Unit-1: HYDRO ELECTRIC POWER PLANT

INTRODUCTION

Energy is the basic necessity for the economic development of a country. There is a close relationship between the energy used person and his standard of living. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people.

Energy exists in different forms in nature but the most important form is the electrical energy. The modern society is so much dependent upon the use of electrical energy that is has become a part and parcel of our life.

Importance of electrical power generation

The electrical power generation is important due to following reasons:

i. **Convenient form:** Electrical energy is a very convenient form of energy. It can be easily converted into other forms of energy like heat, light, mechanical energy, chemical energy, etc.
ii. **Easy control:** The electrically operated machines have simple and convenient starting, control and operation.
iii. **Greater flexibility:** Electrical energy offers greater flexibility and it can be easily transported from one place to another with the help of conductors.
iv. **Cheapness:** Electrical energy is much cheaper than other forms of energy. Thus it is overall economical to use electrical energy for domestic, commercial and industrial purposes.
v. **Cleanliness:** Electrical energy is not associated with smoke, fumes or poisonous gases. Hence it is non-polluting.
vi. **High transmission efficiency:** Electrical energy can be transmitted conveniently and efficiently from the centers of generation to the consumers with the help of transmission lines.

Various sources of energy available in nature

The different sources of energy available in nature are:

i. Water power
ii. Solid fuel (coal)
iii. Liquid fuel (diesel, petrol)
iv. Gaseous fuel (natural gas)
v. Nuclear power
vi. Solar power
vii. Wind power
viii. Tidal power
ix. Geo thermal power
x. Biomass/Biogas
xi. Ocean thermal
xii. Piezo electric
xiii. Thermo electric
xiv. Magneto hydro dynamic (MHD)

Conventional and Non-conventional sources of energy:

These sources can be classified into 2 categories, namely:

i. Conventional sources of energy
ii. Non-conventional sources of energy

Conventional sources:

Conventional sources of energy are the commonly used sources of energy. They include:

i. Water power or hydro power
ii. Solid fuel (coal)
iii. Liquid fuel (diesel, petrol)
iv. Gaseous fuel (natural gas)
v. Nuclear power

Non-conventional sources:

Non-conventional sources of energy are not so commonly used sources of energy. They include:

i. Solar power
ii. Wind power
iii. Geo thermal power
iv. Tidal power
v. Ocean thermal power
vi. Biogas/Biomass
vii. Piezo electric, thermo electric
viii. MHD etc

Renewable and Non-renewable sources of energy

The sources of energy available in nature can also be classified as:

i. Renewable sources of energy
ii. Non-renewable sources of energy

Renewable sources of energy: They are inexhaustible sources of energy and they are continuously replenished in nature.
Example: Water power, Solar, Wind, Geo thermal, Ocean thermal, etc.

Non-renewable sources of energy: They are exhaustible sources of energy. Once they are used they can't be replenished again.
Example: Solid fuel, Liquid fuel, Gaseous fuel, Nuclear power, etc.

Hydro electric power station:

A generating station which utilizes potential energy of water at a high level for the generation of electrical energy is known as Hydro Electric Power Station.

Factors to be considered for site selection on hydro electric power station:

Availability of water: The primary requirement of hydro power station is the availability of huge quantity of water. Therefore hydel power plants should be built at a place where adequate water is available at good head.

Storage of water: Water used in hydel plant is mainly dependent on rain. Since rainfall is not uniform throughout the year, it is essential to store water by constructing dam to supply continuous power. Therefore the site selected for hydro power station should provide adequate facilities for erecting dam and storage of water.

Head of water: To get high potential energy, the head of water should be high. So the site selected should provide sufficient water head.

Accessibility of site: The site selected for hydel plant should be accessible by rail and or road, so that necessary equipments and machines can be easily transported.

The site should have large catchment area.

The site should preferably have high mountains on the two sides of the dam constructed.

The land for the construction of plant should be available at low price.

The site selected should have less impact on the ecology by the construction of dam.

Classification of hydroelectric power plants:

1. **Based on the head of water:**
   i. *Low head power plant:*

The plant having head less than 30m is called as low head plant. In this type of plan, a small dam is built across the river to provide necessary head. There is no need for surge tank in this plant as the power house is located near the dam. The dam itself is designed to take the pressure created due to backflow of water. This plant uses either Kaplan turbine of Francis turbine.

ii. Medium head plant:

The plant in which the water head lies between 30m to300m is called as medium head power plant. An open channel brings the water from the main reservoir to the forebay from where penstock carries water to the turbines. In this power plant, the surge tank is not required as the forebay itself stores rejected water when the load on the turbine decreases. This plant uses either Kaplan or Francis turbine.

iii. High head plant:

The plants operating at water heads above 300m are called as high head power plants. In these plants, a large quantity of water is stored in the reservoir behind the dam. This stored water is brought to the surge tank by pressure channel and then to the power house using penstock. The surge tank attached to the penstock reduces the water hammer effect on the penstock. The power house has turbines, alternators, circuit breakers and other control devices. Generally Francis turbines are used for heads below 200m and Pelton wheel turbines for higher heads.

2. **Based on the plant capacity:**

Based on the capacity of plant hydro electric power station are classified as:

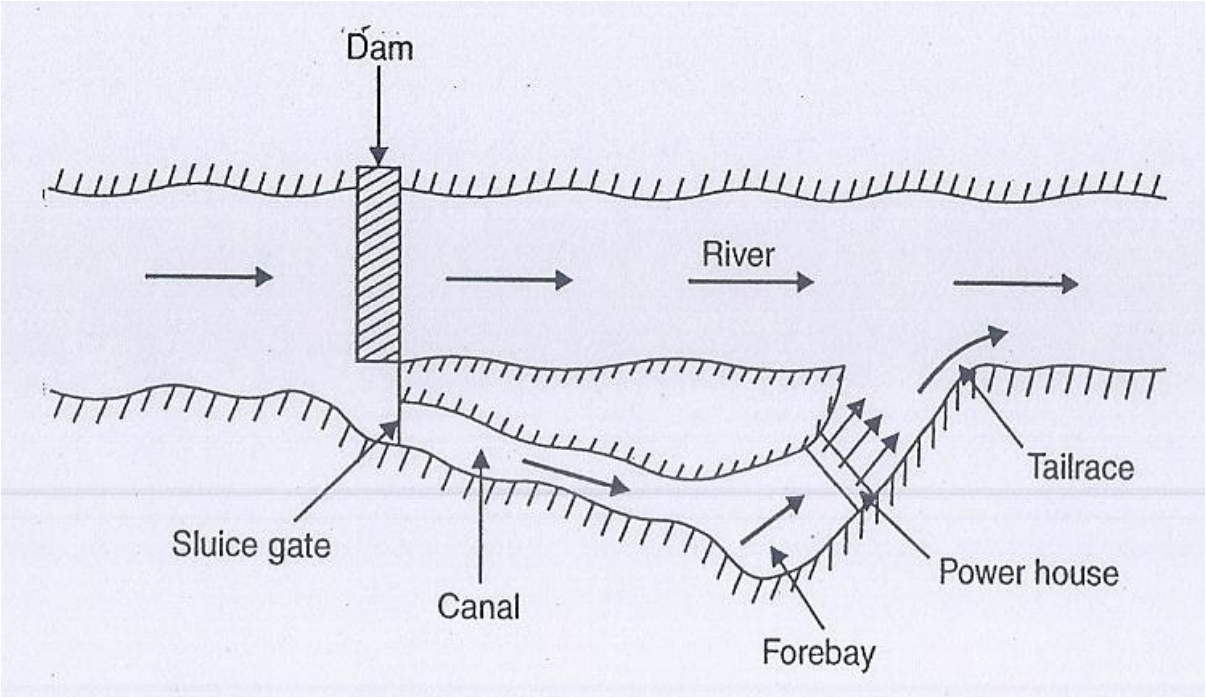
i. Very low capacity plant - up to 0.1MW
ii. Low capacity plant - 0.1 to 1.0MW
iii. Medium capacity plant - 1.0 to 10MW
iv. High capacity plant - above 10MW

