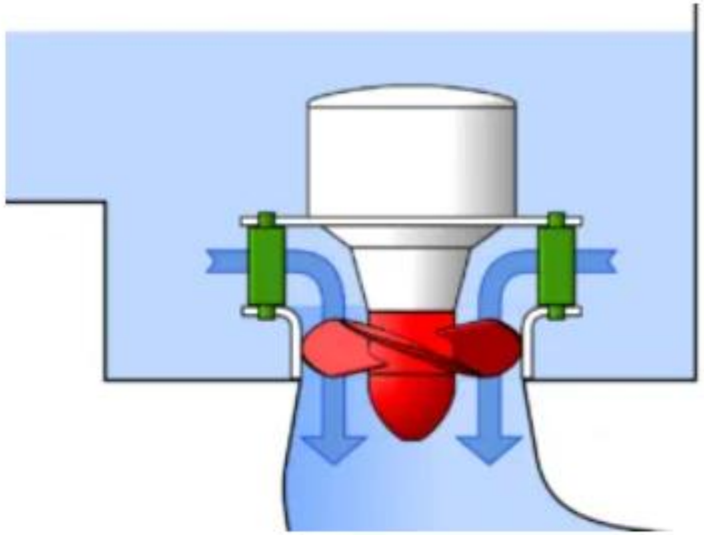
(ii) **Reaction turbines.** Reaction turbines are used for low and medium heads. In a reaction turbine, water enters the runner partly with pressure energy and partly with velocity head. The important
types of reaction turbines are :
(a)Francis turbines (b) Kaplan turbines

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

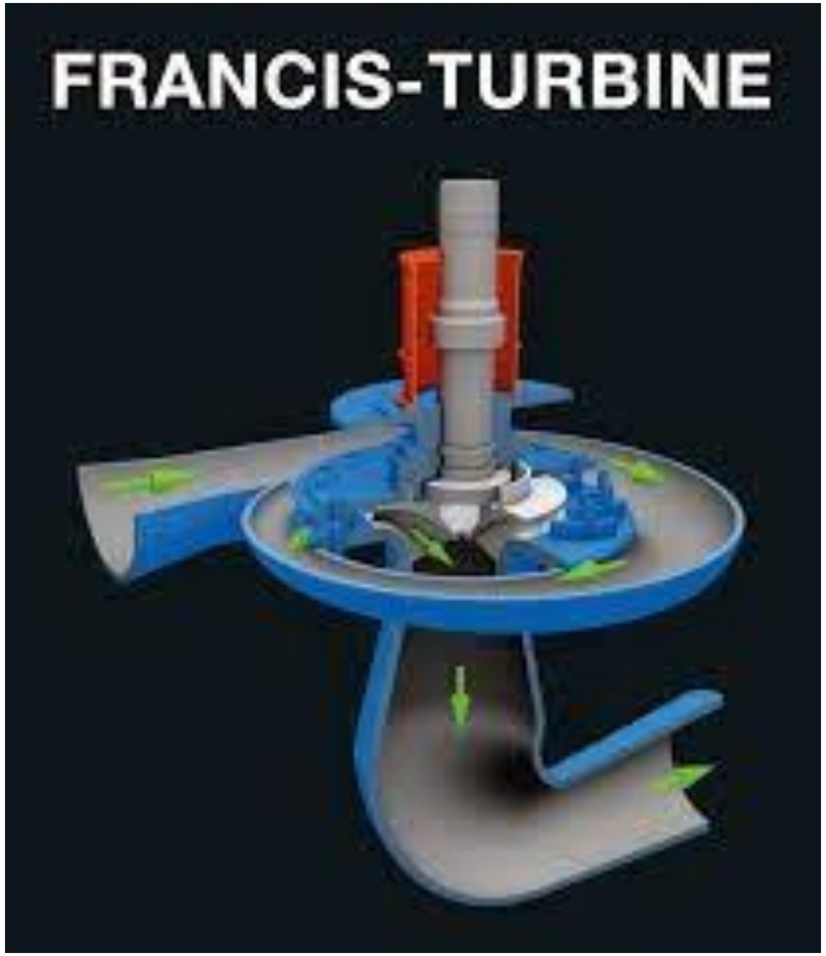
Description of Main Components

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

Description of Main Components



Kaplan turbines



Description of Main Components

Kaplan Turbine

Francis Turbine

Description of Main Components

3. Electrical equipment. The electrical equipment of a hydro-electric power station includes
alternators, transformers, circuit breakers and other switching and protective devices.

Thank You

POWER SYSTEMS –I

Lecture 1
Hydro Electric Power Plant

Dr. Janaki Pakalapati
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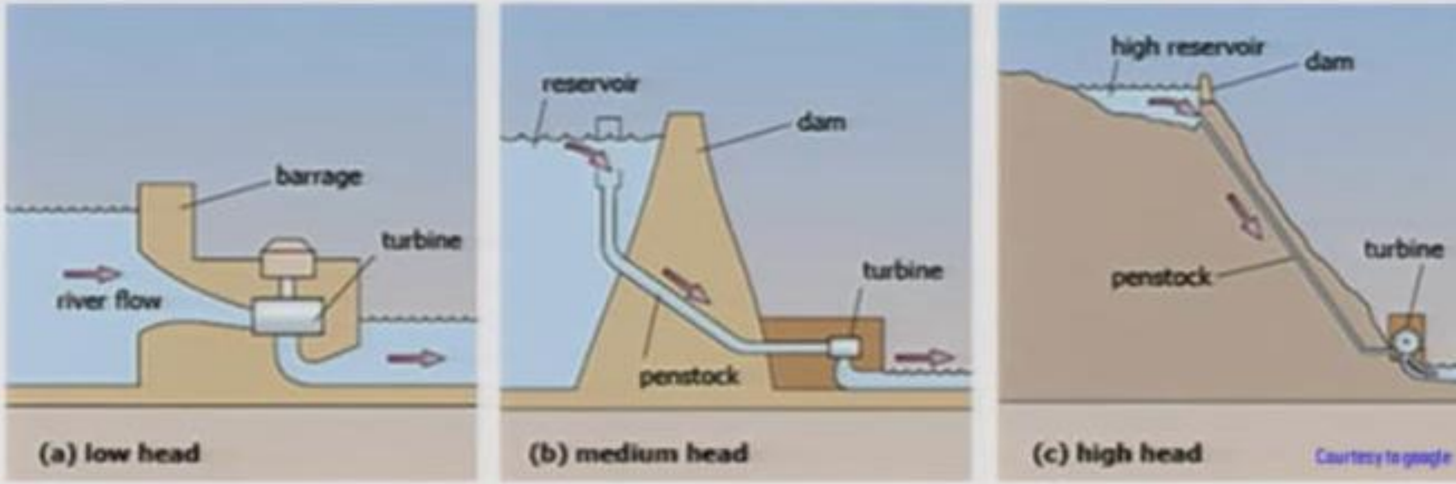
LAYOUT OF HYDRO ELECTRIC POWER PLANTS



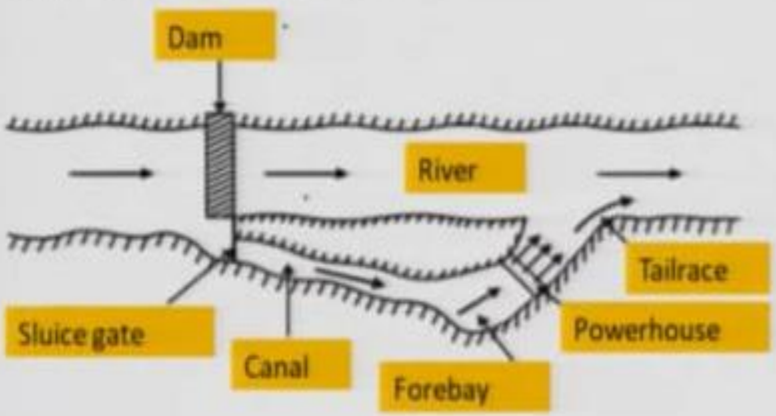
Layout of hydro power plants are classified in three categories based on availability of water head

a. Low-head plants
b. Medium-head plants
c. High-head plants

LAYOUT OF HYDRO ELECTRIC POWER PLANTS

(a) Low-head plants

- If the available water head is less than 30 m, the plant is called a low-head plant.
- The necessary head is created by construction of a dam or barrage.
- The power plant is situated near the dam.
- Regulating gates are provided to discharge the surplus of water.
- Kaplan turbines may be used.

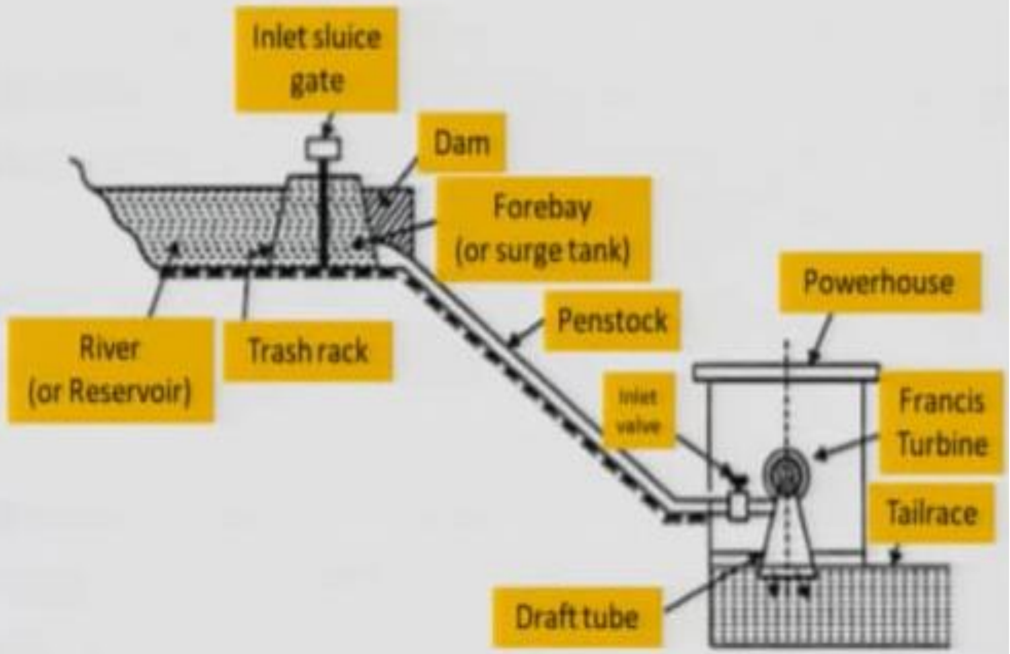


- The only disadvantage is that the power output is reduced when the discharge increases as it causes an increase in the downstream water level, with a consequent reduction in the effective head.
- Structure of such plants is extensive and expensive.
- Generators used in these plants are of low speed and large diameter.

LAYOUT OF HYDRO ELECTRIC POWER PLANTS

(b) Medium-head plants

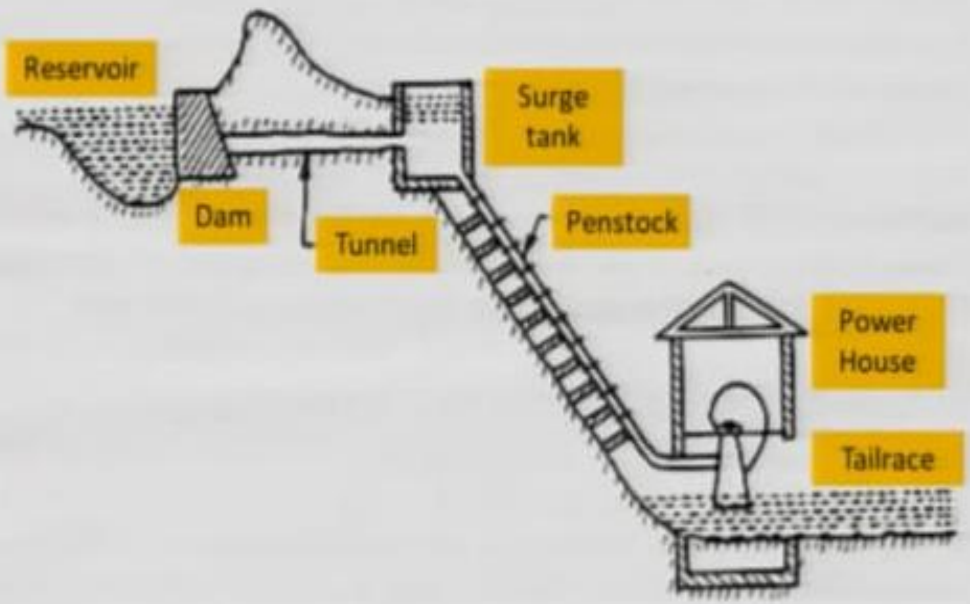
- If the available water head is between 30 and 100 m, the plant is called a medium-head plant.
- In these plants, water is brought from the main reservoir through an open channel to the forebay.
- Water is led to the turbines from the forebay by the penstocks, which may be steel pipes.
- Forebay also stores the rejected water as the load on the turbine decreases.
- Francis turbines are normally used.



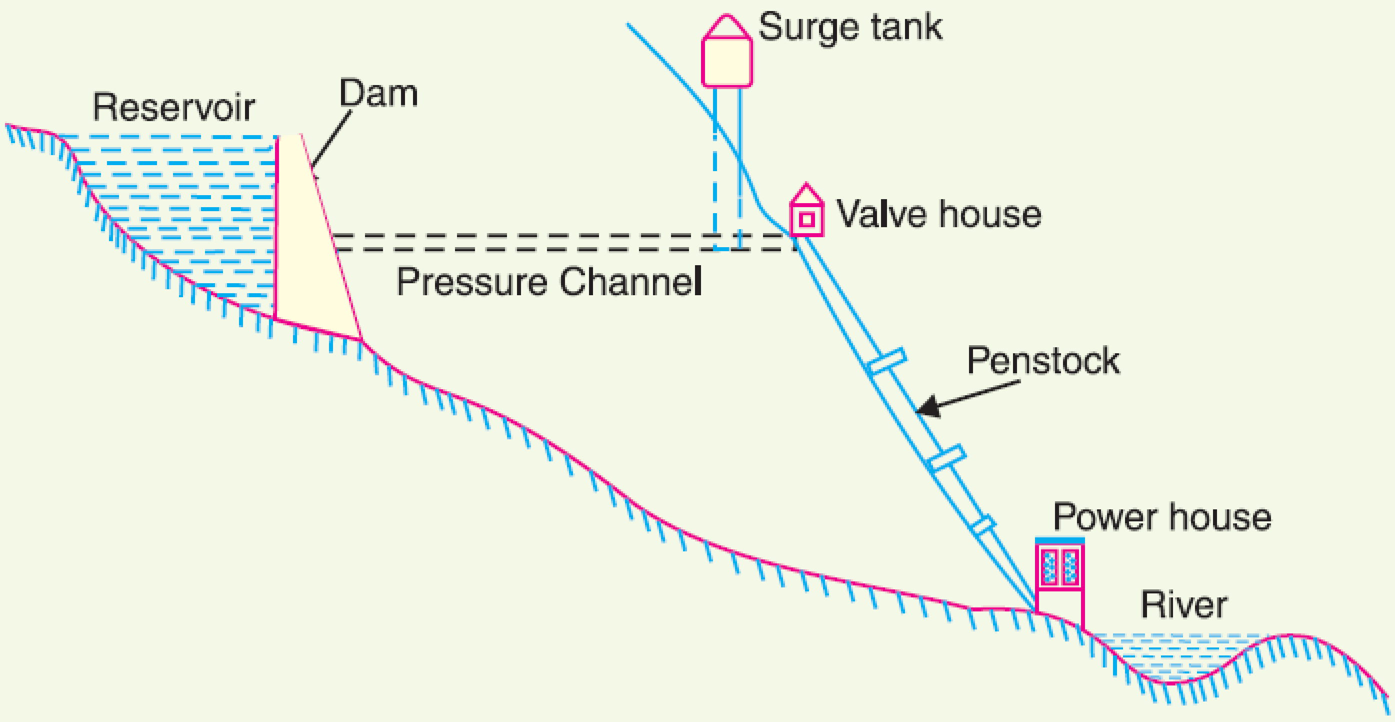
LAYOUT OF HYDRO ELECTRIC POWER PLANTS

(c) High-head plants

- If the available head is more than 100 m, the plant is called high-head plant.
- The civil works include a surge tank, the function of which is to meet the sudden changes in the requirement of water caused by the fluctuations in the system load.
- For heads less than 200 m, Francis turbines are used, while for higher heads, Pelton turbines are used.
- A pressure tunnel brings the water from the reservoir to the value house at the start of the penstocks.
- The generators used are of high head and small diameter.



Layout of Hydro Power Plant

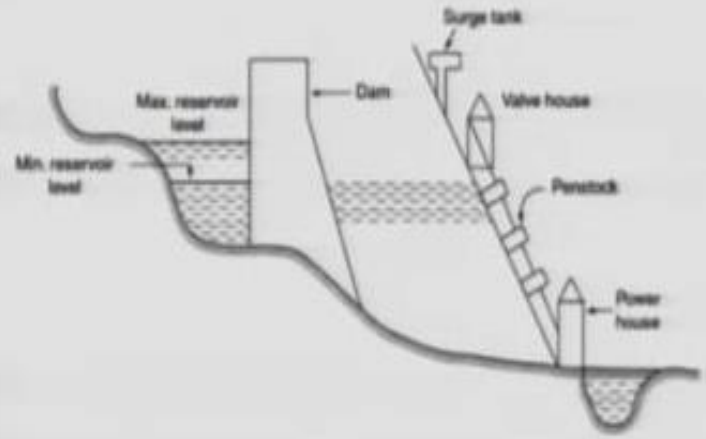


Schematic arrangement of a Hydro-electric plant

LAYOUT OF HYDRO ELECTRIC POWER PLANTS

Function of the various components in a hydroelectric generation system

The various components in a hydroelectric generation system include:



(a) Storage reservoir

The storage reservoir provides required quantity of water to be supplied to the turbines in order that the required power can be developed by the plant.

(b) Dam

In order to store the water and create an artificial head, a dam to be constructed. It is a highly expensive and the most important part of a hydroelectric plant. There are several types of dams, such as:

i. masonary dams (solid gravity concrete dam, arch dam, and buttress dam),
ii. earth dams, and
iii. rock fill dams.

LAYOUT OF HYDRO ELECTRIC POWER PLANTS

Function of the various components in a hydroelectric generation system

(c) Forebay

The water flowing from the dam is received by an enlarged body of water at the intake. It is called the forebay and it is intended to provide the temporary storage of water to meet the hour-to-hour load fluctuations on the station. The enlarged section of a canal or a pond, capable of accommodating the necessary widths of the intake, can serve the purpose of a forebay.

(d) Intake

The passage to water to the penstock, channel, or water conduit is provided by the intake. The intake structure should prevent the entry of debris and ice into the turbines. So, it is to be provided with trash racks, screens, and booms.

Intake structures are of two types: high pressure and low pressure. If the storage reservoirs are big, the high-pressure intake structures are used. In the case of ponds provided to store water to meet daily or weekly load fluctuations, the low-pressure intake structures can be used.

LAYOUT OF HYDRO ELECTRIC POWER PLANTS

Function of the various components in a hydroelectric generation system

(e) Penstock

It is a conduit system for taking water from the intake works and forebay to the turbines. These are two types, and they are low- and high-pressure types. The low-pressure type consists of a canal, a flume, or a pipeline. The high-pressure type consists of steel pipe which can take the water under pressure.

A penstock may be buried below the surface of the earth or it may be exposed. Penstock pipes are generally of steel for high- and medium-head plants and concrete in low-head plants. Each turbine will have its own penstock.

(f) Spillway

During floods, there will be excess water. This is to be discharged without causing any damage to the dam and allowing a predetermined head to be maintained. It will be acting as a safety valve for dam. For this purpose, a spillway which may be of the types: overflow, side-channel, shaft, and siphon spillways. Alternatively, a bypass tunnel or a conduit may be used.

LAYOUT OF HYDRO ELECTRIC POWER PLANTS

Function of the various components in a hydroelectric generation system

(g) Tailrace

The water after running the turbine is to be discharged into the river. For this purpose, a tailrace is required. Some turbines require a draft-tube while others do not. If a draft tube is used, it must be water sealed all the time.

Impulse turbines can discharge the water directly into the tailrace. The tailrace should allow the free exit of water and an unimpeded passage to the jet of water leaving the turbine.

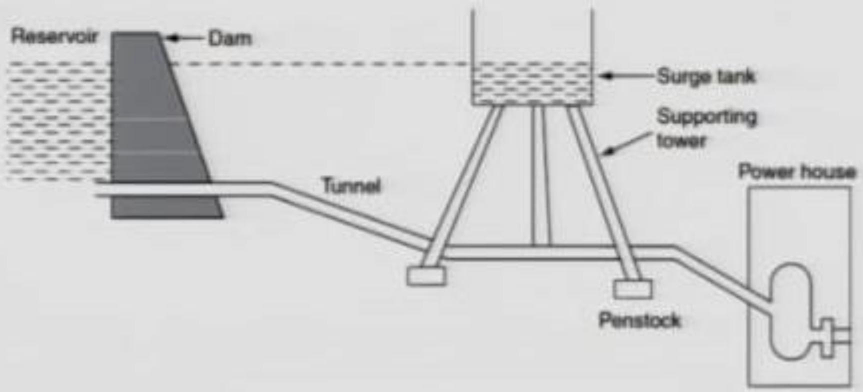
LAYOUT OF HYDRO ELECTRIC POWER PLANTS

Function of the various components in a hydroelectric generation system

(h) Surge tank

The sudden opening and closing of the turbine gates tends to cause a creation of vacuum and shocks in the penstocks. Both the water hammer and the negative pressure (vacuum) are detrimental to the proper functioning of the penstocks and are to be avoided.

A surge tank is used to take care of these sudden changes in the water requirements and the consequent water hammer of vacuum.



LAYOUT OF HYDRO ELECTRIC POWER PLANTS

Hydro electric power plants are also classified as:

Classification according to nature of load supplied

1. Base-load plants
2. Peak-load plants.

Classification according to regulation of water flow

Depending upon the water flow regulation, hydroelectric plants can be classified as:

(a) Runoff river plants without pondage.

(b) Runoff river plants with pondage.

(c) Reservoir plants.

POWER SYSTEMS –I

Lecture 1

Thermal Power Plant

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The Role of Thermal Power Plant in the Modern Power Generation Scenario.

- The development of **thermal power plant** in any country depends upon the available resources in that country.
- The hydro-power plant totally depends on the natural availability of the site and the hydrological cycle.
- The development of nuclear power requires high investment and technology.
- In many times, the hydro-power plant suffers if a drought comes even once during a decade and the complete progress of the nation stops.
- The calamity of rain drought on the power industry has been experienced in many states in the country.