Based on plant capacity, they are also classified as:

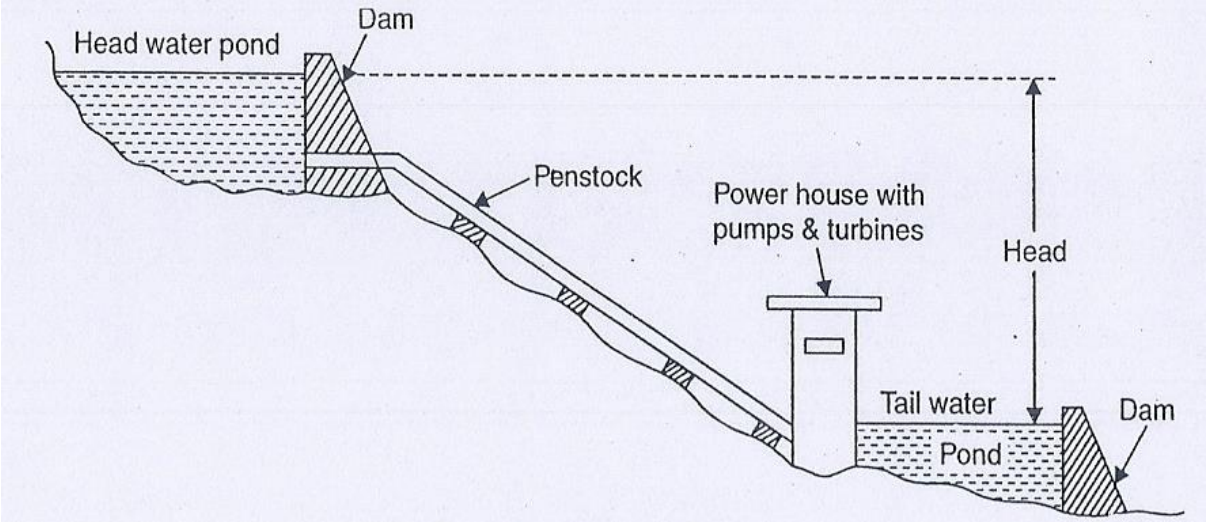
i. Micro hydro plant - less than 100KW
ii. Mini hydro plant - 100KW – 1MW
iii. Small hydro plant - 1MW – 100MW
iv. Hydro plant - 100MW – 1000MW
v. Super hydro plant - more than 1000MW

3. <u>Based on the construction:</u>

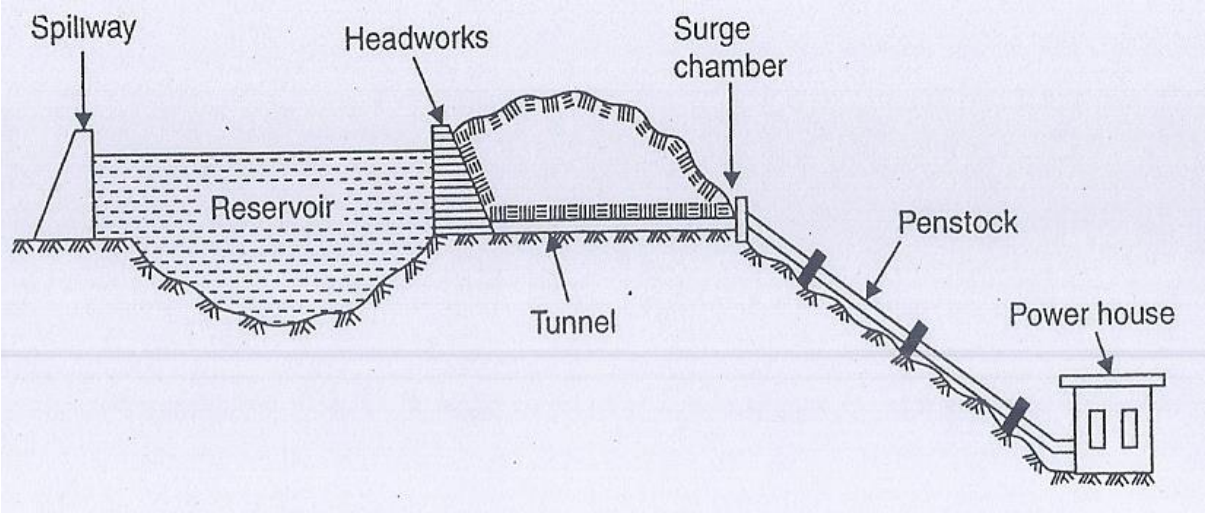
i. **Run off river plants without pondage:** These pants are located such that they use water as it comes without any pondage or storage. In these plants, some quantity of water goes as waste during rainy season. But during low flow periods, the generating capacity of the plant will be low. During periods of high flow, these plants can supply sufficient portion of base load.



ii. **Run off river plants with pondage:** These plants use pondage which store water during off peak periods and use this water during peak periods. Such plants can take care of hour to hour fluctuations in load on the station. Thus pondage increases the generating capacity of the station.



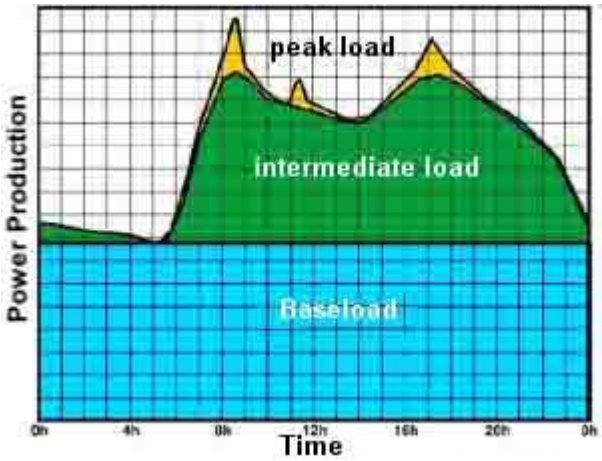
iii. **Reservoir plants:** These plants store water in big reservoir behind the dam. Water storage in the reservoir increases the generating capacity of the plant. Most of the hydro electric plants belong to this category.



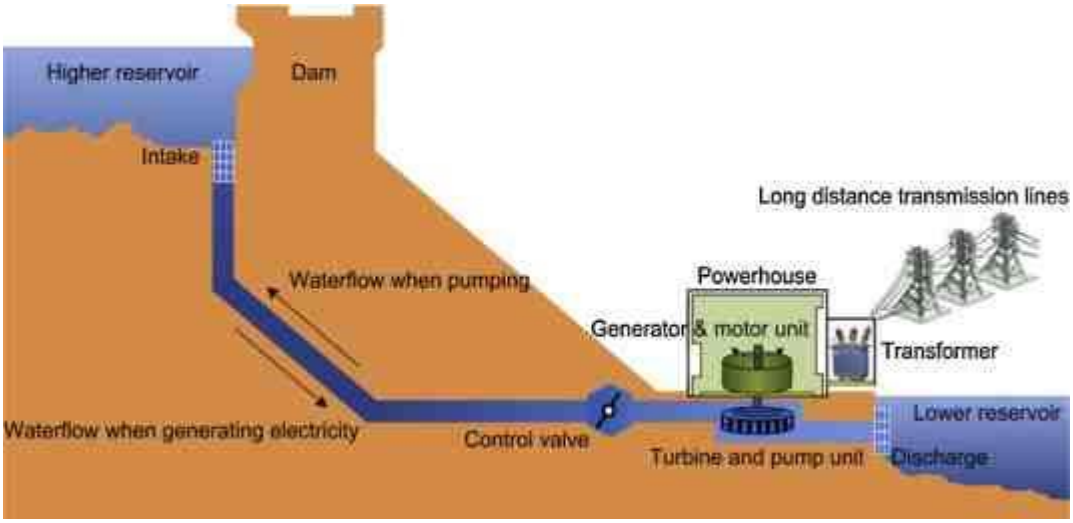
4. <u>Based on load:</u>

i. ***Base load plants:*** Base load plants generate power continuously and supply base load of the system. These power plants operate on high load factor. Run off river plants without pondage is used as base load plant.

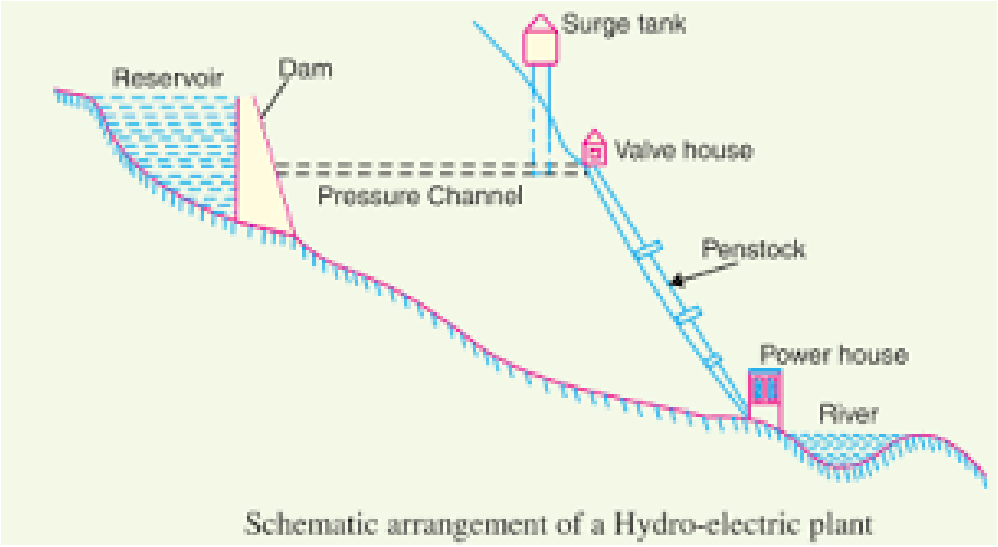
ii. ***Peak load plants:*** These hydro plants are used to supply the peak load of the system. Run off river plants with pondage or reservoir plants are used as peak load plants.



iii. ***Pumped storage plants****:* This is s special type of plant meant to supply peak loads.



General layout of hydro electric power plant:



Schematic arrangement of a Hydro-electric plant

Main components of hydro electric power plant

Note: This is only Basic Information for students. Please refer "Reference Books" prescribed as per syllabus

The important components of hydro electric power plant are catchment area, dam, reservoir, fore bay, penstock, anchor blocks, surge tank, spill ways, trash rack, tail race, prime mover, power house, draft tube and alternator.

Catchment area: The rain water falls on a large area called catchment area and water gets collected. This water flows in the form of stream to the plants.

Dam: The dam is a barrier constructed to trap water and to provide water head to be utilized in the water turbines. It is the important component of high and medium head hydro power plants.

Reservoir: The main function of reservoir is to store water. The reservoir is obtained by construction of dam across river. The stored water in the reservoir is used to generate electric power and for irrigation purpose.

Fore bay: Fore bay serves as a regulation reservoir storing water temporarily when the load on the turbine is reduced and to provide water when the load is increased. The fore bay may be a pond or a small canal constructed behind the dam.

Penstock: Penstocks are made of reinforced concrete or steel tubes or pipes which carry water from the reservoir to the turbine of the power house.

Anchor blocks: Anchor blocks hold the penstock and prevent the movement of penstock due to dynamic forces at vertical and horizontal bends and on slopes.

Surge tank: It is a small reservoir tank open at the top. It is placed at the beginning of the penstock. When the turbine is running at steady load, there are no surges in the flow of water though the penstock. When the load on the turbine is decreased, the governors close the gates of the turbine reducing water supply to the turbines. This excess water in the penstock rushes back to the surge tank and increases its water level. Thus it prevents penstock from bursting. On the other hand, when the load on the turbine increases, the additional water is drawn from the surge tank to meet the increased load. Thus, the surge tank controls the pressure variations in the penstock and prevents water hammering effect.

Trash rack: Trash rack is provided to stop the entry of debris which might damage the gates and runners of the turbine or blocking of nozzles of the impulse turbine.

Spill ways:During heavy rain fall, the water level in the reservoir exceeds beyond the maximum level and water may start flowing over the dam. This phenomenon is known as over tapping. Spill way discharges the excess water of the reservoir beyond the maximum level and acts as a safety valve to the reservoir.

Prime mover*:* The prime mover also called as turbine converts the potential and kinetic energy of the water into mechanical energy. The prime mover in turn rotates the shaft of the electric generator which generates electricity.

Alternator: It is the AC generator coupled to the turbine. When the water at high head is made to fall on the turbine blades, the turbine rotates. The turbine in turn rotates the alternator which generates electricity.

Power house: The power house is normally located near the foot of the dam. The power house has turbines, alternators, circuit breakers and other control devices. The water is bought to the power house with the help of penstocks and passed on to the turbines which rotates the alternators.

Tail race: Water after passing through the turbine is discharged into tail race. A tail race is an open channel or a tunnel depending on the power house location. The tail race may in turn discharge the water into the original river or some other river.

Draft tube: Draft tube is a metal pipe or a concrete tunnel which connects the turbine runner to the tail race. The area at the top of the draft tube is same as that of turbine runner. Its cross sectional area gradually increases towards the outlet. Because of this shape of the draft tube, the water flowing through the draft tube is decelerated and comes out of the tube with minimum kinetic energy.

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Water hammer and its effect:

Whenever the electrical load on the generator drops down suddenly, the governor partially closes the gate which admits water to the turbines. Due to this sudden decrease in the rate of flow of water to the turbine, there will be sudden increase of water pressure in the penstock. This results in hammering action in the penstock and it is known as water hammer. If this water hammer is not prevented it may result in bursting of penstock. The surge tank is used to control the pressure variations in the penstock and prevent water hammering effect.

Advantages and Disadvantages of Hydro power plant:

Advantages:

- It requires no fuel as water is used for the generation of electrical energy.
- It is neat and clean since no smoke and ash is produced.
- It requires low running cost because water is freely available in nature.
- It is simple in construction and requires less maintenance.
- It does not require long starting time like thermal power stations. It can be put into service instantly.
- It is robust and has a long life.
- It does not need highly skilled persons for operation.