- To overcome this difficulty, it is necessary to develop thermal power plants in the country which are very suitable for base load plants.
- The coal resources in India account for about 5.7% of the proven reserves in the world.
- The geological reserves of coal in India are 193.8 billion tonnes. The thermal power sector contributes nearly about 66% of installed capacity in India.
- The coal production in the country is increasing at the rate of 4.6% every year and new plants are set up in many parts of the country to increase the power production to meet the demand to increase the per capita income of the country.

Due to increased power generation –

- The country’s income can be increased.
- The standard of living can be increased.
- Reducing the unemployment
- Development in all sectors.
- Development in new technology.
- The GDP of the country can be increased.

Components of Thermal Power Plant

A thermal power plant generates electricity. In addition to generating electricity, certain thermal power plants are designed to generate heat for industrial purposes, such as district heating or water desalination.

- River or Canal
- Heater
- Boiler
- Superheater
- Economizer
- Alternator
- Condenser
- Cooling tower and ponds
- Air pre-heater
- Turbine
- Feedwater pump

#1 River or Canal

- It is well known here that a large amount of water is required, and this water is also used to generate electricity through the process of electrolysis.

#2 Heater

- Depending on the name according to which it is used, low-pressure heaters or high-pressure heaters increase or decrease the pressure of water.

#3 Boiler

- There are two sections in the boiler: one for coal storage and handling, which stores the coal and then uses it as needed.
- The ash handling and storage plant is the other section, where the coal burning process's produced ash is sent for ash storage.
- The pulverized coal and air mixture is added to the boiler, which is burned in the combustion area. When the fuel is ignited, a sizable fireball forms in the center of the boiler, radiating a significant amount of heat energy.
- At high temperatures and pressures, the heat energy is used to turn the water into steam. The boiler walls are covered with steel tubes where steam is produced from water. After passing through the superheater, economizer, and air preheater, the flue gases from the boiler are finally exhausted into the atmosphere through the chimney.

#4 Superheater

•This superheater tube is located at the very end of the boiler where the water is the hottest. In the superheater, the saturated steam generated in the boiler tubes is heated to a maximum temperature of 540 °C. The superheated high-pressure steam is then fed into the steam turbine.

#5 Economizer

•A boiler's feedwater is heated by an economizer before being supplied to the boiler. When the water pressure is raised, some heat is generated and sent from the economizer to the boiler.

#6 Alternator

•An alternator is connected to the steam turbine. Electricity is produced when the turbine turns the alternator. A transformer is then used to increase the electrical voltage that is generated before transmitting it to the intended location.

#7 Condenser

•The condenser is used to cool the working fluid or, more precisely, to remove heat from the water. The condenser uses cold water circulation to condense the exhaust steam. Here, the steam cools down and turns back into water after losing both pressure and temperature.

Condensing is necessary because compressing a fluid in a gaseous state requires a significant amount more energy than compressing a liquid. The cycle becomes more effective as a result of condensing.

#8 Cooling Tower and Ponds

To condense the steam, a condenser needs an adequate quantity of water. Most plants employ a cooled cooling system, which involves cooling and reusing warm condenser water. A cooling tower is a 150m-tall hyperbolic structure made of steel or concrete.

#9 Air Pre-Heater

Air from the atmosphere is drawn in by the main fan and heated in the air pre-heater. In the boiler, pre-heated air is mixed with coal. Preheating the air has the benefit of enhancing coal combustion.

#10 Turbine

The turbine's primary purpose is to turn the blades when steam passes through it, converting the heat energy into mechanical energy. Turbine blades rotate as a result of high-pressure, superheated steam being fed into the steam turbine.

The steam turbine, which serves as the prime mover, transforms the energy in the steam into mechanical energy. As the steam travels through the turbine, its pressure and temperature are reduced and its volume is increased. The condenser exhausts the expanded low-pressure steam.

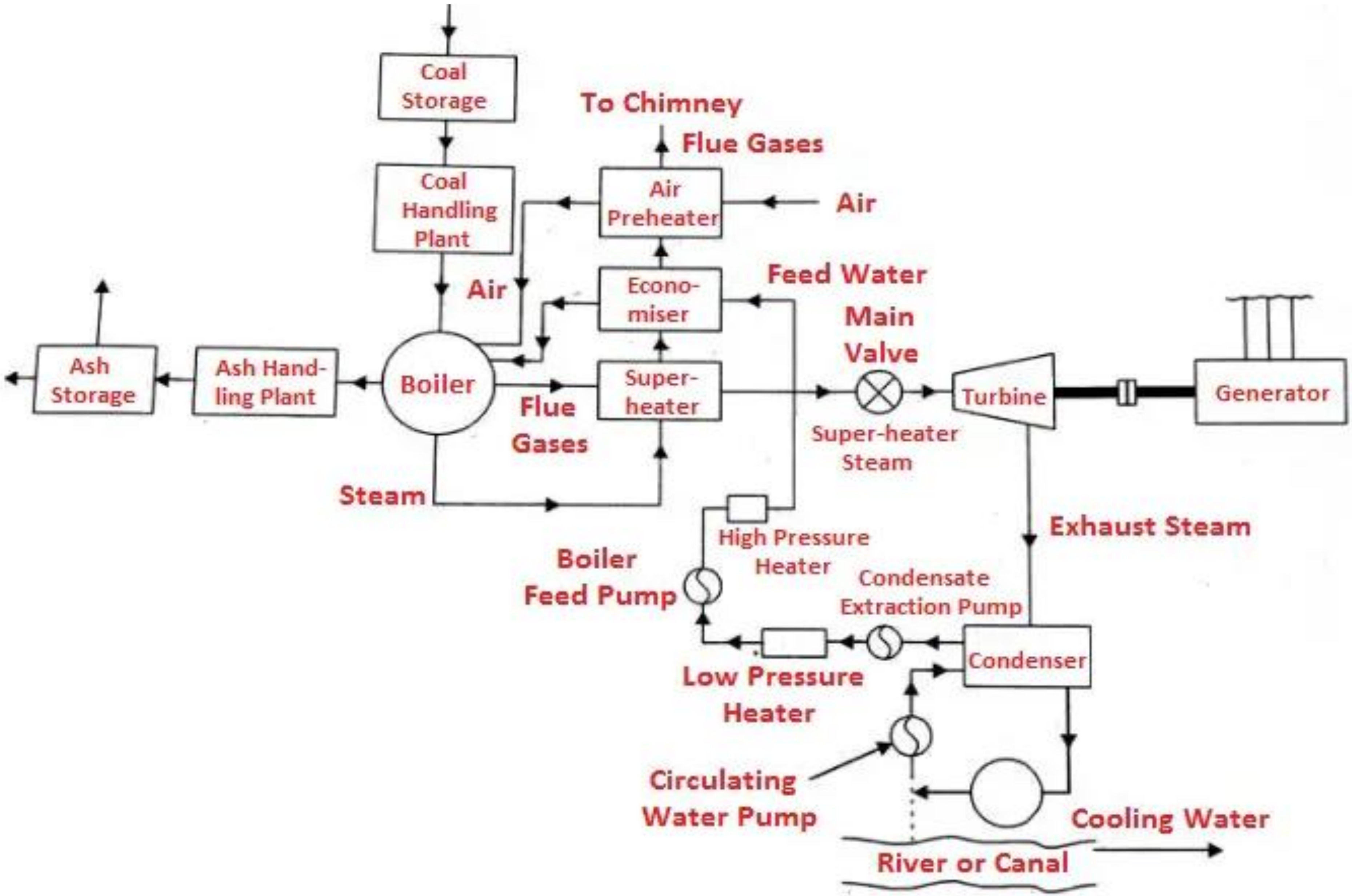
#11 Feedwater Pump

A feedwater pump once more supplies the condensed water to the boiler. During the cycle, some water could be lost, but it is still adequately supplied by an outside water source.

The layout of the Modern Thermal Power Plant

The general layout of the thermal power plant is shown in the figure and it consists of the following four circuits:

- Coal and ash circuit
- Ash and gas circuit
- Feedwater and steam flow circuit
- Cooling water circuit.



Layout of a Thermal Power Plant

Working of Thermal Power Plant

- Coal received in the coal storage yard of the power station is transferred to the furnace by the coal handling unit.
- The heat generated due to the burning of coal is used in converting water included in the boiler drum into steam at suitable pressure and temperature.
- The steam generated is passed through the superheater. Superheated steam then flows through the turbine. The pressure decreases after some work is done in the turbine. Steam after leaving the turbine pass through the condenser which maintains the low pressure at the exhaust of the turbine.

- The pressure of the steam in the condenser depends on the flow rate and temperature of the cooling water flow, and on the effectiveness of the air removal equipment. Water circulating through the condenser may be taken from various sources such as rivers, lakes, or the sea.
- If insufficient water is not available, the hot water coming out of the condenser can be cooled in cooling towers and circulated through the condenser again. Bled steam from the turbine at extraction points is sent to low-pressure and high-pressure water heaters.
- The air taken from the environment is first passed through the air preheater, where it is heated by exhaust gases. The hot air then passes through the furnace. The exhaust gases flow through the dust collector and then through the economizer, and air pre-heater, and finally, they are exhausted into the atmosphere through the chimney.

Factors for Selection of Site for Thermal Power Plant

The following factors are to be considered for the selection of the site:

#1 Availability of Coal

- The coal should be available in sufficient quantity nearer to the plant at a low cost.

#2 Ash Disposal Facilities

- There must be sufficient space to dispose of a large quantity of ash.

#3 Space Requirement

- Sufficient land should be available for the construction of the plant at a low cost with future expansion scope.

#4 Nature of land

- The site for the plant should have good bearing capacity to withstand the dead load of the plant.

#5 Availability of water

- A large quantity of water should be available for drinking, condensing, disposal of ash, and as feedwater at a low cost throughout the year nearer to the site.

#6 Transportation facilities

- The site should be connected by suitable transportation lines such as road and rail to bring the machinery, coal, etc.

#7 Availability of labor

- A cheap and large number of laborers should be available at the proposed site as a large number of laborers are required during the construction of the plant.

#8 Public problem

- The site should be away from the towns to avoid the nuisance of smoke, fly ash, etc.

#9 Nearness to the load centre

- The site should be nearer to the load center to reduce transmission costs and losses.
- The initial cost of the plant
- The nature and magnitude of the load to be handled.
- The necessity of future expansion of the plant.

Materials Required for Thermal Power Plant

- The following basic materials are essentially required by the thermal power plant:
- Feedwater
- Coal
- Cooling water.
- Water for ash disposal.
- SO2
- Air

1. Feedwater

- The feed water is the water circulated through a closed circuit of the power plant which is further converted into steam in the boiler. For example, a plant of 100 MW capacity may require nearly 500 tons of water per hour to be circulated through the system

2. Coal

- The coal is required for converting the feed water into the steam in the boiler. A sufficient quantity of coal is required. So that the plant should run without any stoppage due to the coal shortage. Nearly 1500 tons/day coal is required for 100 MW capacity plant generating 5 kg/kWh of steam.

3. Cooling water

- The cooling water is required for condensing the steam coming out from the turbines. Nearly 25000 tons/hr quantity of water is required for a 100 MW plant.

4. Water for ash disposal

- A large quantity of water is required for disposing of the ash. Nearly 5 kg of water is required per kg of ash disposal.

5. SO_2 (Low Sulfur contains coal)

- We should always be required to have low sulfur content coal because on burning such coal generates SO_2 and it is highly poisonous to human and animal health and as well as for the crops. Nearly 1.8 tons/hr amount of SO_2 is coming out by burning the coal containing sulfur up to 1 to 1.5% in 100 MW capacity plant. This SO_2 should be properly removed from the exhaust gases through improved technology.
- **6. Air**
- Air is required for the combustion of the fuel as well as required for cooling the water in the cooling tower. Nearly 1200 tons of air per hour for a 100 MW capacity plant, in addition to this nearly 25000 tons of air per hour is to be required for circulating in the cooling tower.

Types of Fuels Utilized in Thermal Power Plant

- Following are the types of fuels utilized in thermal power plants:
- Natural gas
- Coal
- Oil
- Geothermal energy
- Nuclear fuel
- Waste heat from industrial process
- Biomass – These plants are fuelled by waste from sugarcane, landfill methane and municipal waste, etc.
- Solar heat
- Blast furnace gas.

Advantages of Thermal Power Plants

The following are the advantages of thermal power plants:

- The fuel cost of the thermal power plant is relatively low.
- Thermal energy can be produced everywhere in the world.
- The heat production system is simple compared to other systems.
- The overall system is cost-effective.
- Easy mechanism.
- The same heat could be reused.
- Easier maintenance of the power station.
- The use of water is prominent here, therefore any place with ample water is a perfect location for installing a thermal power plant.
- These plants require comparatively small space to be installed.
- Its construction cost is cheaper due to the nearness of urban areas.
- These plants are completed within a few years.
- They are generally located near the urban areas.
- The scope of expansion is unlimited.
- These are located in a place where the displacement of people is minimum.
- They can be located near the consumption centers.
- The cost-benefit ratio is always better than the hydel power plant.

Disadvantages of Thermal Power Plant

- The following are the disadvantages of thermal power plants:
- The raw materials used are exhaustible resources,
- The ability of these plants depends on the quality of the coal.
- High maintenance cost.
- High production of CO_2 in the atmosphere.
- Exhaust gases harm the environment badly.
- Low overall efficiency.
- Thermal engines require a huge amount of lubricating oil that is very expensive.
- Nuclear thermal power plant demands an excessive amount of water for cooling purpose.
- Coal-type thermal power plant requires a larger duration before it supplies the generated power to the grid.
- This type of power station is ultimately responsible for the rise in seawater levels.
- Shorter life span.
- It is very difficult to maintain the optimum supply for a long period.

POWER SYSTEMS –I

Brief description of the components of Thermal Power Plant

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Brief description of the components

- Boilers
- Super heaters
- Economizers
- Electrostatic precipitators
- Steam turbines:impulse and reaction turbines
- Condensers
- Feed water circuit
- Cooling towers
- Chimney

Boilers

Boilers

- A Boiler is a closed vessel in which steam is generated (from water to steam) with the help of coal-burning or other fuel substances.
- It is used in thermal power plants for steam generation and further, the steam is used for rotating the turbine for the generation of electricity.

Pulverized Coal-fired Boiler

A pulverized coal-fired boiler is an industrial boiler that generates thermal energy by burning pulverized coal.

How does a steam boiler work?

- In a pulverized coal-fired boiler, The coal is pulverized to a fine powder, so that less than 2 % is +300 micro-meter and 70 – 75 % is below 75 microns.
- The pulverized coal is blown with part of the combustion air into the boiler plant through a series of burner nozzles.
- Combustion takes place at temperatures from 1300 – 1700 °C, depending largely on coal grade.
- The flue gas formed in the furnace passes over the superheater, economizer, air-preheater, and ESP, and finally is evacuated by the induced draft fan into the chimney.

Cont…

- The ash from the combustion chamber, which falls is collected in the bottom ash hoppers. The ash which is fine & flies with the flue gas is separated by ESP and collected in ESP hoppers.
- The Feed water enters the boiler through the economizer tubes provided in the path of the flue gas. The feed water is heated in the economizer and then enters the boiler drum situated outside the furnace at the top of the Boiler.
- The water is circulated in the tubes and converted into steam by gaining heat inside the furnace. The dry and saturated steam from the boiler drum then passes through the superheater section and is finally available at the boiler outlet header.

Advantages and Disadvantages of Pulverized Coal-Fired Boiler

- **Advantages**
- Ability to burn all ranks of coal.
- It permits combination firing (i.e. can use coal, oil, and gas in the same burner)
- **Disadvantage**
- The high power demand for pulverizing.
- Require more maintenance.
- Fly ash erosion
- Pollution complicates unit operation

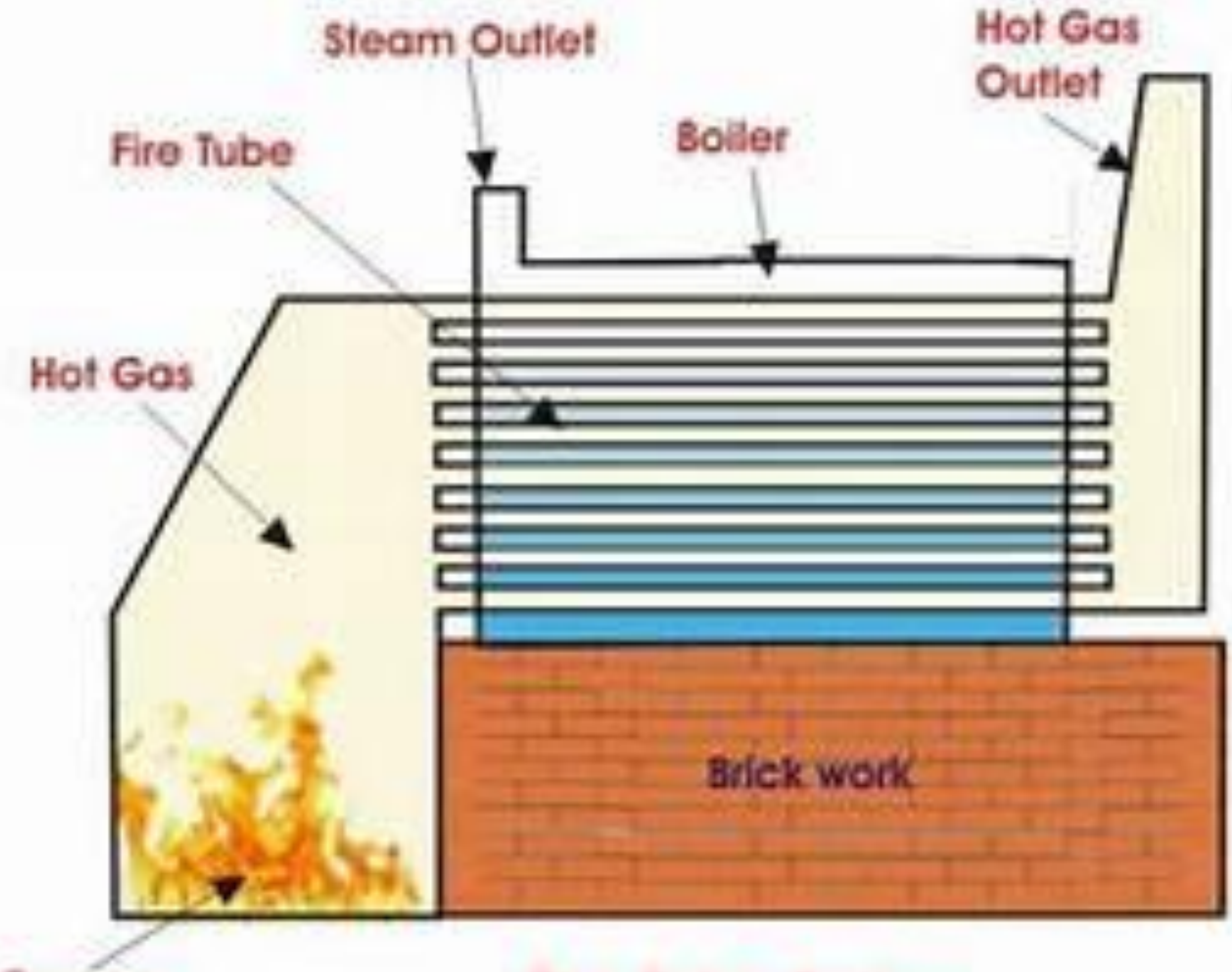
Types of Boilers

Coming to classification there are multiple types of boilers but mainly it has been classified into two types:

1. **Fire Tube Boiler**
2. **Water Tube Boiler**

Fire tube boiler

- A fire-tube boiler is a boiler that has fire (high-temperature exhaust gas) inside the tubes and is surrounded by water.
- The type of boiler is called fire tube boiler" because the hot flue gas flows through the tubes and the water surrounds the tubes.



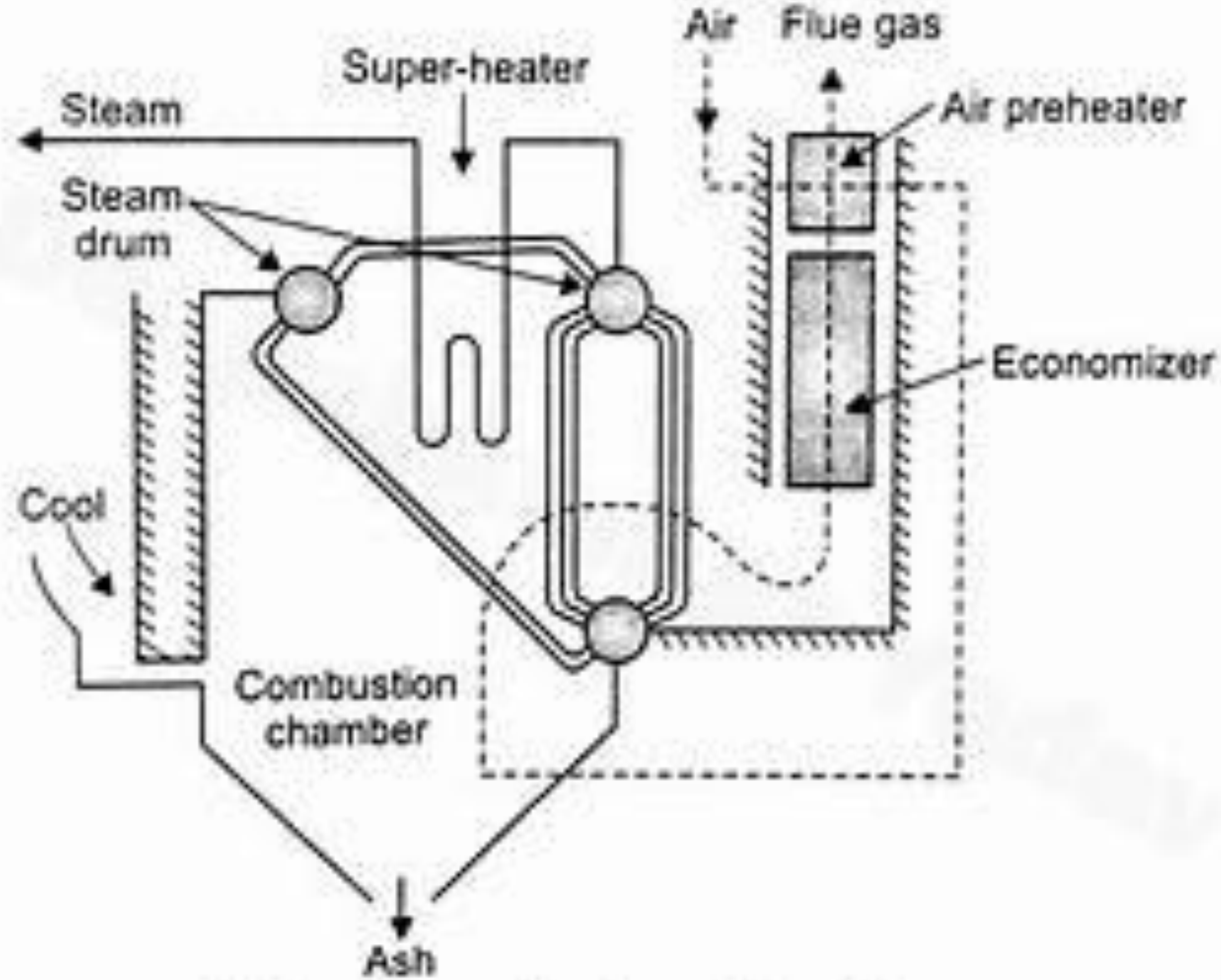
Fire Tube Boiler

There are various types of fire tube boilers and here is the following list:

- Cochran Boiler
- Cornish Boiler
- Locomotive Boiler
- Velcon Boiler
- Lancashire Boiler
- Simple Vertical and
- Scotch Marine Boiler.