Disadvantages:

- It requires high capital cost due to construction of dam.
- It requires large land area.
- The duration required for construction is very long (about 10years)
- Skilled and experienced personal are required to build the plant.
- Power generation depends on weather conditions.
- Transmission cost and losses are very high because hydro electric plants are located in hilly areas which are away from load centers.
- Due to construction of dams and reservoirs, a large portion of area is submerged in water which leads to environmental and social problems.

Environmental impacts of hydroelectric power plants:

i. Most hydroelectric power plants have a dam and a reservoir. The construction of reservoir results in flooding of large area of upstream land.
ii. The flooding destroys forest land, wildlife habitat, agricultural land and scenic lands.
iii. It also stops the flow of nutrients to the downstream which will harm the plant and animal life in the downstream.
iv. The construction of dam may obstruct fish migration and affect their population.
v. Changes in water quality due to lack of dissolved oxygen near the bottom of reservoirs can be toxic to fish and other aquatic life.
vi. The reservoir will have higher than normal amounts of sediments and nutrients, which can cultivate an excess of algae and other aquatic weeds. These weeds will have negative impact on the growth of other plant and animal life in the river.
vii. The flooding of area due to construction of dam results in anaerobic decomposition of vegetation. This releases greenhouse gases like carbon dioxide and methane leading to global warming.

THERMAL POWER PLANT

A generating station which converts heat energy of coal on combustion into electrical energy is known as steam power plant or thermal power station.

Working of a thermal power plant

A thermal power plant converts heat energy of coal into electrical energy. Here steam is produced in the boiler by utilizing the heat of coal on combustion. The wet steam from the boiler is dried in super heater. This steam is then expanded in steam turbine which causes the turbine to rotate. The steam turbine in turn rotates the alternator which converts the mechanical energy into electrical energy. The exhaust steam from the steam turbine is condensed in the condenser and is fed back to the boiler again.

Factors to be considered for site selection of thermal power plant:

Supply of fuel: The steam power station should be located near the coal mines so that the transportation cost of fuel is minimum.

Availability of water: Huge amount of water is required to produce steam and to condense exhaust steam from the turbine. Therefore the plant should be located at a place where there is abundant supply of water.

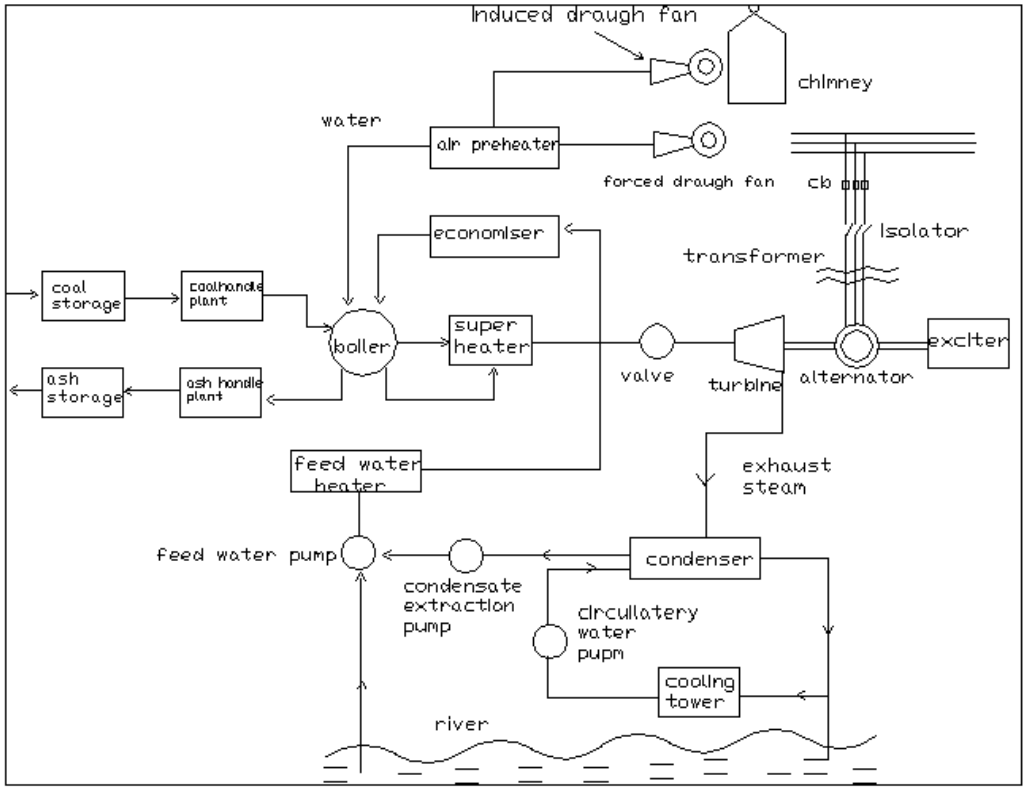
Transportation facilities: The power station requires the transportation of men, material and machinery. Therefore the power plant should be well connected by road or rail.

Cost and type of land: The cost of land should be less. Also the land should be capable of bearing the load of heavy equipments.

Nearness to load centre: To reduce the transmission cost and transmission losses, the plant should be located near the load centre.

Distance from populated area: As huge amount of coal is burnt in thermal power station, a large amount of smoke and fumes are produced which pollute the surrounding area. Therefore the plant should be located at a considerable distance from the populated area.

General Layout of Thermal Power Plant:



Main components of thermal power plant:

Fig shows the general layout diagram of thermal power station. The main components of thermal power plant include:

a) **Fuel system:** The fuel system includes coal storage, coal handling, ash handling and ash storage. The coal is transported to the power station by road or rail and is stored in the coal storage plant. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverized (crushed into small pieces). This increases the surface area of coal which helps in rapid combustion without using large quantity of air.The pulverized coal is fed to the boiler through belt conveyor. The coal is burnt in the boiler and the ash produced after combustion is removed to the ash handling plant. Then the ash is delivered to the ash storage plant for disposal.

b) **Boiler:** It is a closed vessel in which water is converted into steam at high pressure and temperature by utilizing the heat of coal on combustion. The flue gases from the boiler make their journey through super heater, economizer, air preheater and are finally exhausted to the atmosphere through the chimney.

c) **Super heater:** The steam produced by the boiler is wet and it is passed through super heater where it is dried and super heated. The super heater consists of a group of tubes made of special alloy steel. These tubes are heated by the heat of the flue gases during their journey from the furnace to the chimney. The heated tubes convert the wet steam

into dry steam. The super heater increases the overall efficiency of the plant. It also avoids the corrosion of turbine blades.

d) **Boiler furnace:** It is a chamber which provides support and enclosure for the combustion of coal to liberate heat energy.
e) **Economizer**: Economizer is a feed water heater. It derives the heat from the flue gases to heat the feed water. The feed water from the economizer is then fed to the boiler.
f) **Air pre heater:** The air pre heater increases the temperature of the air supplied for cola burning by deriving the heat from the flue gases.
g) **Draught system:** The main purpose of the draught system is to supply air to the furnace and to take away the flue gases from the boiler through the chimney. The draught system uses forced draught fan for supplying air to the furnace and induced draught fan for exhausting the flue gases through the chimney.
h) **Steam turbine:** The dry and super heated steam is fed to the steam turbine through the main valve. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy.
i) **Alternator:** The steam turbine is coupled to the alternator. The alternator converts the mechanical energy of turbine into electrical energy. The electrical output the alternator is fed to the bus bars via transformer, circuit breaker and isolators.
j) **Feed water system:** The condensate from the condenser is used as feed water to the boiler. The feed water on the way to the boiler is heated by feed water heater and economizer.
k) **Cooling arrangement:** The cooling arrangement consists of condenser and cooling tower. The condenser condenses the exhaust steam from the turbine. The natural source for water from the river, canal and lake is circulated in condenser to condense the steam. The circulating water in the condenser takes up heat of the exhaust steam and becomes hot. This hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser to condense the steam.