Water-tube boiler

- A water-tube boiler is a boiler in which water is contained in the tubes and fire (high-temperature exhaust gas) surrounds the water.
- The type of boiler is called water tube boiler because the water flows through the tubes and the hot exhaust gas surrounds the tubes.

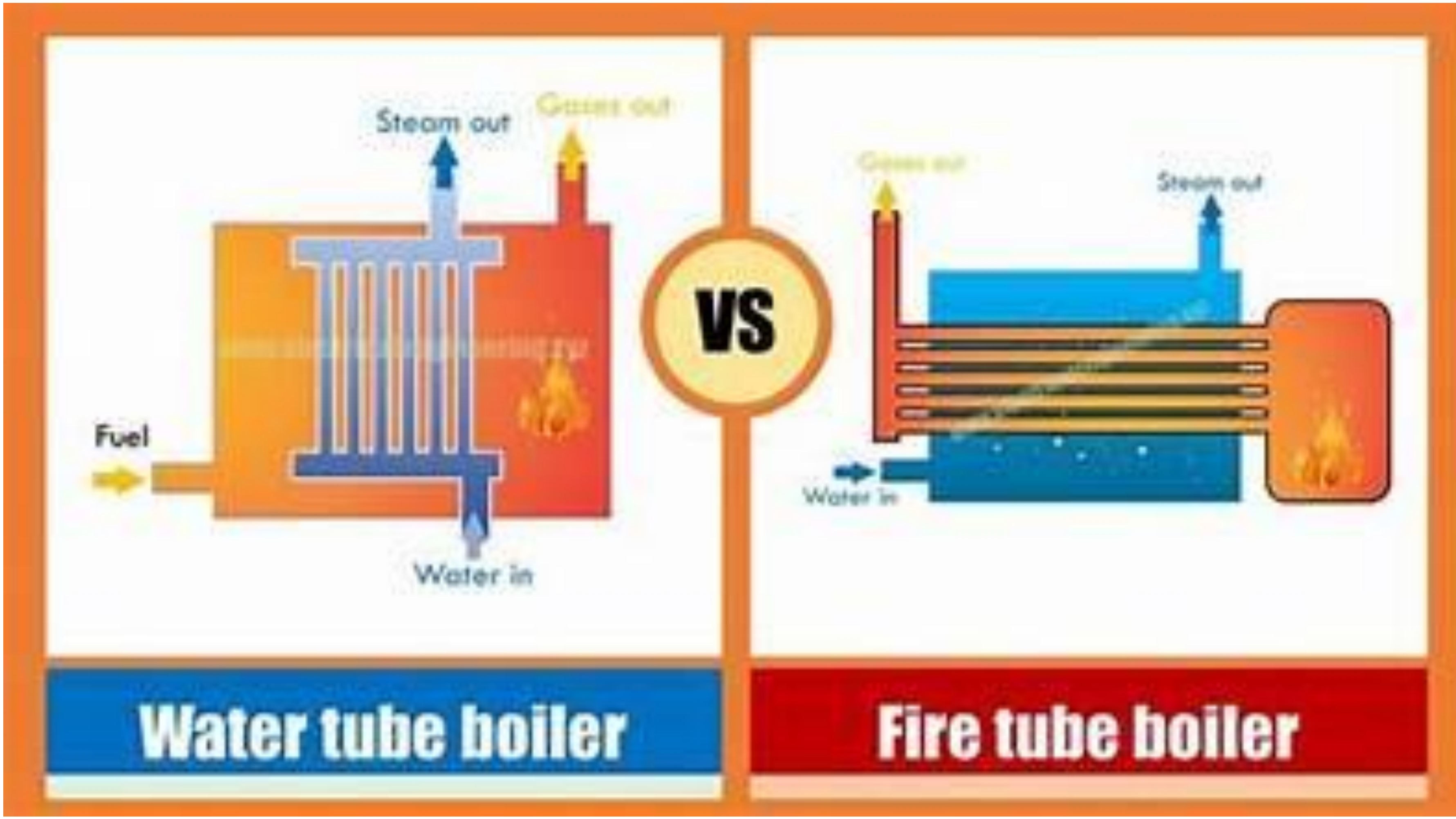


Water tube boiler

There are various types of water tube boilers. Some of them are the following:

- Benson Boiler
- Lamont Boiler
- Babcock and Wilcox Boiler
- Loeffler boiler and
- Yarrow boiler.

DIFFERENCES BETWEEN FIRE TUBE AND WATER TUBE BOILERS



DIFFERENCES BETWEEN FIRE TUBE AND WATER TUBE BOILERS

S. No.	Fire Tube Boiler	Water Tube Boiler
1	The Hot flue gases flow inside the tube and water has surrounded the tube.	Whereas In the water tube boiler, The water flow inside the tube, and the hot flue gases have surrounded the tube.
2	This is heavy in weight.	This is light in weight.
3	This is also called an internal fire tube boiler and	This one is called an Externally Fire-tube boiler.
4	Here the pressure is limited to only 20 bar but	In the water tube boiler, the pressure is around 100 bar and more.
5	The rate of Steam generation is Lower. Why? because the pressure is limited to only 20 bar.	The rate of Steam generation is High. Why? because the pressure is limited to 100 bar and more.
6	The explosion chances are less in a fire tube boiler because of low pressure.	Here explosion chances are more because of high pressure.

S.No.	Fire Tube Boiler	Water Tube Boiler
7	The overall efficiency is around 75 percent.	In the water tube, the overall efficiency is around 90 percent.
8	Efficiency is less compared to the water tube.	Efficiency is more.
9	Load fluctuations cannot be handled.	Load fluctuations can be handled easily.
10	The direction of water circulation is not well defined in this boiler.	The direction of water circulation in a water tube boiler is well-defined. A definite path is provided for the circulation of water.
11	This is not suitable for a large Power Plant. It is used in the process industry.	But It is suitable for Large Power plants.
12	It is simple in design.	It is complex in design.
13	A less skilled operator can work on this boiler.	But here it requires a more skilled operator.

S.No.	Fire Tube Boiler	Water Tube Boiler
14	This is having a low maintenance cost.	But the Water tube boiler has High maintenance costs.
15	Fire Tube Boiler example: Locomotive Boiler Velcon Boiler Simple Vertical and Scotch Marine Boiler.	Water Tube boiler example: Babcock and Wilcox Boiler Lamont Boiler Loeffler boiler and Yarrow boiler.
16	A fire-tube boiler requires more floor area for a given output.	The water-tube boiler requires less floor area for a given output.
17	The fire-tube boiler is bulky and difficult to transport. But	These (Water Tube Boilers) are light in weight, hence transportation is not a problem.

url of thermal PP

https://youtu.be/IdPTuwKEfmA?si=6VH2ZiWt8N_EGjfW

POWER SYSTEMS –I

Types of nuclear reactors

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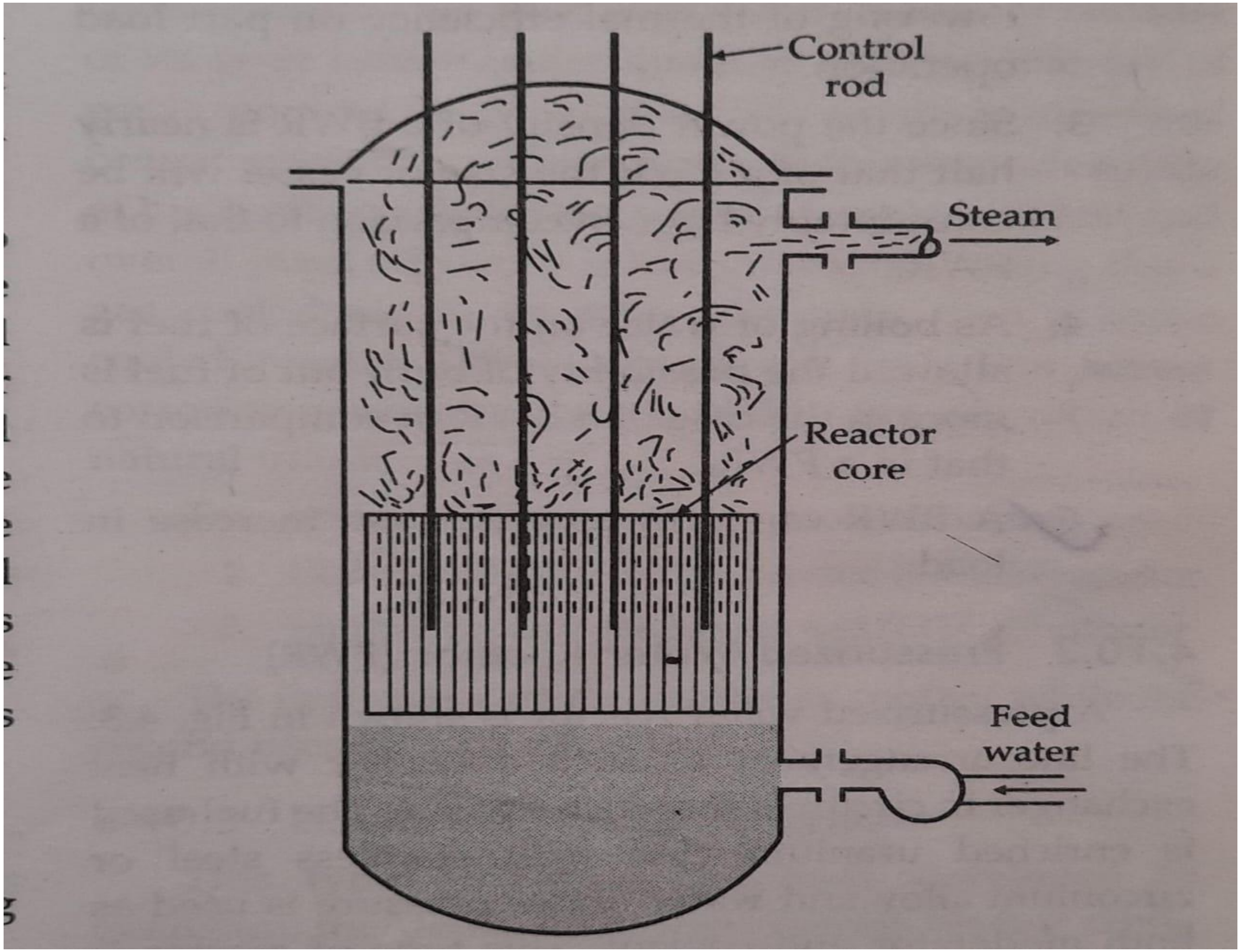
Boiling Water Reactor



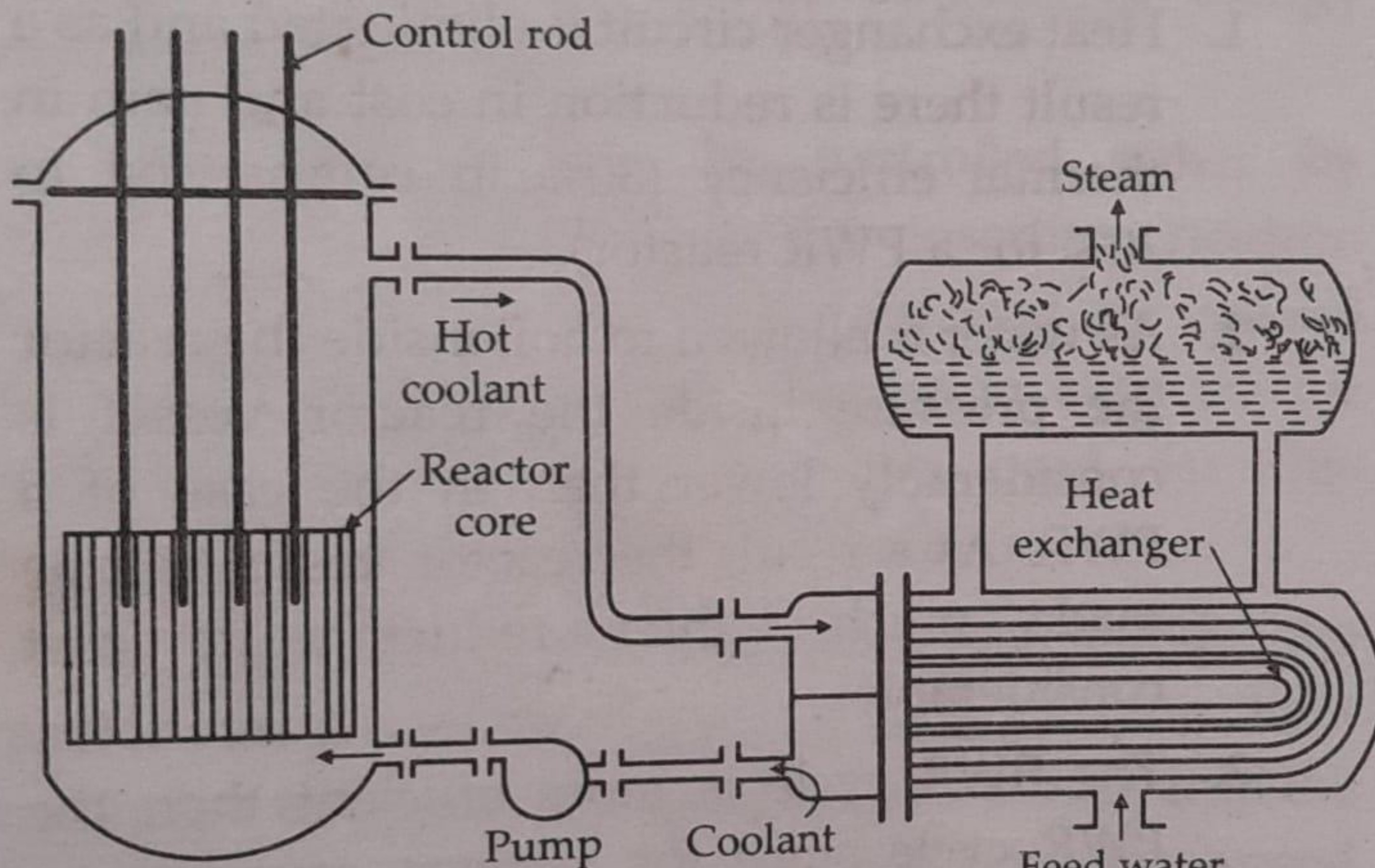


Fig. 4.3 A pressurized water reactor (PWR).

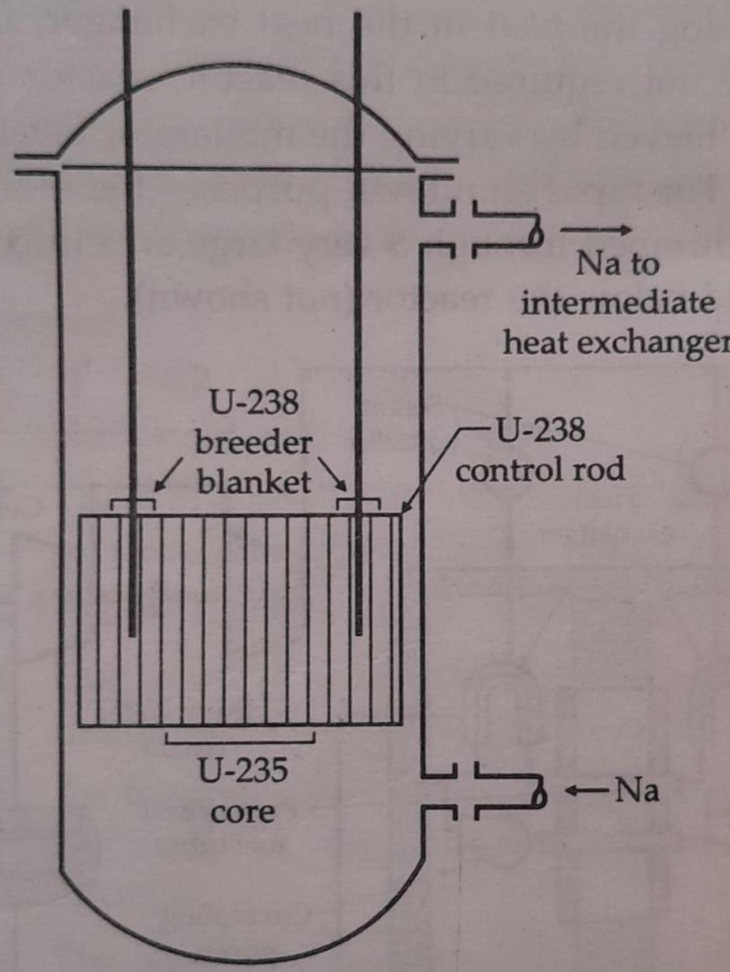


Fig. 4.7 A fast breeder reactor.

POWER SYSTEMS –I

Gas Insulated Substation

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Presentation Overview

- Perspective and Benefits of GIS
- GIS in Indian Scenario
- GIS Technology
- Some Solutions to Problems in GIS
  - Particle Contamination
  - Spacer Design with abnormalities
- Challenges in GIS
- Conclusion

What are your Today and Future Needs?

Humankind needs a reliable and secure power supply that is environmentally friendly and economic.

Safe

Efficient

Reliable

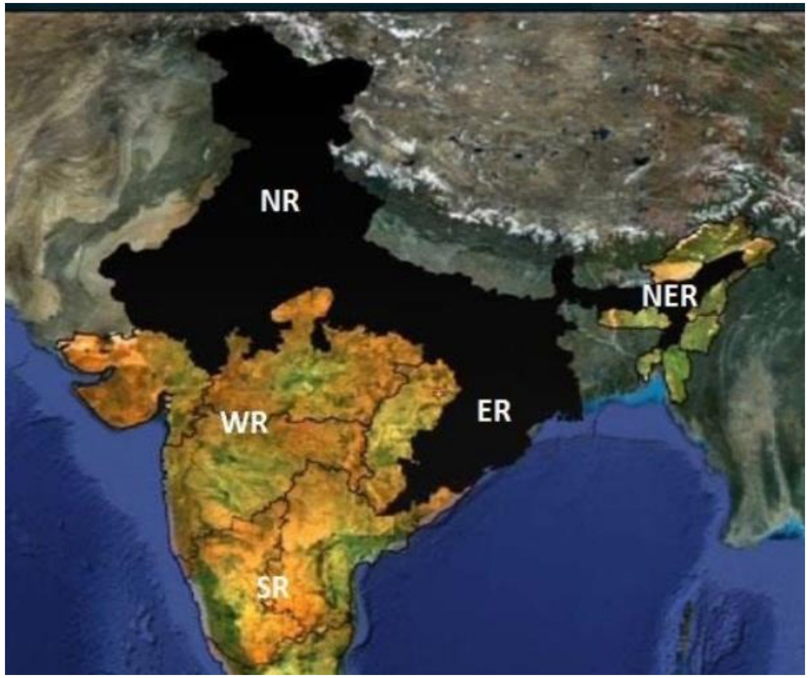
2012 BLACKOUT IN INDIA: Overloading Of Transmission Line

3 of 5 electric grids failed

20 lives in hospitals were in danger

28 states were hit by power cuts

265 miners were trapped in coal mines in West Bengal



Total affected load because of Blackout was 48,000MW

710 million people in India were left without power

How GIS can help fulfill them

You want | **With GIS you get**

You want	With GIS you get
Ensure people safety	> Arc resistance > No accessible live parts > Grounded enclosure(touch proof) > No maintenance = No risks for the people > Harmless gas
Continuity of service	GIS is designed to avoid failure > Not affected by environmental conditions > Low maintenance = Low risks for assets > High flexibility > Mitigate the risk of arc flash
Lower the costs	> Minimal maintenance > Smaller footprint = Smaller costs > No gas handling on site = quicker and easier install > No additional costs for more safety

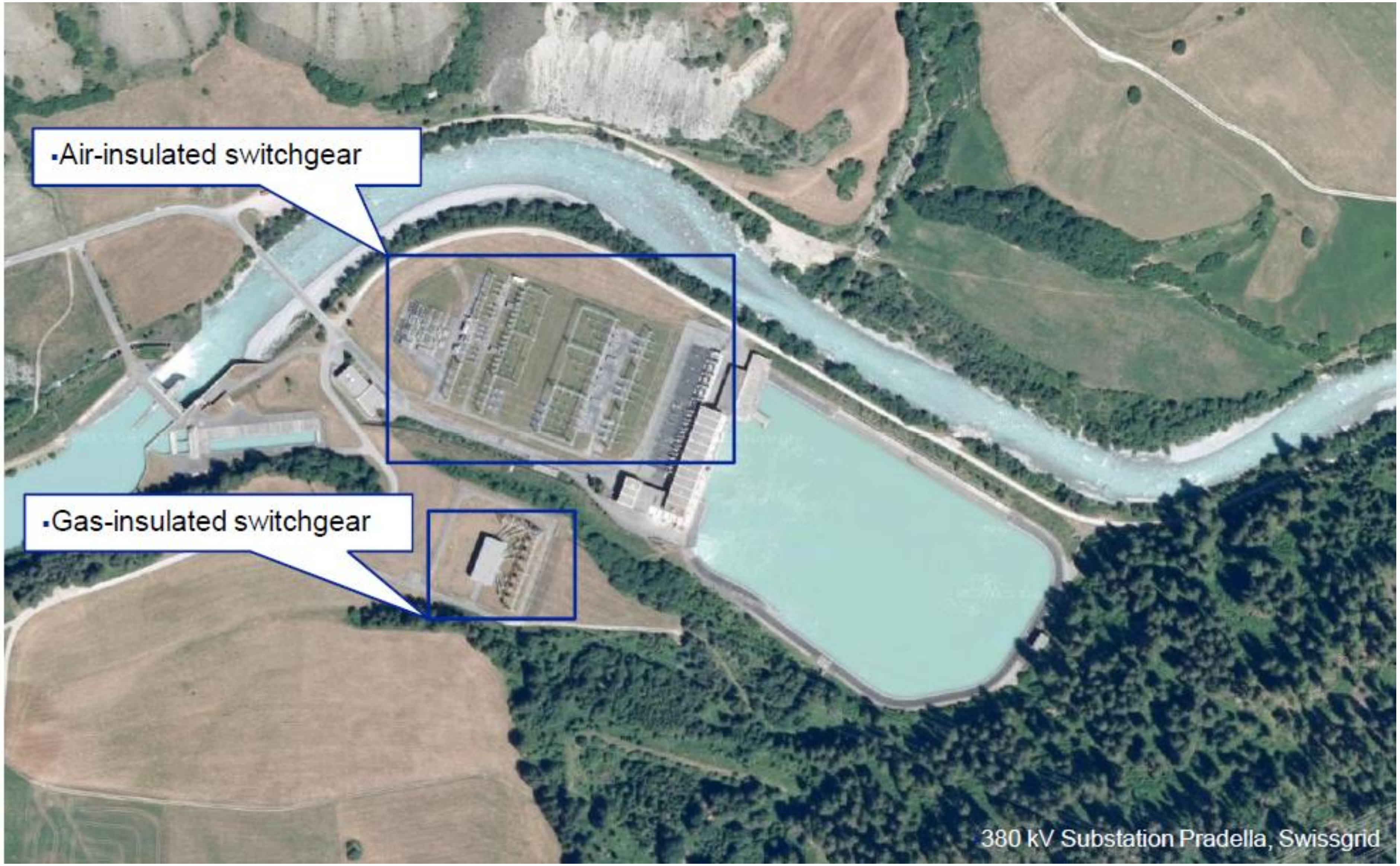
Introduction

- Demand for electrical power has become one of the major challenges faced by the developing countries.
- Considering the relatively low per capita power consumption, there is a constant need for power capacity addition and technological up gradation whereas non-conventional energy systems have proved to be good alternative sources for energy.
- Hence, the emphasis has shifted towards improving the reliability of transmission and distribution systems and ensuring that the innovations are not harmful to the environment.
- Rapid urbanization and overgrowing population is making the task of expanding transmission network very difficult due to right of way problem and limited space availability.
- In addition, conventional air insulated substations have many problems such as pollution by salt or dust, meteorological difficulties, safety etc.

Power transmission and distribution – AIS and GIS

- Environmental challenging areas
- Very low or high temperatures
- Seismic active areas
- Flood areas, wetlands, challenging soil conditions
- Special air conditions (salty, dusty, polluted air)
- Areas with increased concern about visibility
- Security concerns
- Aesthetic concerns
- Project with limited labor resources
- Remote areas
- Mining, oil and gas electrical supply
- AIS extensions or replacements projects because of age or reliability

Low space requirement



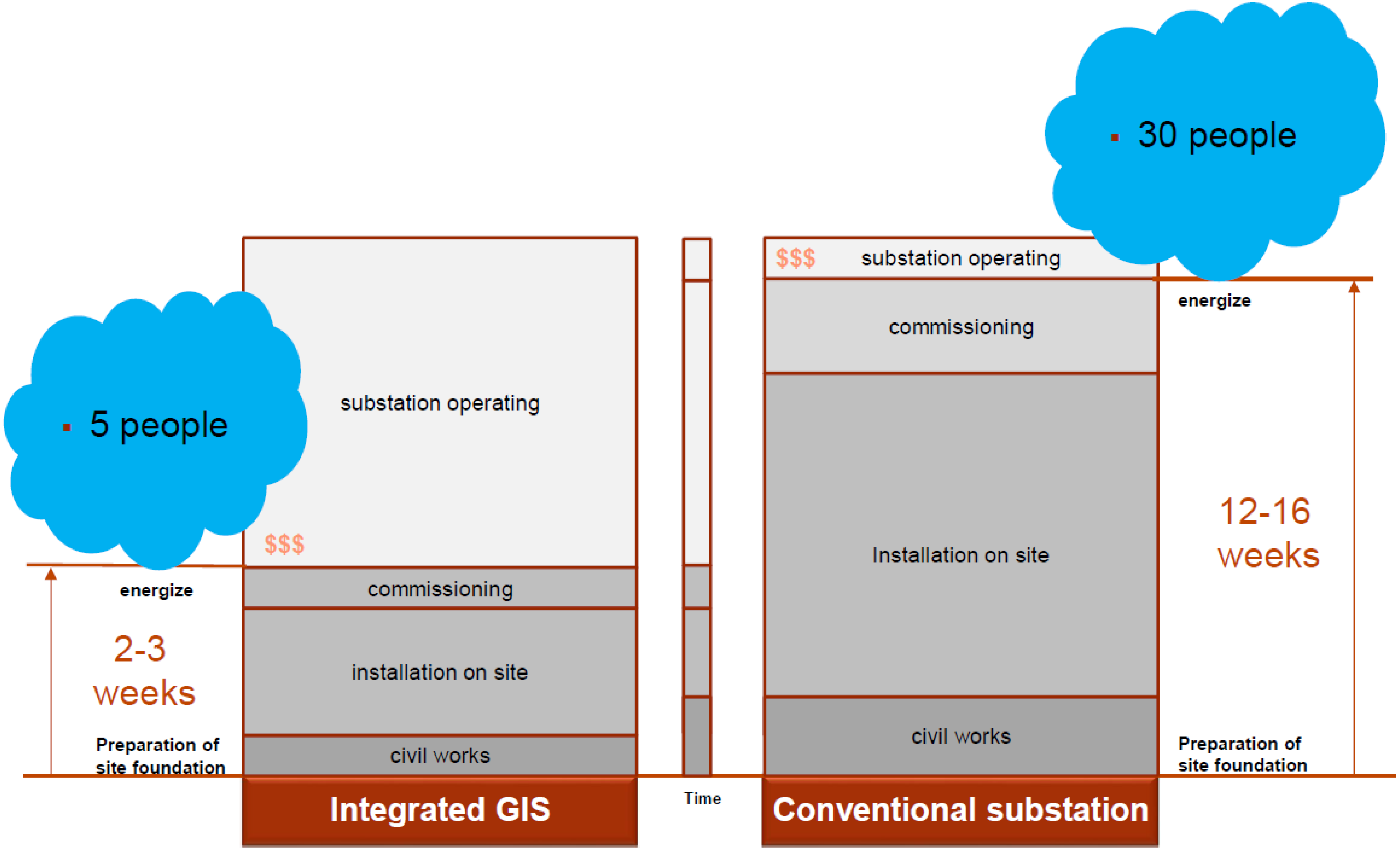
Indoor and Outdoor installation

- Canopies – equipment almost **independent from environment**
- **Building of all types** – Prefab metal to Underground
- Increased **Reliability**
- Use under **difficult climatic conditions**
- **Easy planning** of outages for Service and Maintenance

Reduced installation and commissioning time

- Factory assembled, fully tested and shipped as one bay
- Less civil and on-site construction works

Total savings in installation time



Substation security and aesthetics

- Indoor application secures equipment and prevents vandalism
- Enables substation to be hidden in buildings or underground to preserve the aesthetics of the surroundings

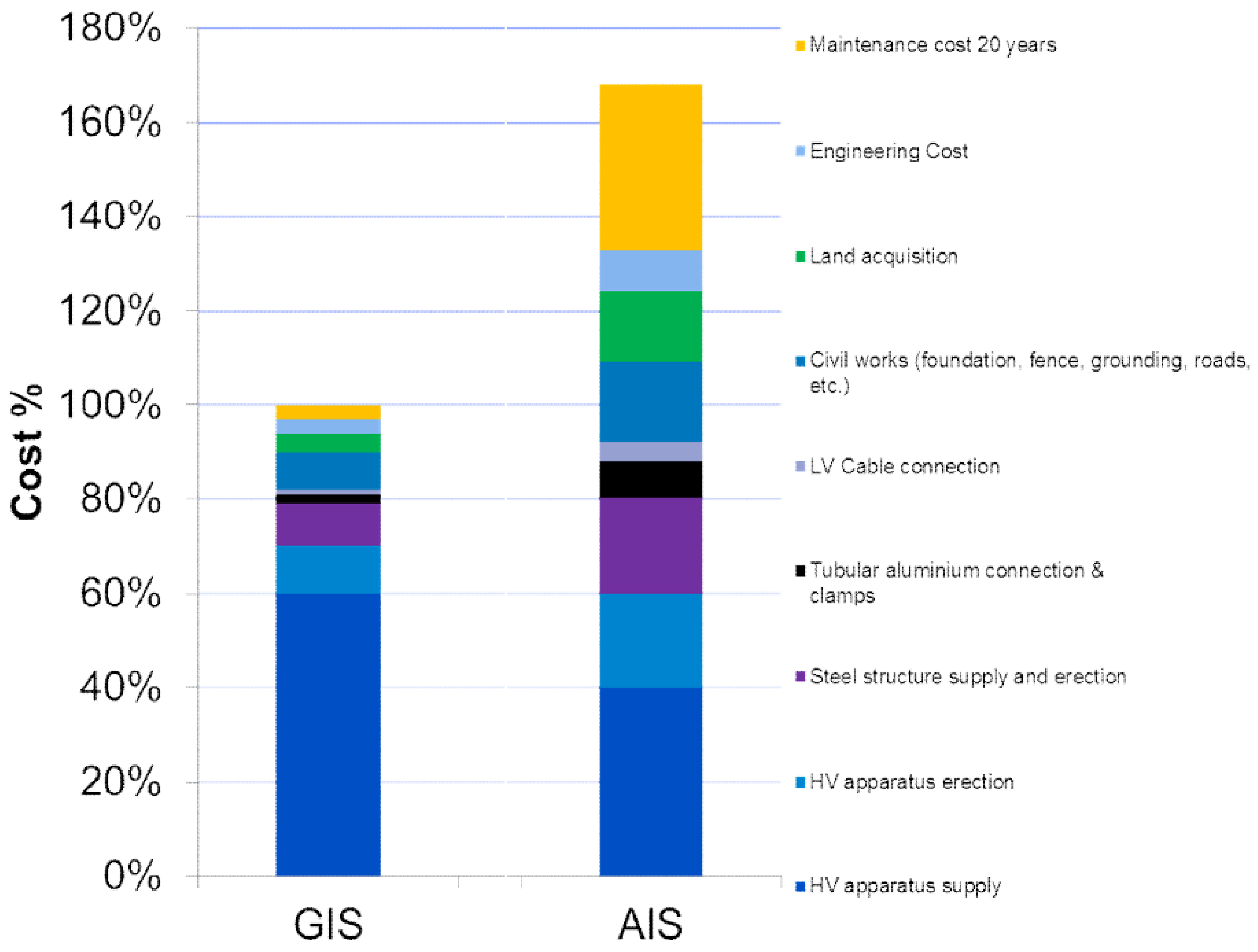
Advanced features for digital substations

- Incorporation of IEC 61850 standards
- One multi-purpose electronic current transformer (ECT) and electronic voltage transformer (EVT) for all applications
- Remote monitoring
- Digital monitoring, measurement, control and protection based on IEC 61850 are integrated into the local control cubicle within the bay for C-product lines

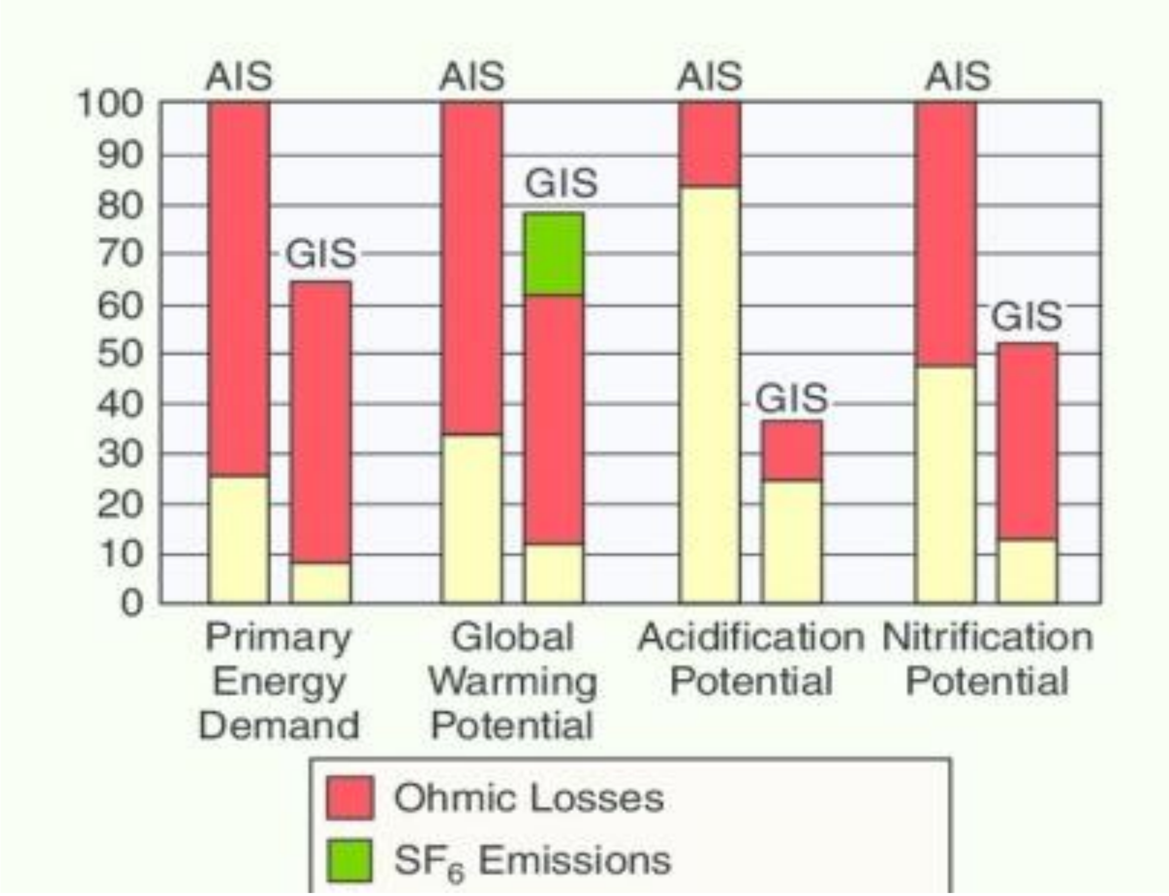
CIGRE Survey on Reliability

CIGRÉ WG A3.06 has completed a survey of reliability and failures of in-service high voltage equipment. The equipment types considered are SF_6 circuit breakers, disconnectors, earthing switches, instrument transformers and gas insulated switchgear (GIS). 90 utilities from 30 countries have contributed failure and population data, making this the most comprehensive reliability survey for high voltage apparatus ever carried out. The overall major failure frequency for circuit breakers is found to be 0.30 major failures per 100 circuit breaker years of service, which is lower than in a previous survey. Shunt reactor switching is associated with substantial higher failure frequencies than other switching duties. For disconnectors and earthing switches the overall major failure frequency is determined to be 0.21 failures per 100 equipment years of service. A 3:1 ratio between the number of failures caused by the operating mechanisms and failures caused by the primary components of the disconnectors and earthing switches is observed. Instrument transformers show an overall failure frequency of about 0.053 major failures per 100 single phase instruments transformer years of service. In general, individual equipment installed in GIS appears to have lower failure frequencies than equipment in air insulated substations. The overall major failure frequency for GIS bays is about 0.37 major failures per 100 GIS circuit breaker bay years of service. (A GIS circuit breaker bay includes one circuit breaker and all associated disconnectors, instrument transformers, interconnecting busducts and/or parts of busbars and associated terminals.) Six very comprehensive CIGRÉ Technical Brochures containing all results with commentaries, information concerning how the survey was conducted, methods used for statistical analyses, recommendations for utilities and manufacturers, etc. are to be published shortly.

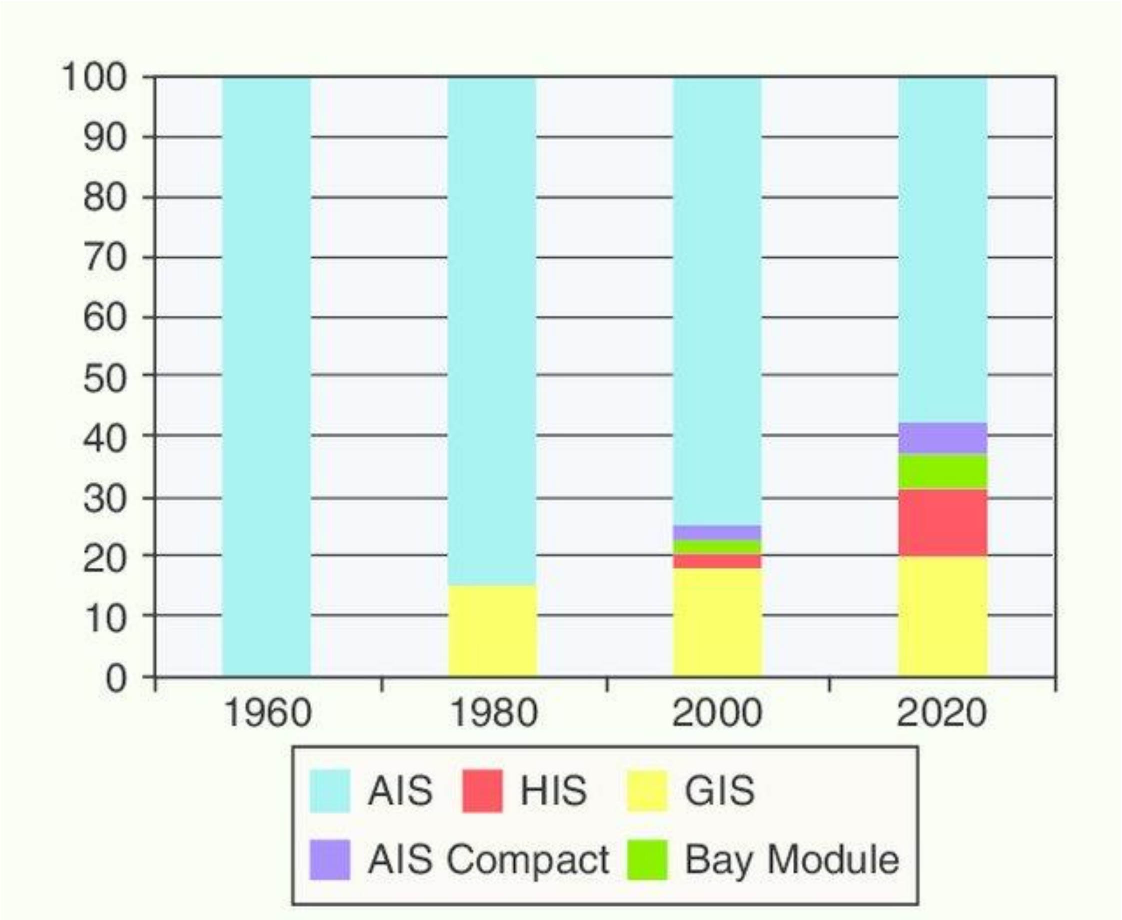
Economical Comparison GIS – AIS (500 kV)



AIS vs GIS



Environmental impact of AIS and GIS.



Percentage evolution and development of HV substations in the market.

Need for GIS

- Gas insulated sub-station systems offer a compact, cost-effective, reliable and maintenance-free alternative to the conventional air insulated sub-station systems.
- Their compact size offers a practical solution to vertically upgrade the existing sub-station and to meet the ever-increasing power demand in developing countries.
- The assured long life and freedom from frequent maintenance drills offered by these gas insulated sub-stations will help eradicate the conventional air insulated sub-stations in years to come.

The first 110 kV GIS in the world

- In operation from 1965 until 2013
- 48 years of reliable operation !

General Characteristics and Features of GIS

- Remarkable Space Reduction -
  - – Reduces the installation Space to 10% of Conv. Substations
- High Reliability
  - – Complete enclosure of all live parts guards against any impairment of the insulation system.
- High Safety
  - – protected by earthed metal enclosures
- Laboursaving maintenance and inspection
  - – No Aging decay as all the live parts are fully enclosed
- Reduction of term for construction Works
  - – low weight due to aluminium enclosure, corresponding low cost foundations and buildings

GIS Equipments

Gas-Insulated Substations

GE provides a full range of GIS solutions from 60 to 800 kV for utilities and industries worldwide.

Gas-Insulated Lines

GE's Gas-Iinsulated Lines (GIL) meet the challenges of electrical networks up to 800 kV for multiple applications.

Green Alternative to SF_6

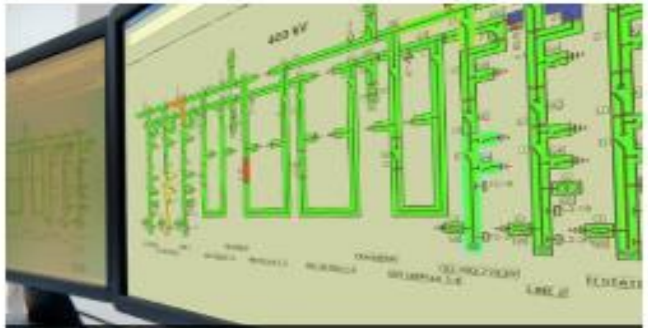
g³-green gas for grid- is GE's environmentally friendly alternative to SF_6 for high voltage applications above 66 kV.

Hybrid Gas-Insulated Switchgear

Hybrid Gas-Insulated Switchgear for networks up to 550 kV in generation, transmission and industrial applications.

Mobile GIS

Mobile Gas-Insulated Switchgear for temporary and emergency applications.



GIS Digital Solutions

Digital gas monitoring, partial discharge monitoring, controlled switching and low power instrument transformers up to 800 kV.

Use of SF6 Gas

- Sulphur hexafluoride is the electric power industry's preferred gas for electrical insulation and especially, for arc quenching current interruption equipment used in the transmission and distribution of electrical energy.
- The use of SF_6 gas as an insulating medium in switchgear reduces the clearance distance between active and non-active parts of a switchgear facilitating the advantages of gas insulated applications compared to air insulated applications.

Features of SF6 Gas

- High dielectric strength and less clearances
- Good arc-interruption
- Colorless & odor less
- Non Inflammable
- Has very good heat transfer ability
- Is non toxic in pure form
- Has low condensation temperature
- Has high density

Preferred Locations for GIS

- Urban and industrial areas

  (space, pollution related problems)

- Mountainous areas

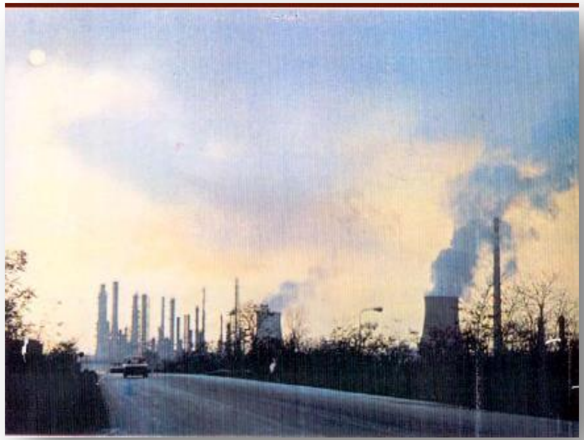
  (site preparation, snow and ice)

- Coastal areas

  (salt-associated problems)

- Underground substations

  (site preparation)



Demerits of GIS

- High Cost
- Excessive damage in case of internal fault
- Requirement of cleanliness are essential as
  Dust or moisture can cause internal flashovers
- Repair of damaged part at site is difficult
- As GIS are generally indoor so they need a separate building
- Procurement of gas and supply of Gas to site is problematic.
- Adequate stock of gas must be maintained.