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Advantages of thermal power plant:

1. The cost of the fuel is cheap.
2. The initial cost is less when compared to hydel or nuclear power station.
3. It requires less space when compared to hydro electric plant.
4. Cost of power generation is less than that of diesel power station.
5. Whether conditions will not affect power generation.
6. Large amount of power can be generated by thermal power station.
7. It can be located near the load centers which reduces transmission cost and losses.

Disadvantages of thermal power plant:

1. Thermal power station pollutes the atmosphere due to production of ash, dust, fumes and smoke.
2. Running cost is high when compared to hydro electric power station.
3. Maintenance cost is more.

4. The power plant cannot be started instantly.
5. Standby losses in the boiler are more.
6. Losses are more and hence efficiency is less.

Comparison between hydroelectric power station and thermal power station

Sl No	Hydroelectric power station	Thermal power station
1	It uses potential energy of water at high head to generate electrical energy.	It uses heat energy of coal on combustion to generate electrical energy.
2	It uses renewable source of energy.	It uses non renewable source of energy.
3	The plant is clean and does not pollute the environment.	It pollutes the environment due to smoke, ash and fumes.
4	Initial cost is very high because of dam construction and erection of power plant.	Initial cost is less than that of hydro electric and nuclear power plants.
5	Low running cost and maintenance cost.	High running cost and maintenance cost.
6	Requires large space because of reservoir.	Space required is less when compared to hydro electric power plant.
7	Plant can be started instantly.	Requires a lot of time for starting.
8	The plant is robust and hence the life of the plant is more.	The plant is less robust and hence the life of the plant is less when compared to hydel power plant.
9	Power generation is less when compared to thermal plant	Power generation is high.

Environmental Impacts of Thermal Power Plant:

The following are the environmental impacts of thermal power plant:

1. Large amount of land is used to dispose fly ash from the coal based Plants. Due to this there is a change in soil properties. It becomes more alkaline due to the alkaline nature of fly ash.
2. Soft bodied soil workers like earth worms will die out.
3. Increased transportation activities due the operation of the power plant lead to increase in noise levels in the adjacent localities. Also the employees are exposed to high noise levels.
4. Air quality degenerates due to:
   - Production of carbon dioxide, the main green house gas.
   - Production of oxides of sulphur and nitrogen:
     - SO_2 is a product of Combustion and depends on the amount of sulphur in Coal. SO_2 contributes to the formation of small acidic particulates that can penetrate into human lungs and be absorbed by the bloodstream. Sulphur dioxide also causes acid rain, which can damage crops, forests, and soils, and acidifies lakes and streams.
     - Nitrogen in fuel reacts with Oxygen at high temperatures to form NO_2. Fossil fuel power plants are the second largest emitter of NO_2.This is a

hazardous pollutant creating visual and respiratory problems. Also NO_2 combines with water to form acid rain, smog, and ground ozone.

- Production of gases of mercury, which is a poisonous gas.

5. Ash is the residue after combustion. Ash contains toxic elements that can percolate into the drinking water system. The wind carries away the ash particles to surrounding areas causing harm to humans and vegetation.

6. Power plants have elaborate arrangements to collect the ash. A small quantity still goes out through the stack and is categorized as Particulate Matter emission. The particles of size less than 2.5 microns are of great concern since these are responsible for respiratory illness in humans.

Unit-2
NUCLEAR POWER PLANT

A generating station in which nuclear energy is converted into electrical energy is known as nuclear power station.

Factors to be considered for selection of site

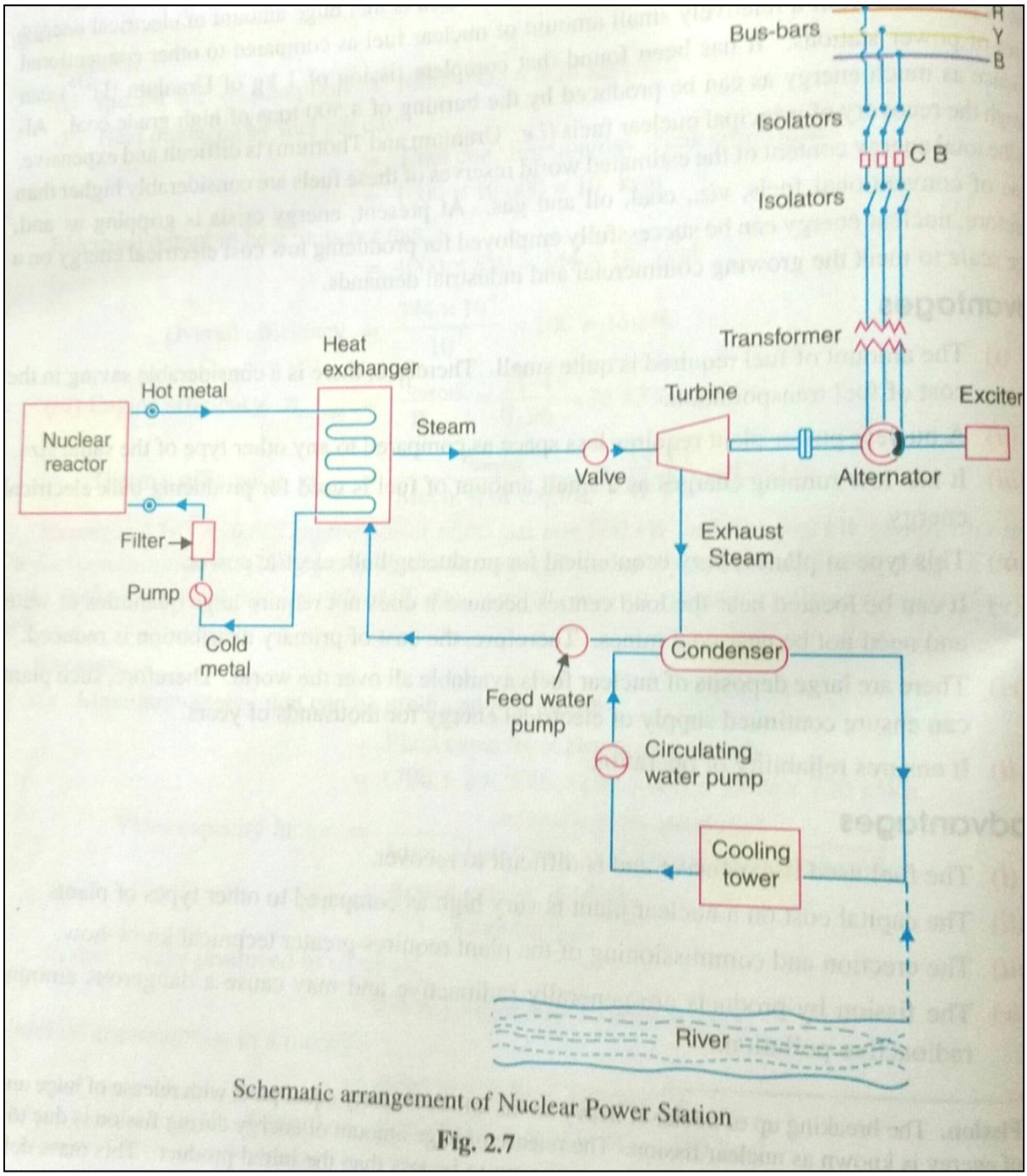
- *Availability of water:* Sufficient water is required for steam generation and cooling purpose in nuclear power plant. Therefore the plant site should be located where large quantity of water is available.
- *Disposal of waste:* The waste produced by fission in the nuclear power station is radioactive and it must be disposed off properly to avoid health hazards. Therefore the site selected should have proper arrangement for disposal of radioactive waste.
- *Distance form populated area*: The site selected for nuclear plant should be away from populated area as there is a danger of presence of radio activity in the atmosphere near the plant.
- *Transportation facilities:* The site selected should have adequate facilities to transport the heavy equipments during erection.
- *Nearness to load center:* The power station should be nearer to the load center to reduce the cost of transmission lines and line losses.
- The site should be available at reasonable cost.