Many firsts in GIS

1967 — 170 kV GIS

1976 — 550 kV GIS

1987 — 800 kV GIS

1992 — 145 kV GIS in prefabricated housing

1997 — Most compact 123 kV GIS

2008 — Ultra high-voltage 1100 kV GIS substation

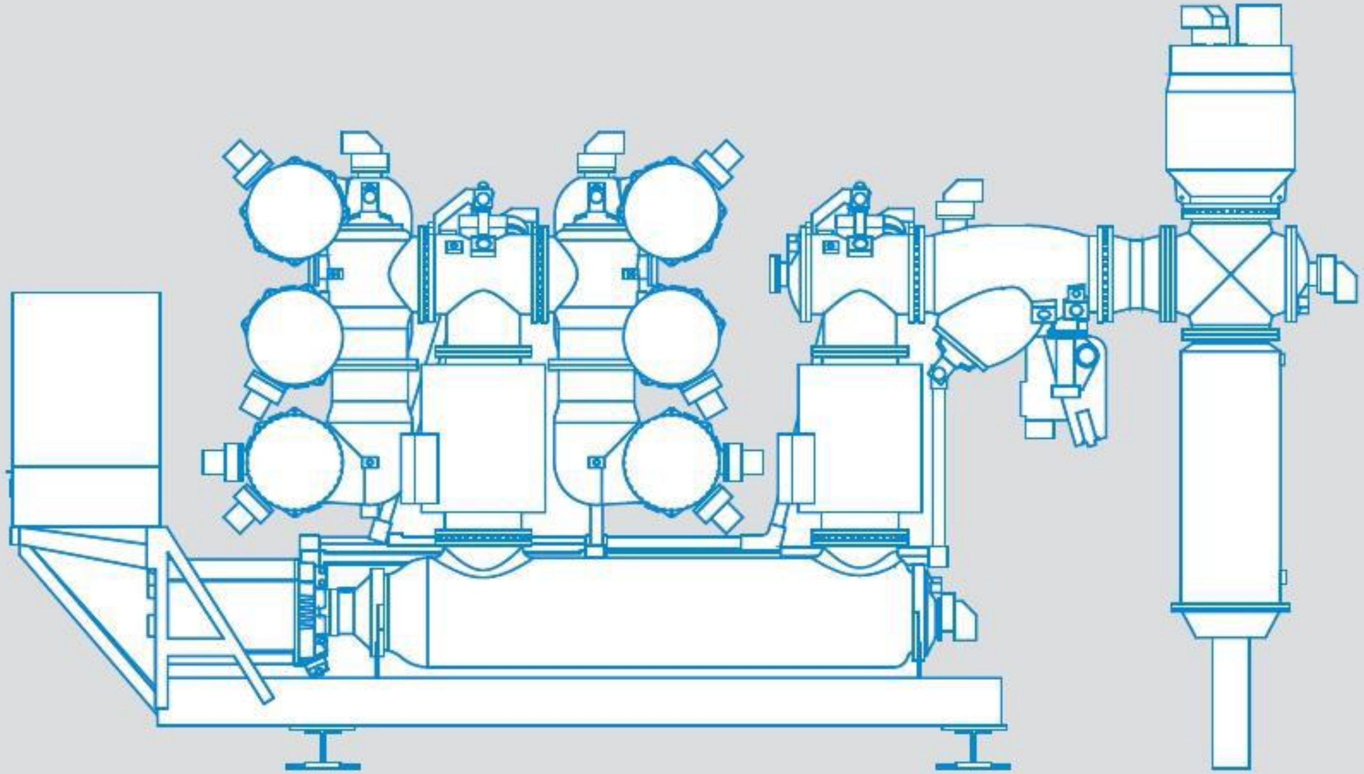
2009 — Largest urban substation

2012 — Ultra high-voltage 1200 kV GIS substation

2013 — Compact 420 kV substation

2015 — Eco-GIS substation

Range of GIS



Market leader with more than

25,000 bays

installed worldwide

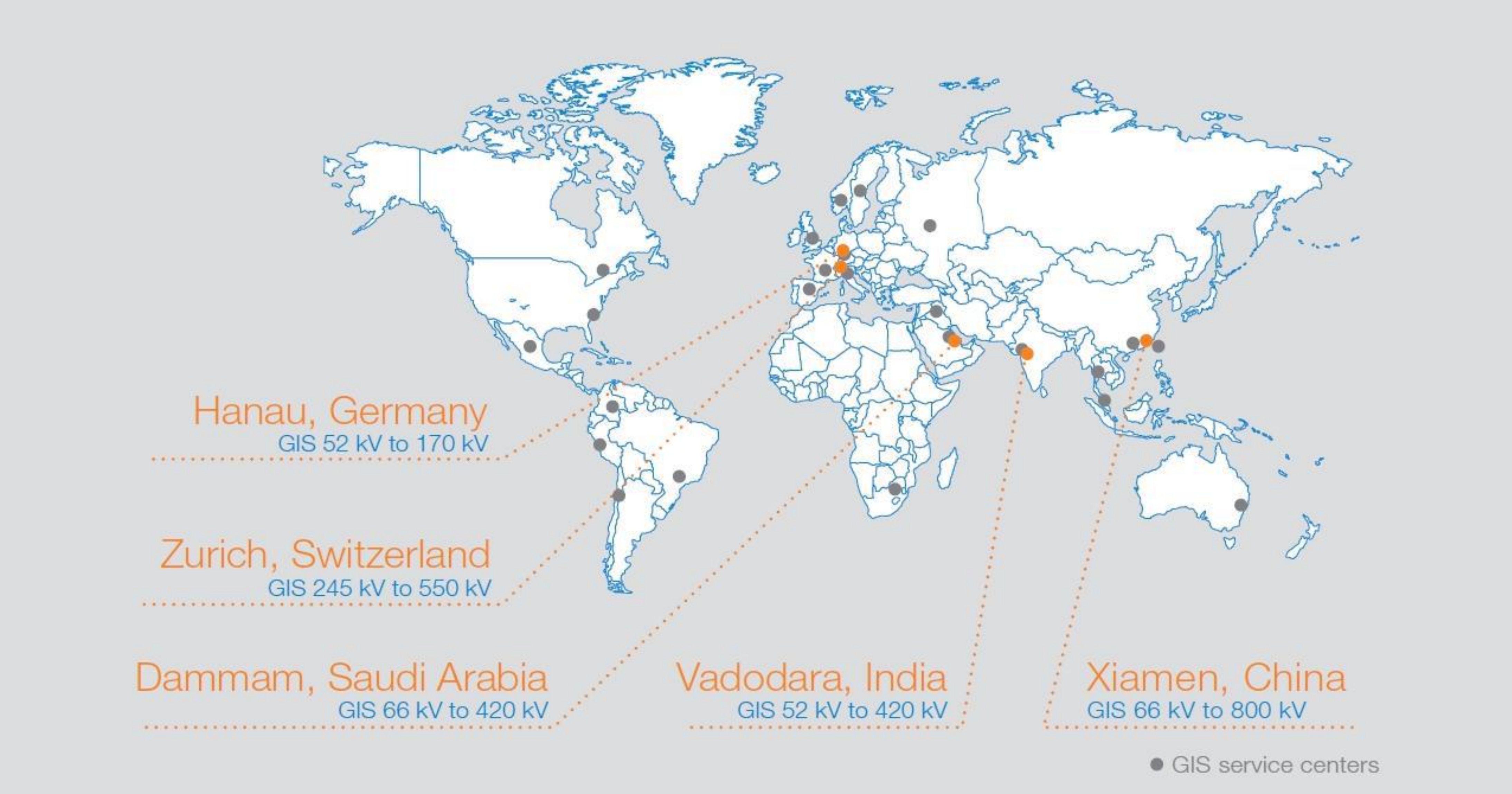
Driving technology and innovation

since 1965

Complete range of GIS

52 kV to 1200 kV

Global manufacturing network



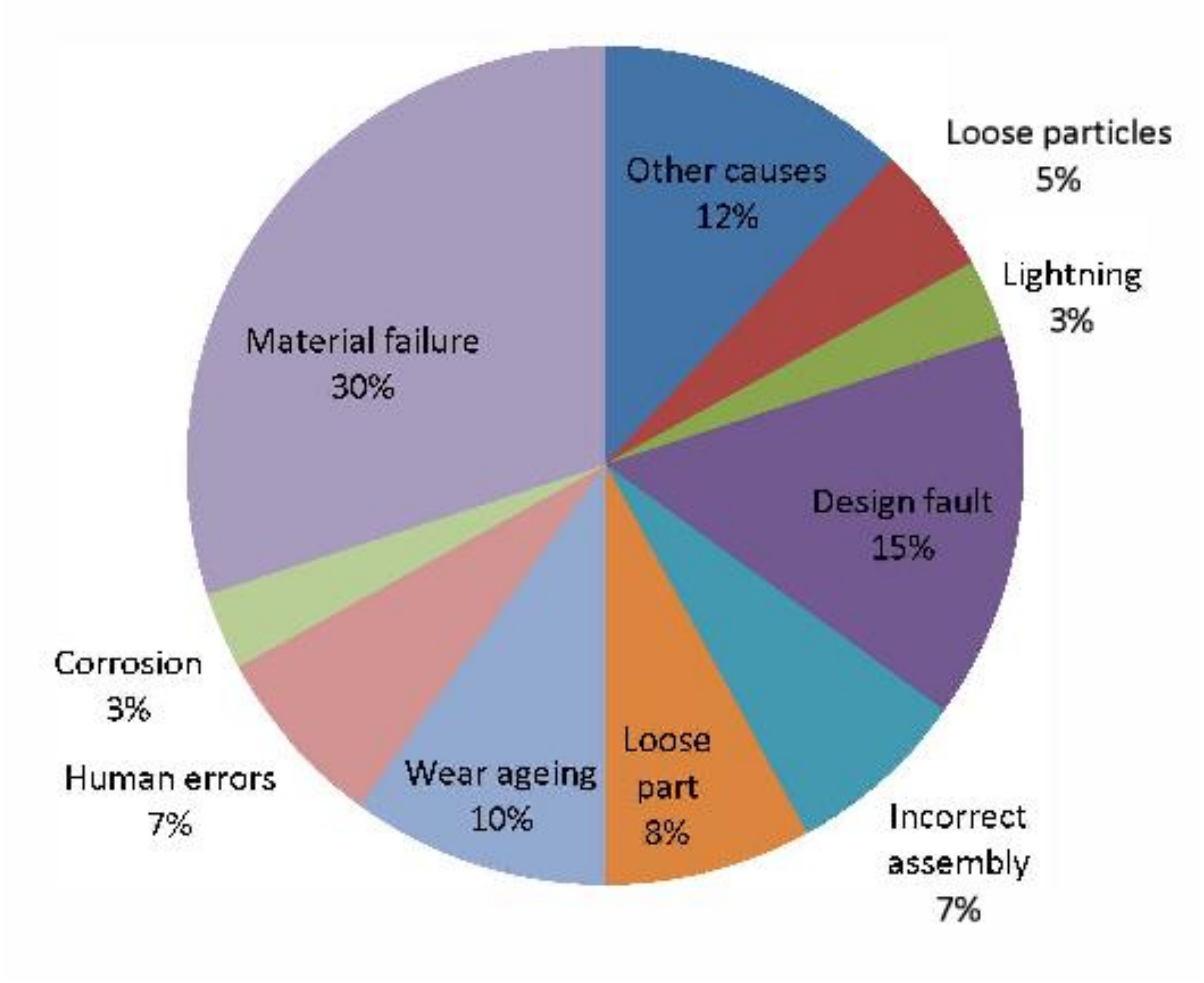
GIS in Indian Scenario

- As per the Ministry of Power, India's electricity consumption is likely to increase by almost four times by 2030, from the existing 1,110 billion units (BUs) to around 4,000 BUs.
- The power distribution segment needs to gear up to meet this future energy requirement.
- Substation equipment has to be made more efficient and reliable.
- In addition, urbanisation, increasing real estate prices and the need to accommodate more renewable energy for meeting climate change targets warrant the need to adopt compact, energy efficient and intelligent devices to ensure reliable power supply to consumers.
- In this regard, gas-insulated switchgear (GIS)-based substations are gaining popularity as the preferred technology in India.

GIS in Indian Scenario

- The demand for GIS is bound to rise keeping in view the overall land availability in the metropolitan cities.
- The substations are bound to be grid connected as a result of which any small problem can always elevate to become a major problem and lead to severe failures and blackout in the power system.
- The above considerations are required to be handled very effectively in order to improve the overall efficiency of the power system.
- Designs (topology) of transmission and distribution grids vary depending on the application. Thus, manufacturers and above all grid operators must find well-balanced solutions under a wide range of criteria.
- Substations using gas-insulated switchgear must make the highest return on investment while confronting those challenges.
- There’s a high level of reliability to GIS, but when something goes wrong, outage times mean less revenue and increased costs.

Observed Failures in Indian GIS



A survey of Indian GIS shows that the maximum failure rate observed is due to

Material failures,

Improper material substitutions,

Wrong material selection,

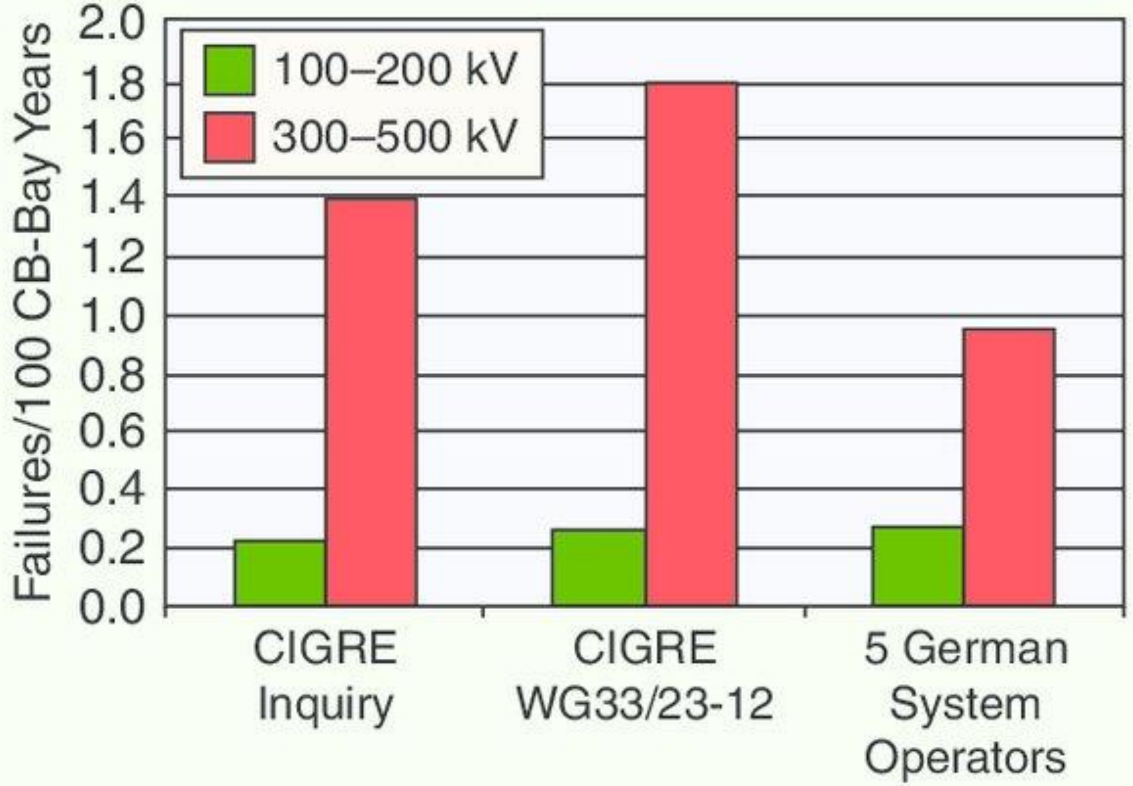
Corrosion of

The studs and hardware,

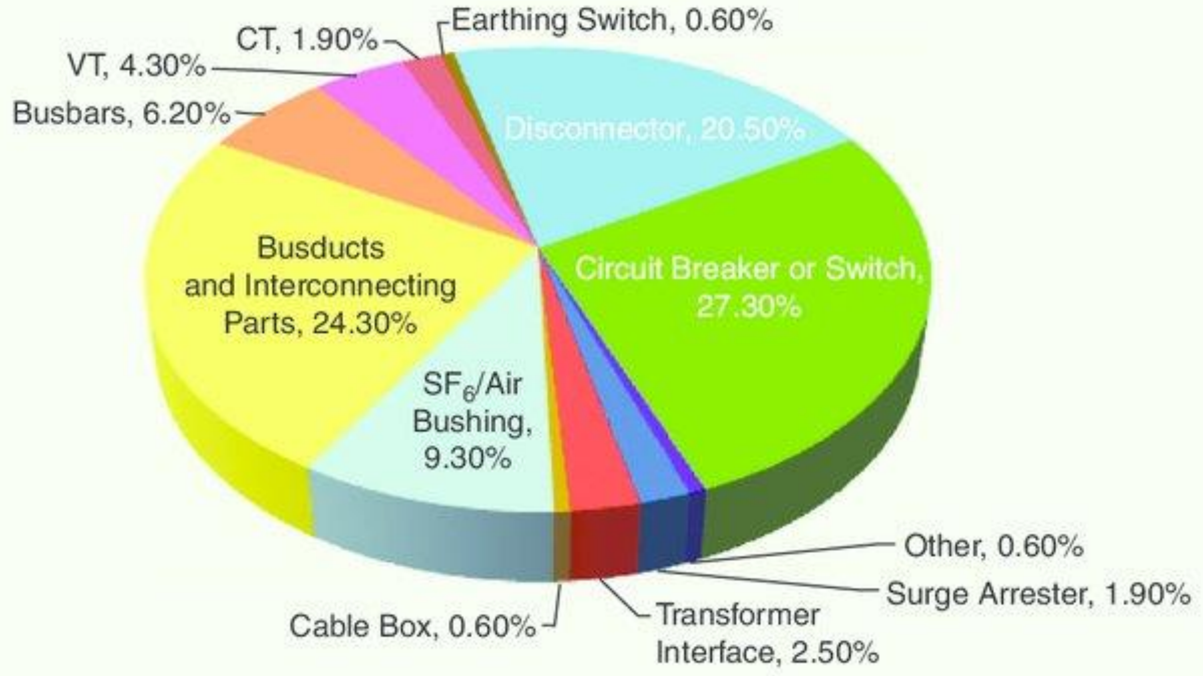
loose parts in subassemblies add up to the overall failures in the GIS.

Natural occurrences like lightning strokes are also of high importance in this observation.

Failures in GIS



Rates of dielectric failures in GIS.



Main components involved in failures

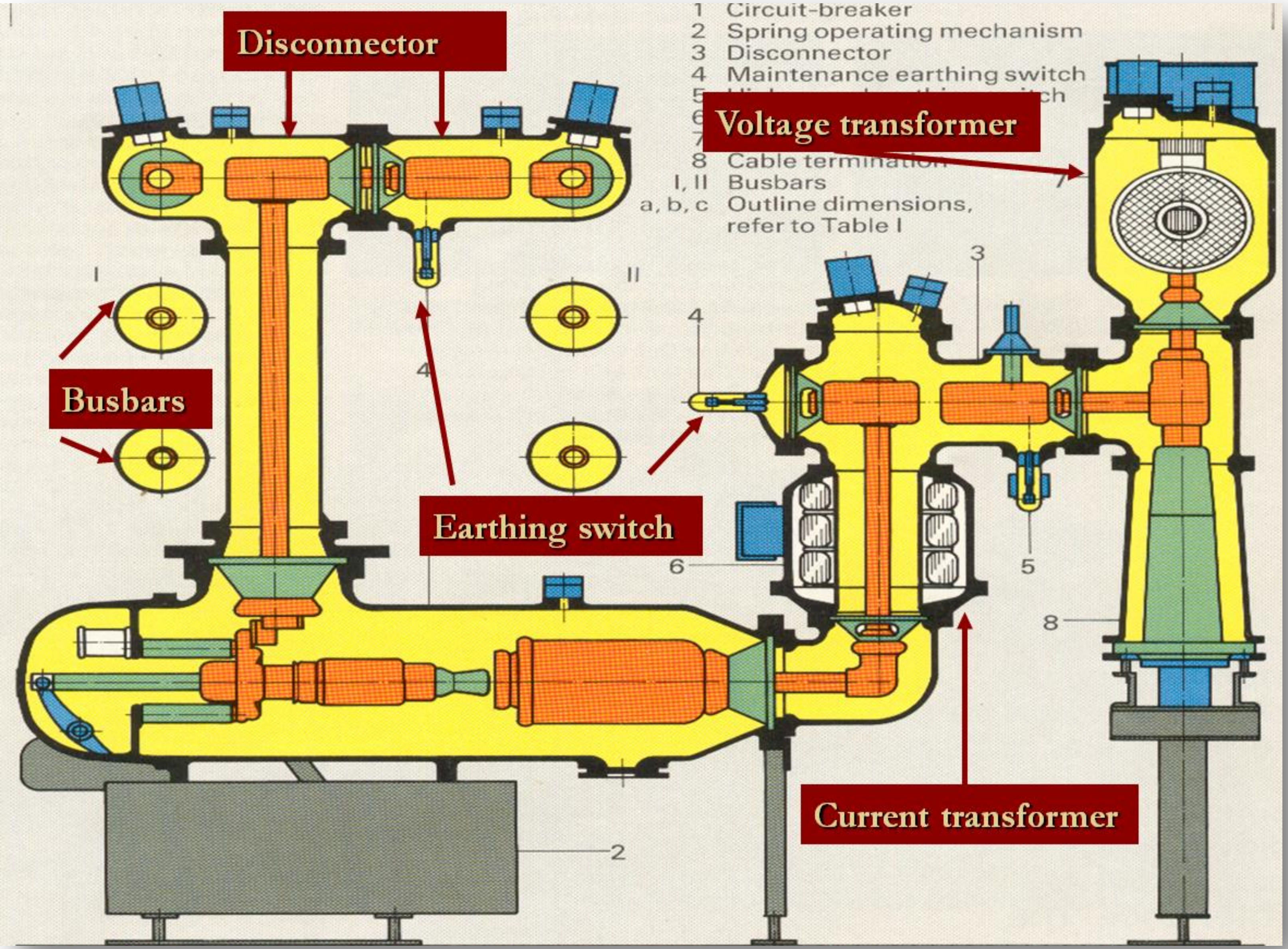
Various Components of GIS

- As in Air Insulated Substation, GIS also has:
  - Circuit Breakers
  - Busbars
  - Connectors
  - Dis-Connectors
  - Surge Arresters
  - Isolators and Load break switches
  - Current and Potential Transformers
  - Earth Switches
  - Bushings and terminations

Installation of GIS

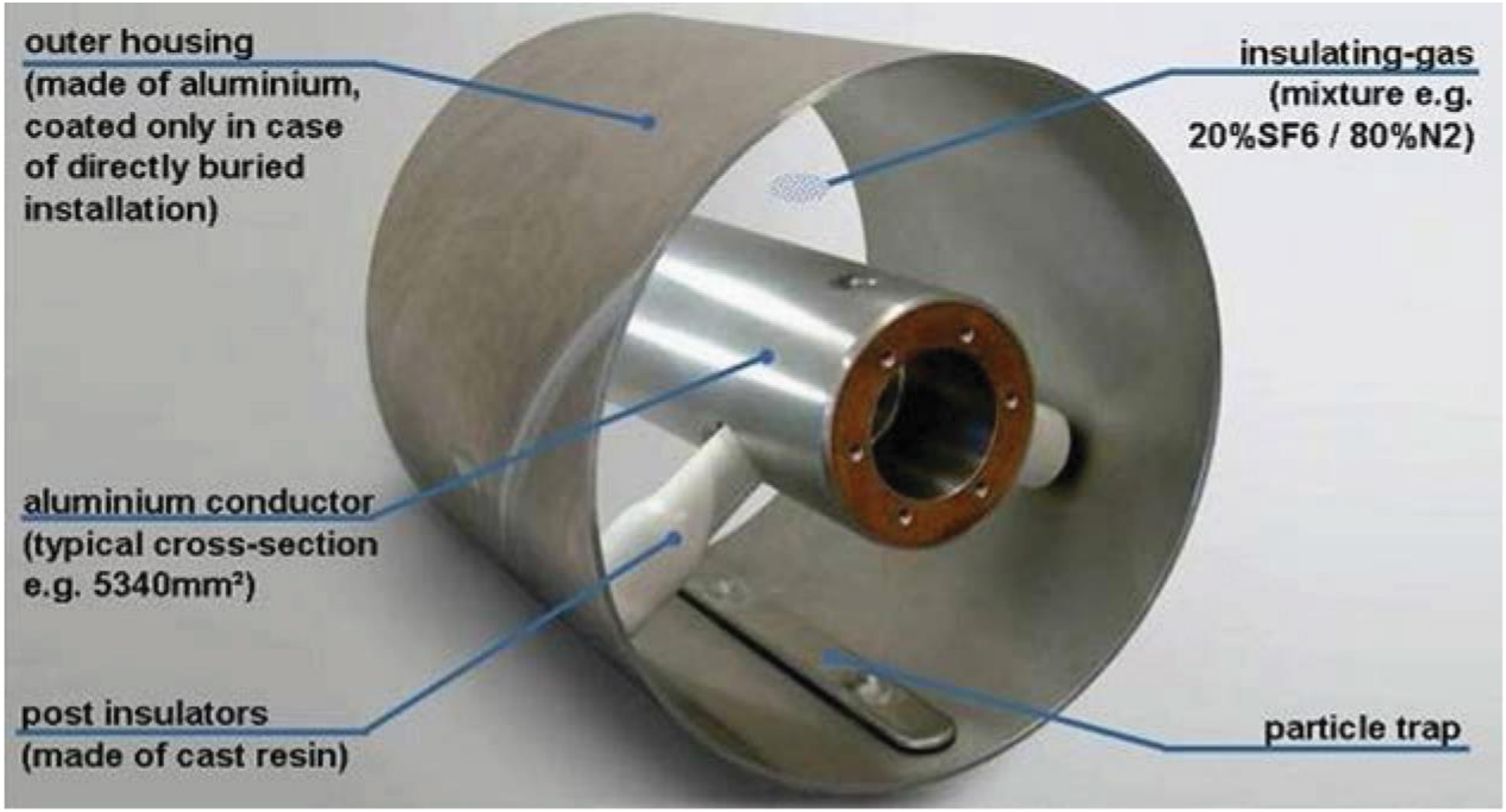
- The various modules of GIS are factory assembled and are filled with SF_6 gas at a pressure of about 3 kg/cm^2.
- Thereafter, they are taken to site for final assembly.
- Such substations are compact and can be installed conveniently on any floor of a multi-storied building or in an underground substation.
- As the units are factory assembled, the installation time is substantially reduced.
- Such installations are preferred in cosmopolitan cities, industrial townships, etc., where cost of land is very high and higher cost of SF_6 gas insulated switchgear (GIS) is justified by saving due to reduction in floor area requirement

GIS Assembly



Description of Gas Insulated Busduct (GIB)

- Compressed Gas Insulated Substations (GIS) basically consist of a conductor supported on insulator inside an enclosure which is filled with SF_6 gas.



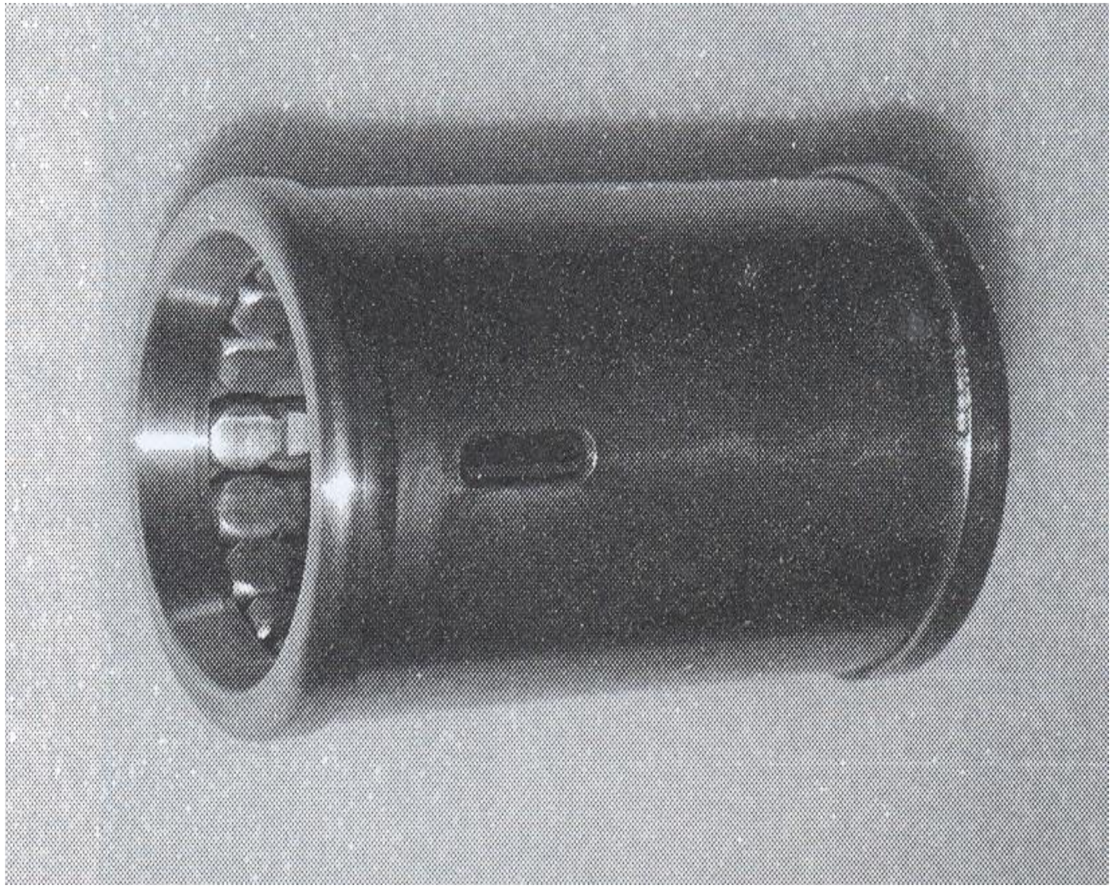
Busbar or Busduct

- Co-axial busbars are common in isolated-phase GIS as this configuration results in an optimal stress distribution

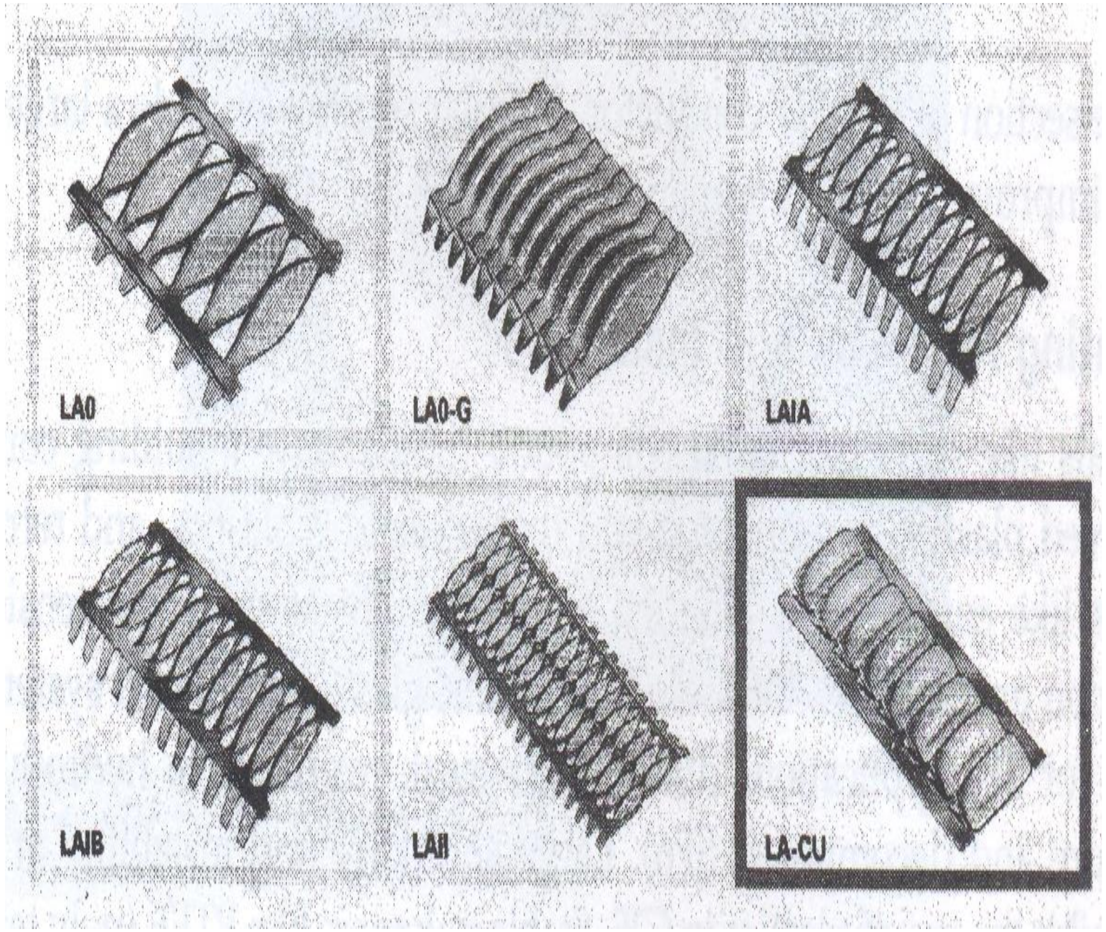
Connectors

➢ The high voltage electrical connections from one module to another in a GIS are carried out with the help of

Spring loaded fingers or bridge contacts and



Multi-lam contacts



Support Insulators

145 kV GIS

Rib-Type

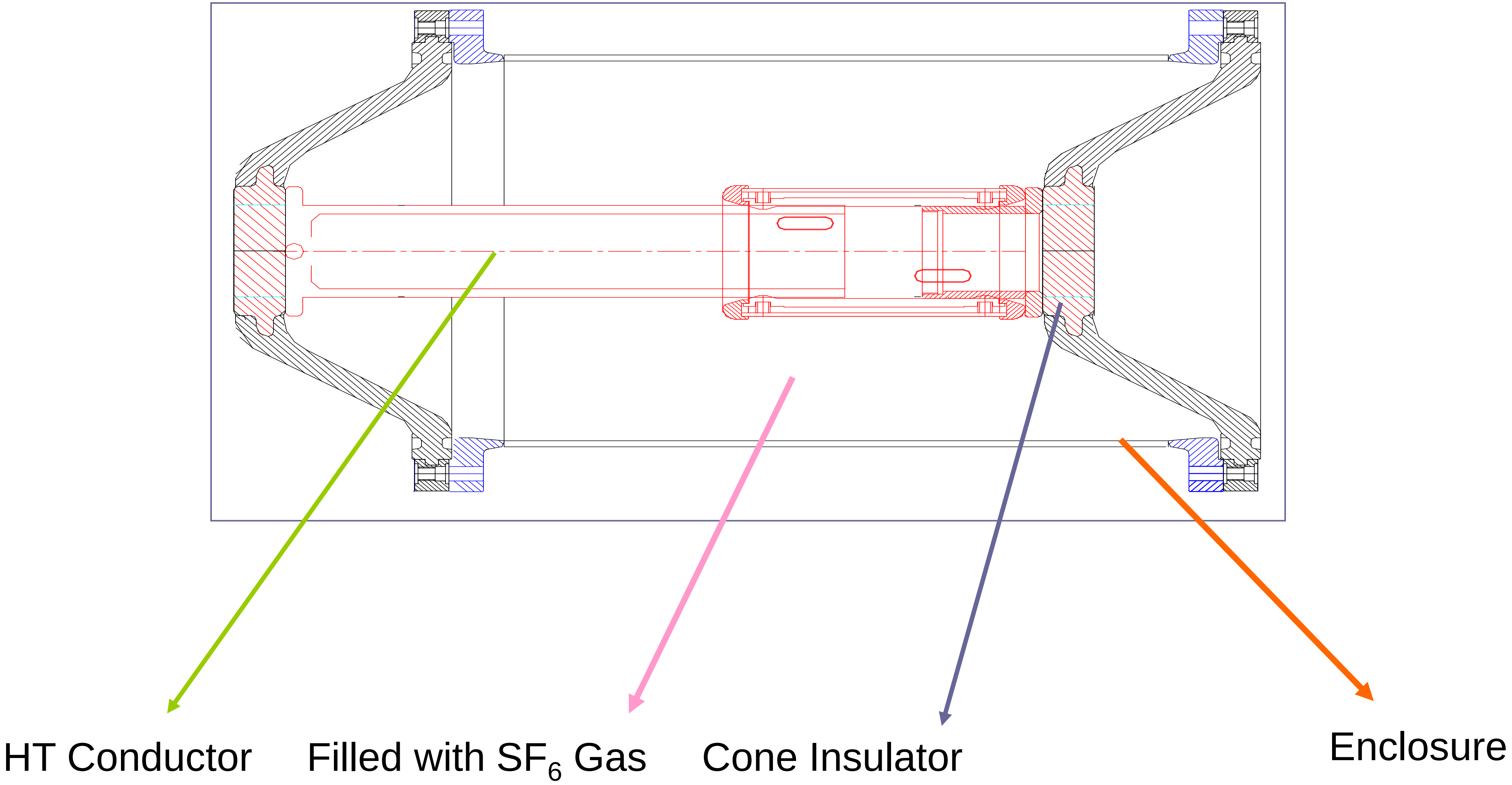
(145 kV GIS)

245 kV GIS

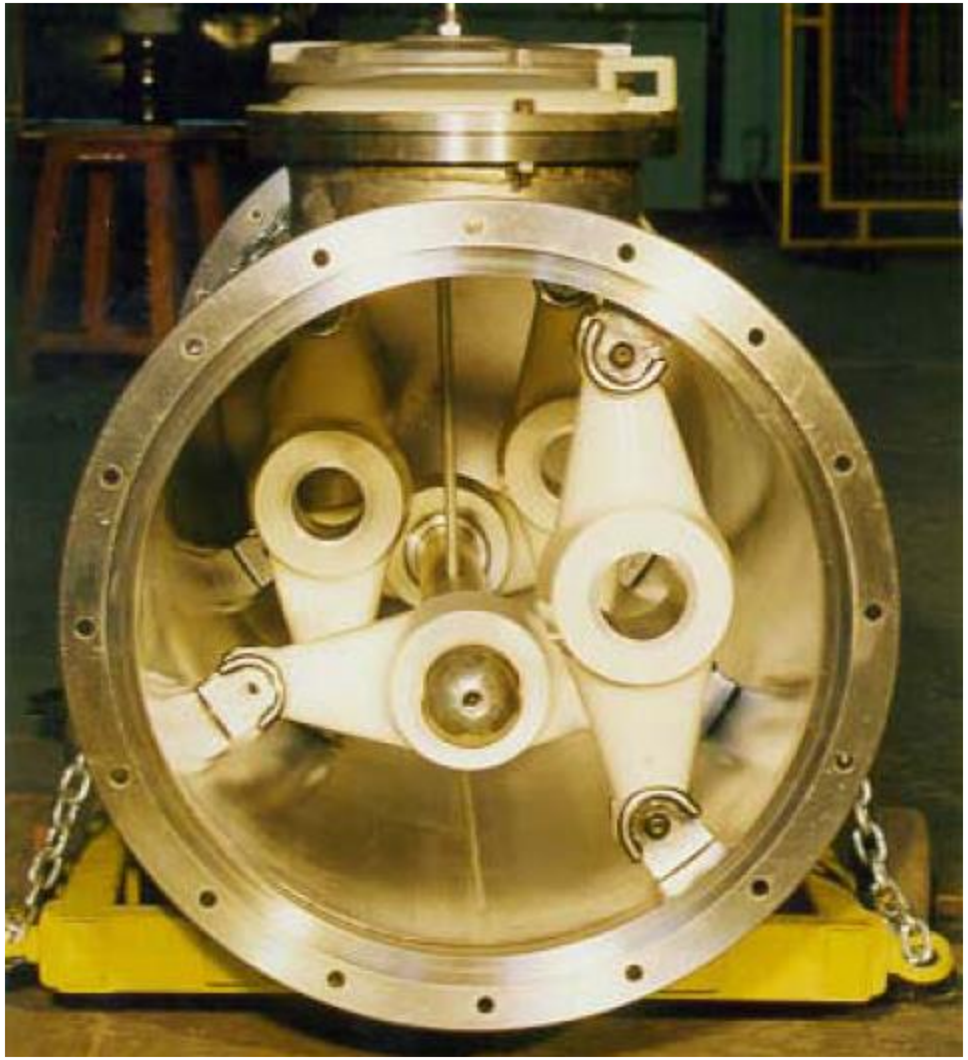
Essential Parts of GIS

- **CONDUCTORS**
  - They conduct the main circuit current and transfer power
  - These are of Copper and Aluminium tubes
  - Longitudinal lengthening or extension by plug in contacts
- **INSULATION**
  - Conductors need insulation above grounded enclosures and also phase to phase insulation.
  - Met by Cast Resin Support insulators and SF_6 gas insulation
- **ENCLOSURE**
  - Gas filled modules have nonmagnetic enclosures
  - They are made of Aluminium alloy or stainless steel

Cross section of a Bus Section



Three Phase Common Enclosure GIS



145 kV Gas Insulated Substation under Service

145 kV Underground GIS

145 kV GIS

230 kV Underground GIS

400 kV Underground GIS

550 kV GIS High performance ratings in a compact design

Rated voltage [kV]	420	550
Rated frequency [Hz]	50/60	50/60
Rated normal current [A]	5000	6300/5000
Rated short-time withstand current (up to 3 s) [kA]	63	63/80
Bay width [mm]	2160/2700	3120
Ambient temperature range [°C]		-30 ... +55

- High performance ratings up to 6300 A and 80 kA
- Less space required than comparable GIS systems
- Fully factory tested for short delivery and installation time
- Modular architecture permits flexibility and adaptation to changing needs
- IEC 61850 compatible control and monitoring

800 kV Extra high-voltage GIS

Rated voltage [kV]	800
Rated frequency [Hz]	50
Rated normal current – busbar / feeder [A]	6300/5000
Rated short-time withstand current (up to 3 s) [kA]	63
Bay width [mm]	9420
Ambient temperature range [°C]	-30 ... +40

- High performance ratings in a compact design 800 kV, 6300 A, 63 kA
- Reliable, well proven technology based on five decades of GIS experience
- Reduction amount of SF_6-gas up to 20 percent compared to previous designs
- Modular components enable maximum flexibility and customization in layout configuration
- Convenient operation and serviceability

1200 kV GIS - Ultra-high voltage applications

Rated voltage [kV]	1200
Rated frequency [Hz]	50
Rated normal current – busbar / feeder [A]	8000/5000
Rated short-time withstand current (up to 3 s) [kA]	63
Bay width [mm]	n/a
Ambient temperature range [°C]	-30 … +40

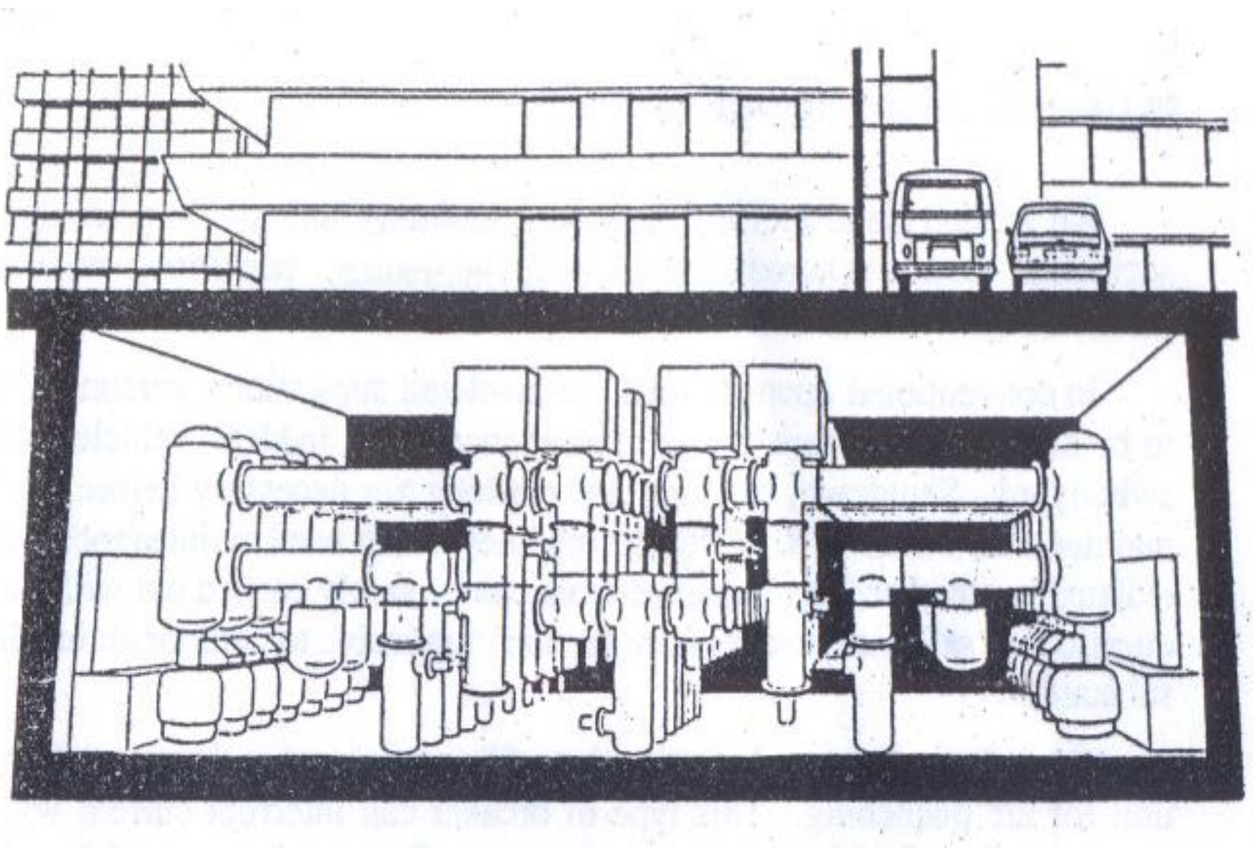
- High performance ratings in a compact design 1200 kV, 8000 A, 63 kA
- Reliable, well proven technology based on five decades of GIS experience
- Very large power plants
- Long range power transmission
- Convenient operation and serviceability
- Comprehensive experience and excellent performance in extra high voltage and UHV GIS technology
- Excellent design, test and service capabilities