Working of Nuclear power plant

A generating station in which nuclear energy is converted into electrical energy is known as nuclear power station. In nuclear power station, enriched Uranium (U^{235}) is subjected to controlled nuclear fission in a special apparatus known as nuclear reactor. The heat energy released during nuclear fission is carried by the coolant to the heat exchanger which produces steam at high pressure and temperature. This steam runs the steam turbine which converts heat energy of steam into mechanical energy. The turbine in turn drives the alternator which converts mechanical energy into electrical energy. The exhaust steam from the turbine is condensed in the cooling system.

Nuclear power station produces huge amount of electrical energy form a relatively small amount of nuclear fuel. It is found that one Kg of U^{235} (Uranium) can produce as much energy as produced by burning 4500 tons of high grade coal.

Schematic diagram of Nuclear power plant



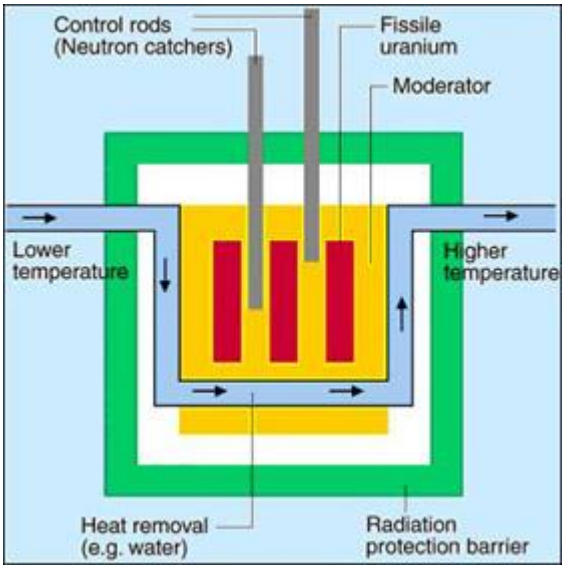
Schematic arrangement of Nuclear Power Station

Fig. 2.7

Components of the nuclear power plant

Nuclear reactor: This is the main component of nuclear power station. This is an apparatus in which the nuclear fuel U^{235} is subjected to controlled nuclear fission to release heat energy. The nuclear reactor consists of a cylindrical pressure vessel which houses the fuel rods of uranium, moderator and control rods.

- **Fuel rods:** They are the fission material which release huge amount of energy when bombarded with slow moving neutrons.
- **Moderator:** The moderator consists of the graphite rods which enclose the fuel rods. The moderator slows own the neutrons before they bombard the fuel rods.
- **Control rods:** The control rods are made of cadmium and are inserted into the reactor. Cadmium is a strong neutron absorber and thus regulates the supply of neutron for fission. When the control rods are pushed inside, they absorb the neutrons and stop the fission chain reaction. But when the control rods are withdrawn, more and more fission neutrons cause fission reaction and increase the heat produced. Thus lowering and raising of control rods regulate the power output of nuclear reactor.
- **Coolant:** The heat produced in the reactor is removed by the coolant which is generally sodium or potassium metal. The coolant carries the heat to the heat exchanger.



Heat exchanger: The coolant gives up the heat to the heat exchanger which is utilized is raising the steam. After giving up the heat, the coolant is fed back to the reactor.

Steam turbine: Steam produced in the heat exchanger is fed to the steam turbine through a valve. The steam turbine converts the heat energy of steam into mechanical energy. Steam turbine is also known as prime mover.

Alternator: The steam turbine drives the alternator which converts mechanical energy into electrical energy. The output from the alternator is fed to the bus bars through transformer, circuit breakers and isolators.

Cooling system: The exhaust steam form the turbine is condensed in the condenser. The condensed steam is fed back to the heat exchanger through feed water pump. The hot water in the condenser is cooled by using cooling tower.

Working of Nuclear Reactor

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Merits and demerits of Nuclear power plant

Merits

- Amount of fuel required is very less. Therefore there is a considerable saving in the cost of fuel transportation.
- Nuclear power plant requires less space as compared to any other type of same size.
- Low running cost as small amount of fuel is used for producing bulk electrical energy.
- It can be located near load centers and therefore cost of primary distribution is reduced.
- There are large deposits of nuclear fuels all over the world. Therefore these plants can produce electrical energy for thousands of years.

Demerits

- Fuel used is expensive.
- Capital cost is very high when compared to other types of plants.
- Erection and commissioning of plant requires great technical knowledge.
- The byproducts of nuclear fission are radioactive and may cause radioactive pollution
- Disposal of radioactive waste is a big problem. They should be disposed off in a deep trench or in the sea away from sea shore.
- Nuclear plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.

Comparison between thermal power plant and nuclear power plant

Sl. No.	Nuclear power station	Thermal power station
1	Heat released due to nuclear fission of U^{235} is used for steam generation.	Heat released due to combustion of coal is used for steam generation.
2	Amount of fuel required is very less.	Large amount of fuel is required.
3	Transportation cost of fuel is less.	High transportation cost of fuel.
4	Space required for the nuclear power plant is less.	Space required is more when compared to nuclear power plant.
5	Low running cost and high capital cost.	High running cost and relatively low capital cost.
6	A large deposit of nuclear fuel is available. Hence these plants ensure continuous supply of electrical energy for 1000 of years.	Due to depletion of fossil fuel, this method of power generation cannot sustain for many years.
7	It produces radioactive waste and hence disposal of waste is very difficult.	Does not produce radioactive waste and hence waste disposal is not very difficult.
8	It uses wet steam of relatively low temperature and pressure.	It uses dry steam and its temperature and pressure is high when compared to nuclear power plant.

Nuclear power plant impacts and waste disposal

The main environmental concern related to nuclear power plant is the creation of radioactive waste such as uranium mill tailings, spent reactor fuel and other radioactive wastes.

Spent uranium fuel is classified as high level radioactive waste because of its high level of radioactivity. While other wastes such as uranium mill tailings, protective clothing, wiping clothes, etc are classified as low level wastes.