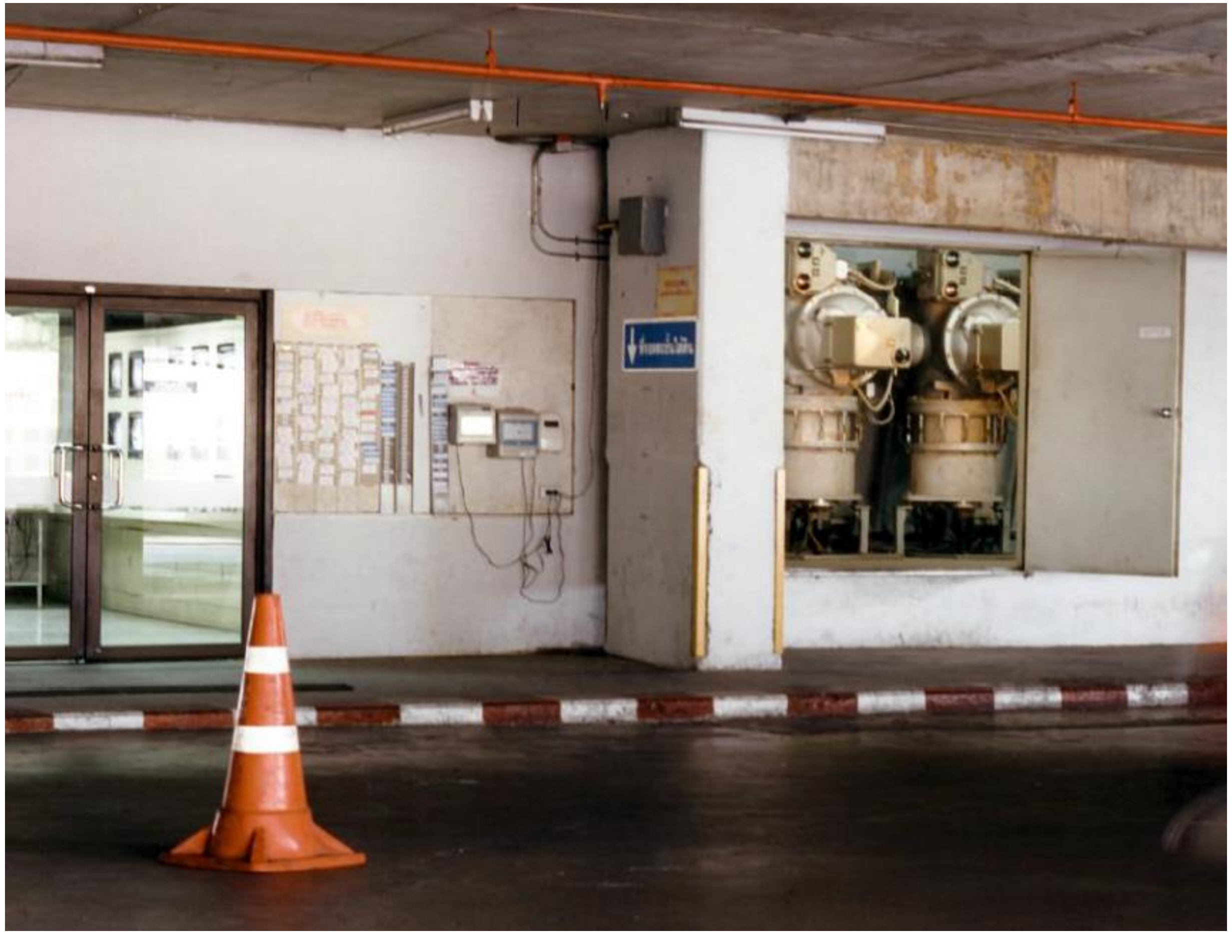
Modular GIS in prefabricated housing

Rated voltage [kV]	145	170	300	420
Rated frequency [Hz]				50/60
Rated lightning impulse withstand voltage (1.2/50 μs) [kV]	650	750	1050	1425
Rated normal current - busbar/feeder [A]	3150	4000	4000	5000

- Quick delivery and installation time for fast substation energization
- Reduced total system cost, project cost savings and on-site work
- Wide range of common circuit configurations
- Reduced project interfaces resulting in lower risks of delay
- Substantial space savings compared to conventionally built AIS substation
- Extended temperature range from -55 °C to +55 °C

GIS in the basement of a multi-storied building



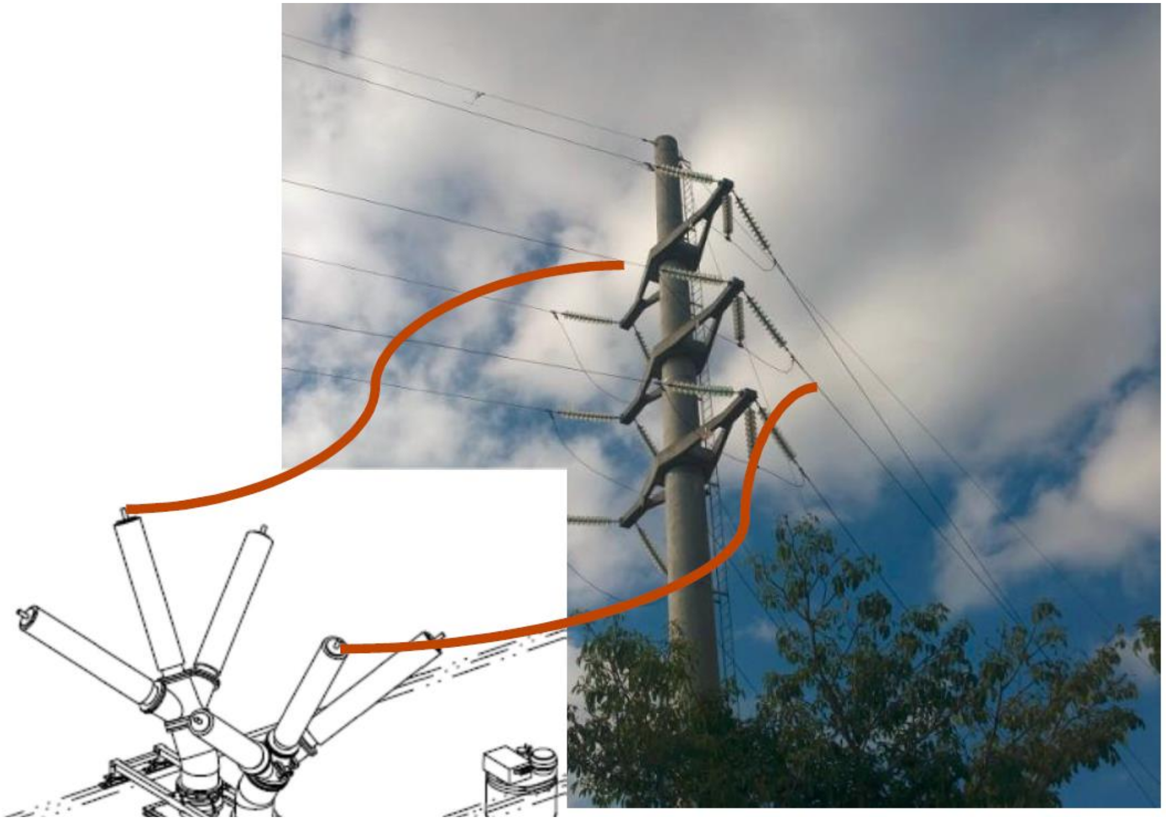


GIS Integration

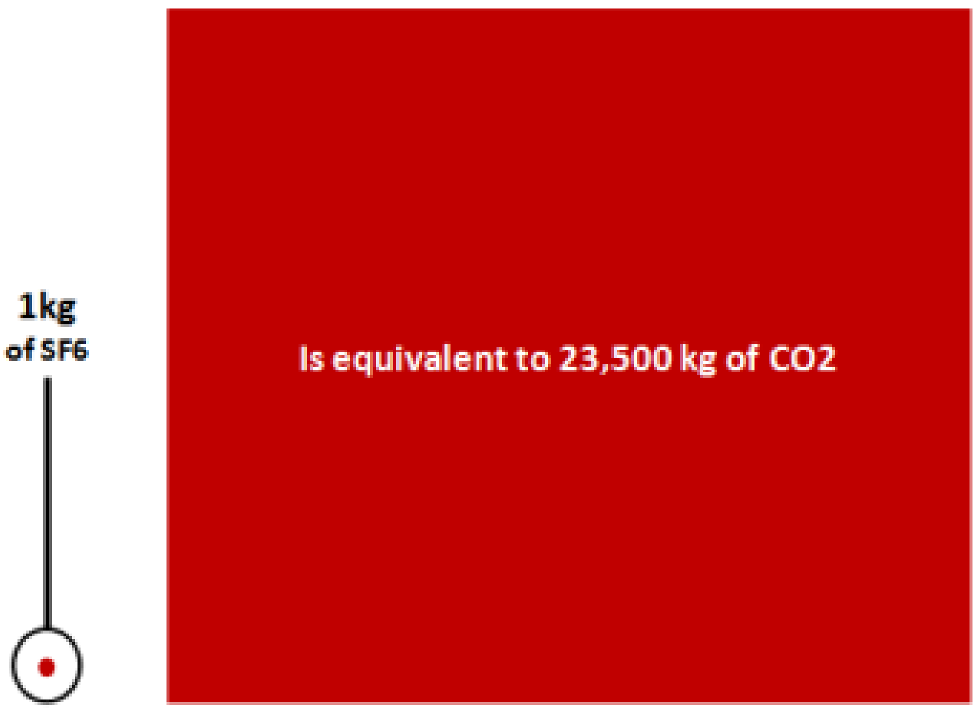
- The integrated GIS provide substantial reduction of installation time compared to conventional substations.
- It is the ideal solution for customers in need of substations that can be quickly energized for grid expansions, backup or emergency power needs, and for short installation time requirements.

- The integrated GIS package comes with all primary and secondary equipment including control, protection, monitoring and communication completely installed in the prefabricated housing.
- Due to its prefabricated design and short deployment time, it is ideal for applications in the oil, gas and mining industries where it can be easily transported to the sites.

Integrated GIS



Why should we worry about SF6



The global installed base of SF6 is expected to grow by

75%

by 2030

Annual global SF6 emissions are the equivalent to yearly CO2 emissions produced by approx.

100 million cars

The energy distribution industry is responsible for

80 %

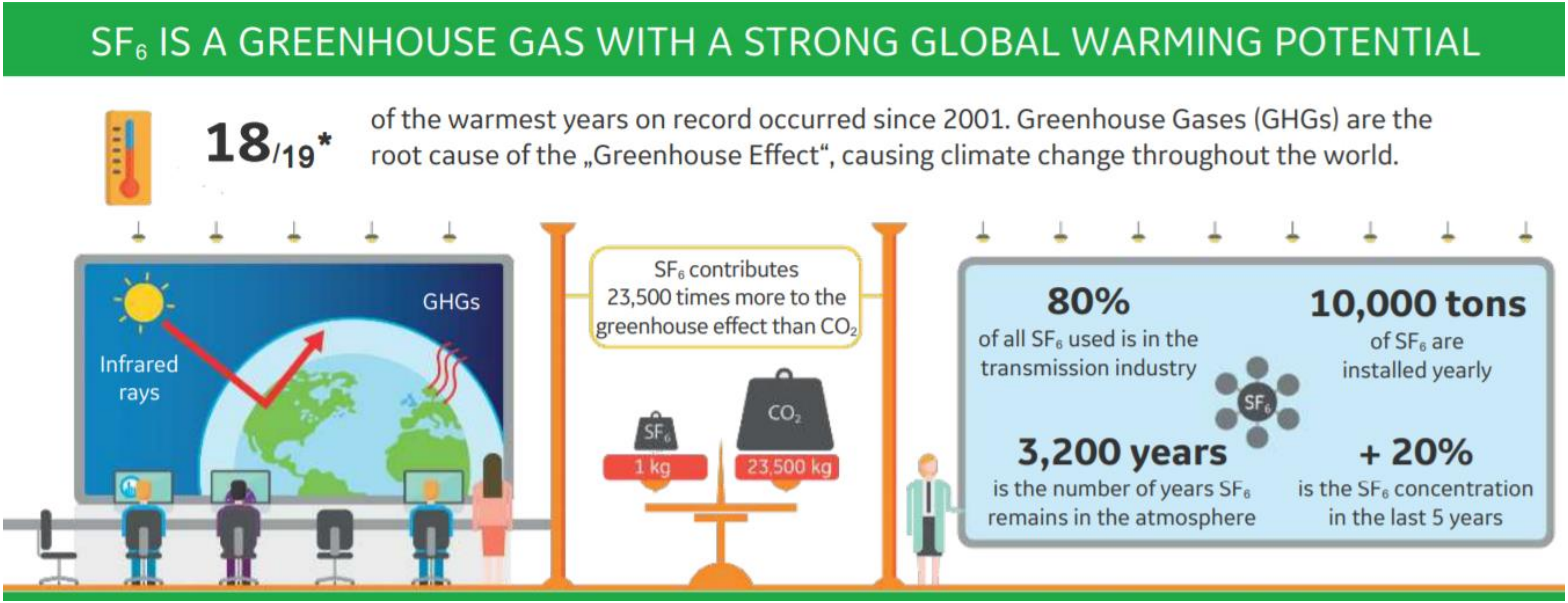
of SF6 emissions

Based on 5-year percentage change

Challenges in GIS: **The new gas mixture**

- Eco-efficient gas mixture, consisting of the three components:
  - Perfluoroketones (C5 PFK)
  - CO_2 or N_2
  - O_2
- The gas mixture has a very low green-house warming potential (GWP <1)
- Compared to SF_6-gas the CO_2 equivalent emissions of the new gas mixture is lower by 99.995%
- The new technology is deployed for the first time at a substation located in Oerlikon, Zurich, using a 170 kV GIS as a pilot installation for the leading Swiss utility, ewz

Challenges in GIS : Green GIS



Challenges in GIS : Green GIS

THE g^3 REVOLUTION

Replacing 1 kg of SF_6 with ~½ kg of g^3

=

Saving of

16 CARS

running one year (10,000 km each)

OR

Saving of

1 CAR

circling the Earth 4 times

g^3 products operate under the same ambient conditions and temperature ranges as state-of-the art SF_6 products. (-25°C and -30°C)

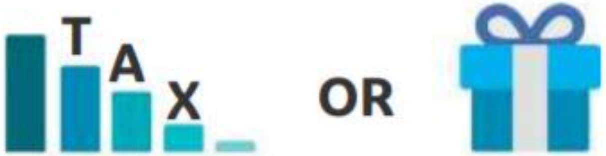
Same dimensions, same technical performance and safety with a drastically reduced impact of gas releases to atmosphere

Challenges in GIS : Green GIS

THE BENEFITS OF g^3 OVER SF_6

Environmental impact of g^3 vs SF_6

Utilities can **adopt best practices** in terms of environment sustainability



Utilities may qualify for **tax reduction or incentives** related to greenhouse gas emissions reduction

g3
green gas for grid

g^3 is a revolutionary gas for the electrical transmission industry, offering the same technical performances as SF_6 with an **environmental impact reduced by 98%**

g3 is an insulating gas mixture using NovecTM Dielectric Fluids from 3M

Eco-GIS: World's first eco-efficient GIS installation, Switzerland

- The 170/24 kV substation deploys the first breakthrough GIS with eco-efficient gas mixture with a global warming potential (GWP)* of less than 1 as an alternative to SF_6-gas
- The fluoroketone-based SF_6 alternative gas mixture is a chemical compound developed for switchgear applications in collaboration with 3M
- Potential to lower carbon dioxide (CO_2) equivalent emissions by up to 50 percent through the life-cycle of the equipment

* GWP specifies the extent to which a greenhouse gas contributes to the warming of the atmosphere

Tariff Methods

Dr.P.Janaki
Associate Professor,
Department of EEE,
LIET

Syllabus

- Costs of Generation
- Fixed, Semi-fixed and Running Costs.
- Desirable Characteristics of a Tariff Method.
- Tariff Methods:
  - Flat Rate,
  - Block-Rate,
  - two-part,
  - three –part and
  - power factor
- Numerical Problems

Introduction

- A power station is required to deliver power to a large number of consumers to meet their requirements.
- While designing and building a power station, efforts should be made to achieve overall economy so that the per unit cost of production is as low as possible.
- This will enable the electric supply company to sell electrical energy at a profit and ensure reliable service.
- The problem of determining the cost of production of electrical energy is highly complex and poses a challenge to power engineers.
- There are several factors which influence the production cost such as cost of land and equipment, depreciation of equipment, interest on capital investment etc.
- Therefore, a careful study has to be made to calculate the cost of production.

Economics of Power Generation

- The art of determining the per unit (i.e., one kWh) cost of production of electrical energy is known as economics of power generation.
- The economics of power generation has assumed a great importance in this fast developing power plant engineering.
- A consumer will use electric power only if it is supplied at reasonable rate.
- Therefore, power engineers have to find convenient methods to produce electric power as cheap as possible so that consumers are tempted to use electrical methods.
- Before passing on to the subject further, it is desirable that the readers get themselves acquainted with the following terms much used
- in the economics of power generation :

(i) Interest.

(ii) Depreciation.

Economics of Power Generation

(i) Interest.

- The cost of use of money is known as interest.
- A power station is constructed by investing a huge capital.
- This money is generally borrowed from banks or other financial institutions and the supply company has to pay the annual interest on this amount.
- Even if company has spent out of its reserve funds, the interest must be still allowed for, since this amount could have earned interest if deposited in a bank.
- Therefore, while calculating the cost of production of electrical energy, the interest payable on the capital investment must be included.
- The rate of interest depends upon market position and other factors, and may vary from 4% to 8% per annum.

Economics of Power Generation

(ii) Depreciation.

- The decrease in the value of the power plant equipment and building due to
- constant use is known as depreciation.
- If the power station equipment were to last for ever, then interest on the capital investment would have been the only charge to be made.
- However, in actual practice, every power station has a useful life ranging from fifty to sixty years.
- From the time the power station is installed, its equipment steadily deteriorates due to wear and tear so that there is a gradual reduction in the value of the plant.
- This reduction in the value of plant every year is known as annual depreciation.

Economics of Power Generation

- Due to depreciation the plant has to be replaced by the new one after its useful life.
- Therefore, suitable amount must be set aside every year so that by the time the plant retires, the collected amount by way of depreciation equals the cost of replacement.
- It becomes obvious that while determining the cost of production, annual depreciation charges must be included.
- There are several methods of finding the annual depreciation charges.

Cost of Electrical Energy

- The total cost of electrical energy generated can be divided into three parts.

  (i) Fixed cost

  (ii) Semi-fixed cost

  (iii) Running or operating cost.

(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 organisation, interest on capital cost of land and salaries of high officials.
- The annual expenditure on the central organisation 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.

Cost of Electrical Energy

(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.

Cost of Electrical Energy

(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.

Introduction

- The electrical energy produced by a power station is delivered to a large number of consumers.
- The consumers can be persuaded to use electrical energy if it is sold at reasonable rates.
- The tariff i.e., the rate at which electrical energy is sold naturally becomes attention inviting for electric supply company.
- The supply company has to ensure that the tariff is such that it not only recovers the total cost of producing electrical energy but also earns profit on the capital investment.
- However, the profit must be marginal particularly for a country like India where electric supply companies come under public sector and are always subject to criticism.

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 :
    - Recovery of cost of producing electrical energy at the power station.
    - Recovery of cost on the capital investment in transmission and distribution systems.
    - Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.
    - A suitable profit on the capital investment.

Desirable Characteristics of a Tariff

(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.

Desirable Characteristics of a Tariff

(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., no variable) should be charged at a lower rate than the one whose load conditions change appreciably from the ideal.

Desirable Characteristics of a Tariff

(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

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

- (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.

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.

Flat rate Tariff

Disadvantages

- (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.

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.

Block rate Tariff

- 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.

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.,

$$\text{Total charges} = \text{Rs}\,(b \times \text{kW} + c \times \text{kWh})$$

$$b = \text{charge per kW of maximum demand}$$

$$c = \text{charge per kWh of energy consumed}$$

- This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages & Disadvantages

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.

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 ratable 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.

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) k VA 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.

Power factor Tariff

(ii) Sliding scale tariff :

- This is also know 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.

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 $(a + b \times kW + c \times kWh)$
- 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.

Thank you
for your attention

Problem #1

A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100 per kW of maximum demand plus 10 paise per kWh, find the overall cost per kWh.

Solution.

$$\text{Units consumed/year} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$

$$= (200) \times (0{\cdot}4) \times 8760 = 7{,}00{,}800 \text{ kWh}$$

$$\text{Annual charges} = \text{Annual M.D. charges} + \text{Annual energy charges}$$

$$= \text{Rs} (100 \times 200 + 0{\cdot}1 \times 7{,}00{,}800)$$

$$= \text{Rs } 90{,}080$$

$$\therefore \quad \text{Overall cost/kWh} = \text{Rs } \frac{90{,}080}{7{,}00{,}800} = \text{Re } 0{\cdot}1285 = \mathbf{12{\cdot}85 \text{ paise}}$$

Problem #2

The maximum demand of a consumer is 20 A at 220 V and his total energy consumption is 8760 kWh. If the energy is charged at the rate of 20 paise per unit for 500 hours use of the maximum demand per annum plus 10 paise per unit for additional units, calculate : (i)annual bill (ii) equivalent flat rate.

Solution.

Assume the load factor and power factor to be unity.

$$\therefore \quad \text{Maximum demand} = \frac{220 \times 20 \times 1}{1000} = 4 \cdot 4 \text{ kW}$$

(*i*) $$\text{Units consumed in 500 hrs} = 4{\cdot}4 \times 500 = 2200 \text{ kWh}$$

$$\text{Charges for 2200 kWh} = \text{Rs } 0{\cdot}2 \times 2200 = \text{Rs } 440$$

$$\text{Remaining units} = 8760 - 2200 = 6560 \text{ kWh}$$

$$\text{Charges for 6560 kWh} = \text{Rs } 0{\cdot}1 \times 6560 = \text{Rs } 656$$

$$\therefore \quad \text{Total annual bill} = \text{Rs } (440 + 656) = \textbf{Rs. 1096}$$

(*ii*) $$\text{Equivalent flat rate} = \text{Rs } \frac{1096}{8760} = \text{Re } 0 \cdot 125 = \textbf{12.5 paise}$$

Problem #3

The following two tariffs are offered :

(a) Rs 100 plus 15 paise per unit ;

(b) A flat rate of 30 paise per unit ;

At what consumption is first tariff economical ?

Solution.

Let x be the number of units at which charges due to both tariffs become equal. Then,

$$100 + 0{\cdot}15x = 0{\cdot}3x$$

or $$0{\cdot}15x = 100$$

$\therefore$ $$x = 100/0{\cdot}15 = \mathbf{666{\cdot}67\ units}$$

Therefore, tariff (a) is economical if consumption is more than 666·67 units.

Problem #4

A supply is offered on the basis of fixed charges of Rs 30 per annum plus 3 paise per unit or alternatively, at the rate of 6 paise per unit for the first 400 units per annum and 5 paise per unit for all the additional units. Find the number of units taken per annum for which the cost under the two tariffs becomes the same.

Solution. Let x (> 400) be the number of units taken per annum for which the annual charges due to both tariffs become equal.

$$\text{Annual charges due to first tariff} = \text{Rs}\,(30 + 0{\cdot}03\,x)$$

$$\text{Annual charges due to second tariff} = \text{Rs}\,[(0{\cdot}06 \times 400) + (x - 400) \times 0{\cdot}05]$$

$$= \text{Rs}\,(4 + 0{\cdot}05\,x)$$

As the charges in both cases are equal,

$$\therefore \quad 30 + 0{\cdot}03\,x = 4 + 0{\cdot}05\,x$$

or

$$x = \frac{30 - 4}{0{\cdot}05 - 0{\cdot}03} = \textbf{1300 kWh}$$

Problem #5

An electric supply company having a maximum load of 50 MW generates 18×10^7 units per annum and the supply consumers have an aggregate demand of 75 MW. The annual expenses including capital charges are :

For fuel = Rs 90 lakhs

Fixed charges concerning generation = Rs 28 lakhs

Fixed charges concerning transmission and distribution = Rs 32 lakhs

Assuming 90% of the fuel cost is essential to running charges and the loss in transmission and distribution as 15% of kWh generated, deduce a two part tariff to find the actual cost of supply to the consumers.

Solution.

Annual fixed charges

$$\text{For generation} = \text{Rs } 28 \times 10^5$$

$$\text{For transmission and distribution} = \text{Rs } 32 \times 10^5$$

$$\text{For fuel (10\% only)} = \text{Rs } 0{\cdot}1 \times 90 \times 10^5 = \text{Rs } 9 \times 10^5$$

$$\text{Total annual fixed charge} = \text{Rs } (28 + 32 + 9) \times 10^5 = \text{Rs } 69 \times 10^5$$

This cost has to be spread over the aggregate maximum demand of all the consumers *i.e.*, 75 MW.

$$\therefore \quad \text{Cost per kW of maximum demand} = \text{Rs}\,\frac{69 \times 10^5}{75 \times 10^3} = \textbf{Rs. 92}$$

Annual running charges.

$$\text{Cost of fuel (90\%)} = \text{Rs}\;0{\cdot}9 \times 90 \times 10^5 = \text{Rs}\;81 \times 10^5$$

$$\text{Units delivered to consumers} = 85\% \text{ of units generated}$$

$$= 0{\cdot}85 \times 18 \times 10^7 = 15{\cdot}3 \times 10^7 \text{ kWh}$$

This cost is to be spread over the units delivered to the consumers.

$$\therefore \quad \text{Cost/kWh} = \text{Rs}\,\frac{81 \times 10^5}{15 \cdot 3 \times 10^7} = \text{Re}\;0 \cdot 053 = \textbf{5.3 paise}$$

∴ Tariff is Rs 92 per kW of maximum demand plus 5·3 paise per kWh.

Problem #6

A generating station has a maximum demand of 75 MW and a yearly load factor of 40%. Generating costs inclusive of station capital costs are Rs. 60 per annum per kW demand plus 4 paise per kWh transmitted. The annual capital charges for transmission system are Rs 20,00,000 and for distribution system Rs 15,00,000 ; the respective diversity factors being 1·2 and 1·25. The efficiency of transmission system is 90% and that of the distribution system inclusive of substation losses is 85%. Find the yearly cost per kW demand and cost per kWh supplied : (i) at the substation (ii) at the consumers premises.

Solution.

$$\text{Maximum demand} = 75 \text{ MW} = 75{,}000 \text{ kW}$$

$$\text{Annual load factor} = 40\% = 0{\cdot}4$$

(*i*) **Cost at substation.** The cost per kW of maximum demand is to be determined from the total annual fixed charges associated with the supply of energy at the substation. The cost per kWh shall be determined from the running charges.

(*a*) **Annual fixed charges**

$$\text{Generation cost} = \text{Rs } 60 \times 75 \times 10^3 = \text{Rs } 4{\cdot}5 \times 10^6$$

$$\text{Transmission cost} = \text{Rs } 2 \times 10^6$$

Total annual fixed charges at the substation

$$= \text{Rs } (4{\cdot}5 + 2) \times 10^6 = \text{Rs } 6{\cdot}5 \times 10^6$$

Aggregate of all maximum demands by the various substations

$$= \text{Max. demand on generating station} \times \text{Diversity factor}$$

$$= (75 \times 10^3) \times 1{\cdot}2 = 90 \times 10^3 \text{ kW}$$

The total annual fixed charges have to be spread over the aggregate maximum demands by various substations *i.e.*, 90×10^3 kW.

Annual cost per kW of maximum demand

$$= \text{Rs } \frac{6 \cdot 5 \times 10^6}{90 \times 10^3} = \textbf{Rs. 72.22}$$

(*b*) **Running Charges.** It is given that cost of 1 kWh transmitted to substation is 4 paise. As the transmission efficiency is 90%, therefore, for every kWh transmitted, 0·9 kWh reaches the substation.

$$\therefore \quad \text{Cost/kWh at substation} = 4/0{\cdot}9 = \textbf{4·45 paise}$$

Hence at sub-station, the cost is Rs 72·22 per annum per kW maximum demand plus 4·45 paise per kWh.

(*ii*) **Cost at consumer's premises.** The total annual fixed charges at consumer's premises is the sum of annual fixed charges at substation (*i.e.* Rs $6{\cdot}5 \times 10^6$) and annual fixed charge for distribution (*i.e.*, Rs $1{\cdot}5 \times 10^6$).

$\therefore$ Total annual fixed charges at consumer's premises

$$= \text{Rs}\,(6{\cdot}5 + 1{\cdot}5) \times 10^6 = \text{Rs}\,8 \times 10^6$$

Aggregate of maximum demands of all consumers

$$= \text{Max. demand on Substation} \times \text{Diversity factor}$$

$$= (90 \times 10^3) \times 1{\cdot}25 = 112{\cdot}5 \times 10^3 \text{ kW}$$

$\therefore$ Annual cost per kW of maximum demand

$$= \text{Rs}\,\frac{8 \times 10^6}{112{\cdot}5 \times 10^3} = \textbf{Rs. 71.11}$$

As the distribution efficiency is 85%, therefore, for each kWh delivered from substation, only 0·85 kWh reaches the consumer's premises.

$\therefore$ Cost per kWh at consumer's premises

$$= \frac{\text{Cost per kWh at substation}}{0{\cdot}85} = \frac{4{\cdot}45}{0{\cdot}85} = \textbf{5.23 paise}$$

Hence at consumer's premises, the cost is **Rs. 71·11** per annum per kW maximum demand plus **5·23 paise** per kWh.

Example 5.7. *Determine the load factor at which the cost of supplying a unit of electricity from a Diesel and from a steam station is the same if the annual fixed and running charges are as follows :*

Station	*Fixed charges*	*Running charges*
Diesel	*Rs 300 per kW*	*25 paise/kWh*
Steam	*Rs 1200 per kW*	*6·25 paise/kWh*

Solution. Suppose energy supplied in one year is 100 units *i.e.*, 100 kWh. Let L be the load factor at which the cost of supplying a unit of electricity is the same for diesel and steam station.

Diesel Station.

$$\text{Average power} = \frac{100 \text{ kWh}}{8760 \text{ hrs}} = 0{\cdot}0114 \text{ kW}$$

$$\text{Maximum demand} = \frac{0{\cdot}0114}{L} \text{ kW}$$

$$\text{Fixed charges} = \text{Rs } 300 \times \frac{0{\cdot}0114}{L} = \text{Rs } \frac{3{\cdot}42}{L}$$

$$\text{Running charges} = \text{Rs } 100 \times 0{\cdot}25 = \text{Rs } 25$$

$\therefore$ Fixed and running charges for 100 kWh

$$= \text{Rs} \left(\frac{3{\cdot}42}{L} + 25 \right) \qquad \ldots (i)$$

Steam station.

$$\text{Fixed charges} = \text{Rs } 1200 \times \frac{0 \cdot 0114}{L} = \text{Rs } \frac{13 \cdot 68}{L}$$

$$\text{Running charges} = \text{Rs } 100 \times 0 \cdot 0625 = \text{Rs } 6 \cdot 25$$

∴ Fixed and running charges for 100 kWh

$$= \text{Rs}\left(\frac{13 \cdot 68}{L} + 6 \cdot 25\right) \qquad \text{... }(ii)$$

As the two charges are same, therefore, equating exps. (*i*) and (*ii*), we get,

$$\frac{3 \cdot 42}{L} + 25 = \frac{13 \cdot 68}{L} + 6 \cdot 25$$

or

$$\frac{10 \cdot 26}{L} = 18 \cdot 75$$

∴

$$L = 10 \cdot 26 / 18 \cdot 75 = 0 \cdot 5472 = \mathbf{54 \cdot 72\%}$$

Calculate annual bill of a consumer whose maximum demand is 100 kW, p. f. = 0·8 lagging and load factor = 60%. The tariff used is Rs 75 per kVA of maximum demand plus 15 paise per kWh consumed.

Solution.

$$\text{Units consumed/year} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$

$$= (100) \times (0{\cdot}6) \times (8760)\ \text{kWh}$$

$$= 5{\cdot}256 \times 10^5\ \text{kWh}$$

$$\text{Max. demand in kVA} = 100/\text{p.f.} = 100/0{\cdot}8 = 125$$

$$\text{Annual bill} = \text{Max. demand charges} + \text{Energy charges}$$

$$= \text{Rs } 75 \times 125 + \text{Rs } 0{\cdot}15 \times 5{\cdot}256 \times 10^5$$

$$= \text{Rs } 9375 + \text{Rs } 78{,}840 = \text{Rs } 88{,}215$$

A factory has a maximum load of 240 kW at 0·8 p.f. lagging with an annual consumption of 50,000 units. The tariff is Rs 50 per kVA of maximum demand plus 10 paise per unit. Calculate the flat rate of energy consumption. What will be annual saving if p. f. is raised to unity?

Solution.

Maximum demand in kVA at a p.f. of 0·8

$$= 240/0{\cdot}8 = 300$$

$$\therefore \quad \text{Annual bill} = \text{Demand charges} + \text{Energy charges}$$

$$= \text{Rs } 50 \times 300 + \text{Rs } 0{\cdot}1 \times 50{,}000$$

$$= \text{Rs } 15{,}000 + \text{Rs } 5000 = \text{Rs } 20{,}000$$

$$\therefore \quad \text{Flat rate/unit} = \text{Rs } \frac{20{,}000}{50{,}000} = \text{Rs } 0 \cdot 40 = \mathbf{40 \text{ paise}}$$

When p.f. is raised to unity, the maximum demand in kVA

$$= 240/1 = 240$$

$$\text{Annual bill} = \text{Rs } 50 \times 240 + \text{Rs } 0{\cdot}1 \times 50{,}000$$

$$= \text{Rs } 12{,}000 + \text{Rs } 5{,}000 = \text{Rs } 17{,}000$$

$$\text{Annual saving} = \text{Rs } (20{,}000 - 17{,}000) = \mathbf{\text{Rs } 3000}$$

The monthly readings of a consumer's meter are as follows :

Maximum demand = 50 kW

Energy consumed = 36,000 kWh

Reactive energy = 23,400 kVAR

If the tariff is Rs 80 per kW of maximum demand plus 8 paise per unit plus 0·5 paise per unit for each 1% of power factor below 86%, calculate the monthly bill of the consumer.

Solution.

$$\text{Average load} = \frac{36{,}000}{24 \times 30} = 50 \text{ kW}$$

$$\text{Average reactive power} = \frac{23{,}400}{24 \times 30} = 32 \cdot 5 \text{ kVAR}$$

Suppose ϕ is the power factor angle.

$$\therefore \quad \tan\phi = \frac{\text{kVAR}}{\text{Active power}} = \frac{32 \cdot 5}{50} = 0 \cdot 65$$

$$\text{or} \quad \phi = \tan^{-1}(0{\cdot}65) = 33{\cdot}02°$$

$$\therefore \quad \text{Power factor,} \quad \cos\phi = \cos 33{\cdot}02° = 0{\cdot}8384$$

$$\text{Power factor surcharge} = \text{Rs}\,\frac{36{,}000 \times 0 \cdot 5}{100}(86 - 83 \cdot 84) = \text{Rs } 388 \cdot 8$$

$$\text{Monthly bill} = \text{Rs}\,(80 \times 50 + 0{\cdot}08 \times 36{,}000 + 388{\cdot}8)$$

$$= \text{Rs}\,(4000 + 2880 + 388{\cdot}8) = \textbf{Rs 7268·8}$$

The tariff in force is Rs 150 per kVA of maximum demand and 8 paise per unit consumed. If the load factor is 30%, find the overall cost per unit at (i) unity p. f. and (ii) 0·7 p. f.

Solution. Suppose the maximum demand is 1 kVA.

(*i*) *When p.f. is unity*

$$\text{Max. demand charge/unit} = \frac{150 \times 100}{8760 \times 0 \cdot 30} = 5 \cdot 7 \text{ paise}$$

$$\text{Energy charge/unit} = 8 \text{ paise}$$

$$\text{Overall cost/unit} = 5 \cdot 7 + 8 = \mathbf{13 \cdot 7 \text{ paise}}$$

(*ii*) *When p.f. is 0·7*

$$\text{Max. demand charge/unit} = \frac{150 \times 100}{8760 \times 0 \cdot 30 \times 0 \cdot 7} = 8 \cdot 15 \text{ paise}$$

$$\text{Energy charge/unit} = 8 \text{ paise}$$

$$\text{Overall cost/unit} = 8 \cdot 15 + 8 = \mathbf{16 \cdot 15 \text{ paise}}$$

Two systems of tariff are available for a factory working 8 hours a day for 300 working days in a year.
(i) High-voltage supply at 5 paise per unit plus Rs 4·50 per month per kVA of maximum demand.
(ii) Low-voltage supply at Rs 5 per month per kVA of maximum demand plus 5·5 paise per unit.
The factory has an average load of 200 kW at 0·8 p.f. and a maximum demand of 250 kW at the same p.f. The high voltage equipment costs Rs 50 per kVA and the losses can be taken as 4%. Interest and depreciation charges are 12%. Calculate the difference in the annual costs between the two systems.

Solution.

(i) High voltage supply

Max. demand in kVA $= 250/0{\cdot}8 = 312{\cdot}5$

As the losses in *h.v.* equipment are 4%, therefore, capacity of *h.v.* equipment

$= 312{\cdot}5/0{\cdot}96 = 325{\cdot}5$ kVA

Capital investment on *h.v.* equipment

$= \text{Rs } 50 \times 325{\cdot}5 = \text{Rs } 16{,}275$

Annual interest and depreciation $= \text{Rs } 16{,}275 \times 0{\cdot}12 = \text{Rs } 1953$

Annual charge due to maximum kVA demand

$= \text{Rs } 325{\cdot}5 \times 4{\cdot}5 \times 12 = \text{Rs } 17{,}577$

$$\text{Units consumed/year} = \frac{200 \times 8 \times 300}{0 \cdot 96} = 5 \times 10^5 \text{ kWh}$$

Annual charge due to kWh consumption

$= \text{Rs } 0{\cdot}05 \times 5 \times 10^5 = \text{Rs } 25{,}000$

Total annual cost $= \text{Rs } (1953 + 17{,}577 + 25{,}000) = \text{Rs } 44{,}530$

(*ii*) **Low voltage supply.** There is no loss of energy as no equipment is used.

$$\text{Max. demand in kVA} = 250/0{\cdot}8 = 312{\cdot}5$$

Annual charge due to maximum kVA demand

$$= \text{Rs } 312{\cdot}5 \times 5 \times 12 = \text{Rs } 18{,}750$$

$$\text{Units consumed/year} = 200 \times 8 \times 300 = 48 \times 10^4 \text{ kWh}$$

Annual charge due to kWh consumption

$$= \text{Rs } 0{\cdot}055 \times 48 \times 10^4 = \text{Rs } 26{,}400$$

$$\text{Total annual cost} = \text{Rs } (18{,}750 + 26{,}400) = \text{Rs } 45{,}150$$

Difference in the annual costs of two systems

$$= \text{Rs } (45{,}150 - 44{,}530) = \textbf{Rs 620}$$

Hence, high-voltage supply is cheaper than low-voltage supply by Rs 620.

A generating station has two 1000 kW diesel generator sets. The load is *estimated to reach a maximum demand of 2500 kW after two years with an increase of 5.5 ×106 units over the present value. To meet this demand, the following two alternatives are available :*

(i) Purchasing one more set of 1000 kW at Rs 400 per kW. The annual interest and depreciation of the new set are 10% of the capital investment. The cost of generation for the station

is Rs 75 per kW maximum demand plus 5 paise per kWh.

(ii) Purchasing bulk power from a grid supply at Rs 120 per kW maximum demand plus 3 paise per kWh.

Find which alternative in cheaper and by how much ?

Solution.

In order to determine the cheaper alternative, we shall find the annual cost in each case.

(i) Purchasing diesel set

$$\text{Capital cost of set} = \text{Rs } 400 \times 1000 = \text{Rs } 4{,}00{,}000$$

Annual interest and depreciation on capital investment

$$= \text{Rs } 4{,}00{,}000 \times 0{\cdot}1 = \text{Rs } 40{,}000$$

The present capacity of the station is 2000 kW and the expected maximum demand after two years is 2500 kW. Therefore, extra power to be generated is

$$= 2500 - 2000 = 500 \text{ kW}$$

Annual charge due to extra kW max. demand

$$= \text{Rs } 500 \times 75 = \text{Rs } 37{,}500$$

Annual charge due to extra kWh consumption

$$= \text{Rs } 0{\cdot}05 \times 5{\cdot}5 \times 10^6 = \text{Rs } 2{,}75{,}000$$

$$\text{Total annual cost} = \text{Rs } (40{,}000 + 37{,}500 + 2{,}75{,}000)$$

$$= \text{Rs } 3{,}52{,}500$$

(*ii*) Purchasing from grid supply

Annual charge due to extra kW max. demand

$$= \text{Rs } 500 \times 120 = \text{Rs } 60{,}000$$

Annual charge due to extra kWh consumption

$$= \text{Rs } 0{\cdot}03 \times 5{\cdot}5 \times 10^6 = \text{Rs } 1{,}65{,}000$$

$$\text{Total annual cost} = \text{Rs } (60{,}000 + 1{,}65{,}000) = \text{Rs } 2{,}25{,}000$$

Hence alternative (*ii*) is cheaper by 3,52,500 – 2,25,000 = **Rs 1,27,500 per annum**

A supply company offers the following alternate tariffs for supply to a factory :
(i) H.V. supply at Rs 70 per kVA per annum plus 3 paise per kWh.
(ii) L.V. supply at Rs 65 per kVA per annum plus 4 paise per kWh.

The cost of transformers and switchgears for H.V. supply is Rs 50 per kVA and full transformation losses are 2%. The annual fixed charges on the capital cost of H.V. plant are 15%. If the factory runs for 6 hours a day, find the number of days above which the factory should be run so that the H.V. supply is cheaper.

Solution.

Let x = Factory load in kW

y = No. of working days above which H.V. supply is cheaper

(*i*) **H. V. Supply.** Assume the power factor of the load to be unity. As the transformation losses are 2%,

$\therefore$ Rating of transformer and switchgear $= x/0{\cdot}98$ kVA

Energy consumed per annum $= (x/0{\cdot}98) \times y \times 6 = 6{\cdot}12\, xy$ kWh

Annual fixed charges of H. V. supply due to kVA demand

$= \text{Rs } 70 \times x/0{\cdot}98 = \text{Rs. } 71{\cdot}42x$

Cost of transformer and switchgear $= \text{Rs } 50 \times x/0{\cdot}98 = \text{Rs } 51x$

Annual fixed charges of transformer and switchgear

= 15% cost of transformer and switchgear

$= 0{\cdot}15 \times 51x = \text{Rs } 7{\cdot}65\, x$

Total annual fixed charges of H. V. supply $= \text{Rs } (71{\cdot}42\, x + 7{\cdot}65\, x) = \text{Rs } 79{\cdot}07\, x$

Total annual running charges of H. V. supply $= \text{Rs } 6{\cdot}12\, xy \times 0{\cdot}03 = \text{Rs } 0{\cdot}1836\, xy$

Total annual charges of H.V. supply = Rs (79·07 *x* + 0·1836 *xy*) ... (*i*)

(*ii*) L. V. Supply

$$\text{Energy consumed per annum} = x \times y \times 6 = 6\,xy \text{ kWh}$$

$$\text{Annual fixed charges of L. V. supply} = \text{Rs } 65\,x$$

$$\text{Annual running charges of L. V. supply} = \text{Rs } 0{\cdot}04 \times 6\,xy = \text{Rs } 0{\cdot}24\,xy$$

$$\text{Total annual charges of L. V. supply} = \text{Rs } (65\,x + 0{\cdot}24\,xy) \qquad \ldots(ii)$$

The two tariffs will give equal annual cost if the factory is run for *y* days. Therefore, equating exp. (*i*) and exp. (*ii*), we get,

$$79{\cdot}07\,x + 0{\cdot}1836\,xy = 65\,x + 0{\cdot}24\,xy$$

or $$14{\cdot}07\,x = 0{\cdot}057\,xy$$

or $$y = \frac{14\cdot07}{0\cdot057} = \textbf{247 days}$$

i.e., if the factory is run for more than 247 days, then H. V. supply will be cheaper.

Thank you
for your attention