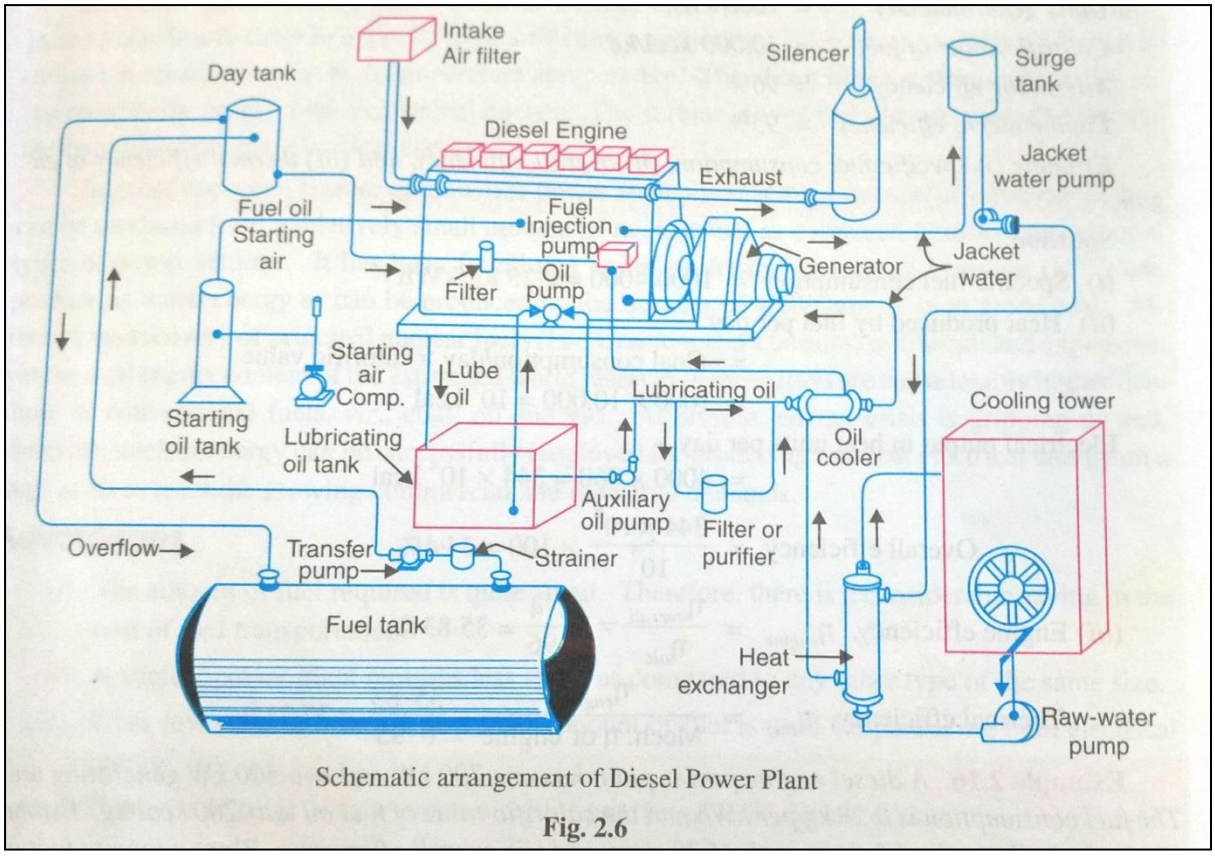
These wastes produce highly penetrating α, β and ɣ radiations which are dangerous to human health. They can lead to dangerous health hazards like cancer. Hence it is necessary to give special attention for disposal of these wastes.

- Gaseous wastes are filtered before discharging into atmosphere. Also the filtered gaseous waste is discharged at high levels so that it is dispersed properly.
- Loss of carbon dioxide from the reactor is monitored. This is done to ensure that the concentration of carbon dioxide in the atmosphere near reactor does not exceed the safe limits.
- The liquid waste is filtered, diluted and adjusted for proper pH level before discharging. Sometimes the radioactivity from liquid waste is removed by ion exchange process. The liquid wastes are then discharged through special drains into concrete storage tanks.
- The solid wastes like rejected control rods, pieces of fuel etc., are stored in shielded concrete containers and dumped into ocean or buried deep underground. The radioactive waste then undergoes natural decaying over a period of time and settles into a safe level of radio-activity.

https://youtu.be/3QXSkXHDZgU

DIESEL POWER PLANT

Schematic diagram of diesel power plant



Schematic arrangement of Diesel Power Plant

Fig. 2.6

Figure shows the schematic diagram of diesel power plant. The main components of diesel power plant are:

- **Diesel engine:** The diesel engine is used as a prime mover in which diesel is burnt and the products of the combustion produces mechanical energy.
- **Fuel supply system:** It consists of fuel tank, strainers, fuel transfer pump, filter and day tank. Fuel is supplied to the plant site by rail or road. This oil is stored in the fuel tank. From the fuel tank, oil is pumped daily to the day tank through strainers. This strainer is used to remove the suspended impurities. This strainer is used to remove the suspended impurities. The clean oil form the day tank is injected into the engine by fuel injection pump.
- **Air intake system:** This system supplies air to the engine for fuel combustion. Filters are provided to remove the dust particles from the air.
- **Exhaust system:** This system leads the exhaust gas from the engine to outside the building and discharges it into atmosphere. A silencer is used in the exhaust system to reduce the noise level.
- **Cooling system:** The heat released by the burning of fuel is partly converted into mechanical work. The remaining heat passes through the engine cylinder, piston rings, etc. and may cause damage to the system. To keep the temperature of the engine parts within safe limits cooling is provided. The cooling system consists of water source pump and cooling towers. The water takes away the heat form the engine and it becomes hot. This hot water is cooled by cooling towers and is re-circulated for cooling.
- **Lubrication system:** This system minimizes wear and tear of the moving parts of the engine. The lubrication oil is drawn from the lubricating oil tank by the pump and is passed through filters to remove impurities. This clean lubrication oil is delivered to the

engine for lubrication. Oil coolers are used to keep the temperature of the lubricating oil low.

- **Engine starting system:** This arrangement is used to rotate the engine initially while starting. For small sets, engines are manually started. For larger sets compressed air is used for starting. Once the engine starts it runs on its own power.
- **Alternator and Governors:** Alternator is coupled to the diesel engine which converts mechanical energy into electrical energy. The governor controls the amount of fuel injected into the engine there by controlling the amount of electrical energy generated.

https://youtu.be/sfZFPqitQZA

Merits and demerits of Diesel power plant:

Merits:

- The design and layout of diesel power plant is very simple.
- It occupies less space.
- It can be located at any place.
- It can be started quickly and can pick up load in short time.
- It requires less water for cooling.
- The overall cost is much less than steam power station of the same capacity.
- The thermal efficiency of diesel plant is higher than that of steam power plant.
- It requires less operating staff.

Demerits:

- It has high running cost as the fuel used in costly.
- The plant doesn't work satisfactorily under continuous overload conditions.
- It causes pollution of the environment.
- The plant can generate only small power and hence used as standby power plant.
- Cost of lubrication is high.
- Maintenance charges are high.

GAS TURBINE POWER PLANT

A generation station which employs gas turbine as a prime mover for the generation of electricity is known as gas turbine power plant.

In gas turbine power plant, air is used as working fuel. Air is compressed by a compressor and is fed to the combustion chamber. Here heat is added to the compressed air by burning natural gas. The hot and high pressure air form the combustion chamber is passed on to the gas turbine where it expands and produces the mechanical energy. The gas turbine drives the alternator switch converts mechanical energy into electrical energy.

Schematic diagram of a Gas turbine power plant

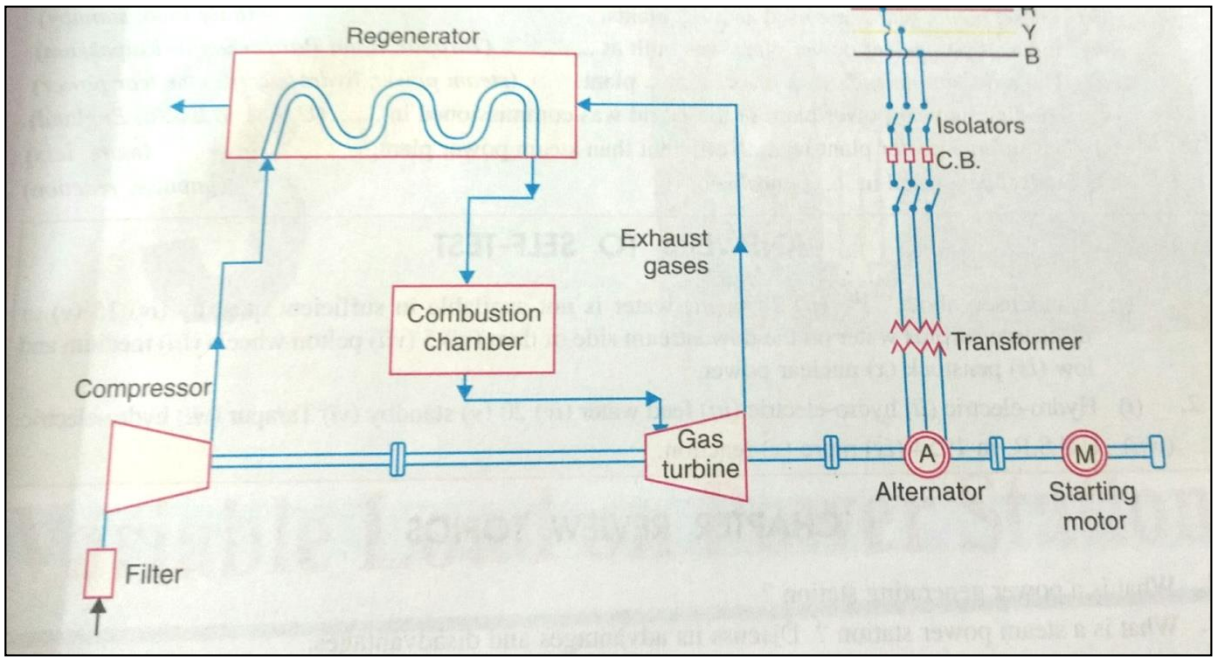


Figure shows the schematic diagram of gas turbine power plant. The main components of gas turbine power plant are:

i) Compressor:

The compressor used in the gas turbine power plant is of rotating type. The air at atmospheric pressure is drawn by the compressor though a filter which removes the dust from the air. The rotator blades of the compressor push the air between stationary blades to increase its pressure. Thus air at high pressure is available at the output of the compressor.

ii) Regenerator:

The regenerator recovers the heat form the exhaust gases of the turbine. The exhaust gas is passed through the regenerator before wasting to the atmosphere. Regenerator consists of a network of tubes. The compressed air from the compressor is passed through these tubes. The hot exhaust gas heats this compressed air in the regenerator. This pre-heated compressed air is fed to the combustion chamber.

iii) Combustion chamber:

The compressed air at high pressure from the compressor is fed to the combustion chamber through the regenerator. In the combustion chamber, air is heated by burning oil or natural gas. The oil or natural gas is injected into the chamber at high pressure so that it mixes with air and under goes combustion. The hot and high pressure gas from the combustion chamber is fed to the gas turbine.

iv) Gas turbine:

The products of combustion chamber consisting of mixture of gases at high pressure and temperature are passed on to the gas turbine. These gases while passing over the turbine blades expand and cause the turbine blades to rotate.

v) Alternator:

The gas turbine is coupled to the alternator. The alternator converts the mechanical energy of turbine into electrical energy. The output from the alternator is given to the busbars through transformer, circuit breakers and isolators.

vi) Starting motor:

The compressor, turbine and the alternator are all mounted on the same shaft. Therefore before starting the turbine, the compressor has to be started. For this purpose, a starting motor is mounted on the same shaft and is energized by the batteries. Once the unit starts, a part of the mechanical energy of the turbine drives the compressor and there is no need for the motor now.

https://youtu.be/1QxWg6mZ3Sk

Merits of gas turbine power plant:

i. It is simple in design compared to steam power station since no boilers are needed.
ii. It is smaller in size compared to steam power station of same capacity.
iii. The initial and operating costs are lower than steam power station of same capacity.
iv. It requires less water as no condenser is used.
v. The maintenance charges are small.
vi. Gas turbines are simple in construction and operation than steam turbines.
vii. It can be started quickly from cold condition.
viii. There are no stands by losses.

Demerits of gas turbine power plant:

i. This requires a starting unit to start the compressor initially. This starting unit needs some external power.
ii. A part of the power developed by the turbine is used for driving the compressor. Therefore the net output is low.
iii. The overall efficiency is low because the exhaust gas of the turbine contains sufficient heat.
iv. The temperature of the combustion chamber is very high (3000ºF). This reduces the life of the power plant.

Unit -3 SOLAR POWER PLANTS

Importance of solar energy and its scope in India

Solar energy is an inexhaustible source of energy capable of meeting significant portion of world's energy needs with minimum environmental impacts. It is an unconventional energy source capable of supplying all energy needs. The earth receives about 1.7 X 10^{17} W of radiations from the sun. The solar energy incident on the earth in one year is more than total fossil energy on the earth.

India happens to be a tropical region which receives a good quantity of solar flux. At some places in Rajasthan, the average solar radiation is found to be 7.4KWh/m^2. If it is possible to utilize even a part of this solar heat, the energy problems would be solved forever. But the solar energy is not constant and varies from day to night and season to season. Also, huge scale conversion of solar energy into electricity is not economical yet. Hence we are not able to convert all the solar energy reaching the earth into usable form.

Ministry of non conventional energy sources, Governement of India, is trying to promote solar energy in a big way. The ministry provides subsidies to manufacturers and users to promote the use of solar energy. It is expected that total solar power utilization in India would be around 10000 MW by the year 2020.

Solar Photovoltaic System:

In photovoltaic type of solar power plant, the light energy of the sun is directly converted into electrical energy. It uses a principle called photovoltaic effect for energy conversion.

The photovoltaic effect is the creation of voltage or electric current in a material upon exposure to light.

How solar panels turn sunlight into electricity

Solar cell:

The energy conversion device that converts sunlight into electricity by the use of photovoltaic effect is called as solar cell. A solar cell is also known as photovoltaic cell or photo electric cell.

A solar cell consists of a **pn** semiconductor junction. Figure shows the construction of solar cell. The **pn** junction of the solar cell is formed by diffusing a thin layer of n-type dopant on p- type base material using diffusion furnace. At the bottom of the cell, a metallic conducting layer is formed and a terminal is taken out. At the top of the cell, a metallic grid is formed and another terminal is taken out. The entire cell is encapsulated to protect from atmospheric degradations.

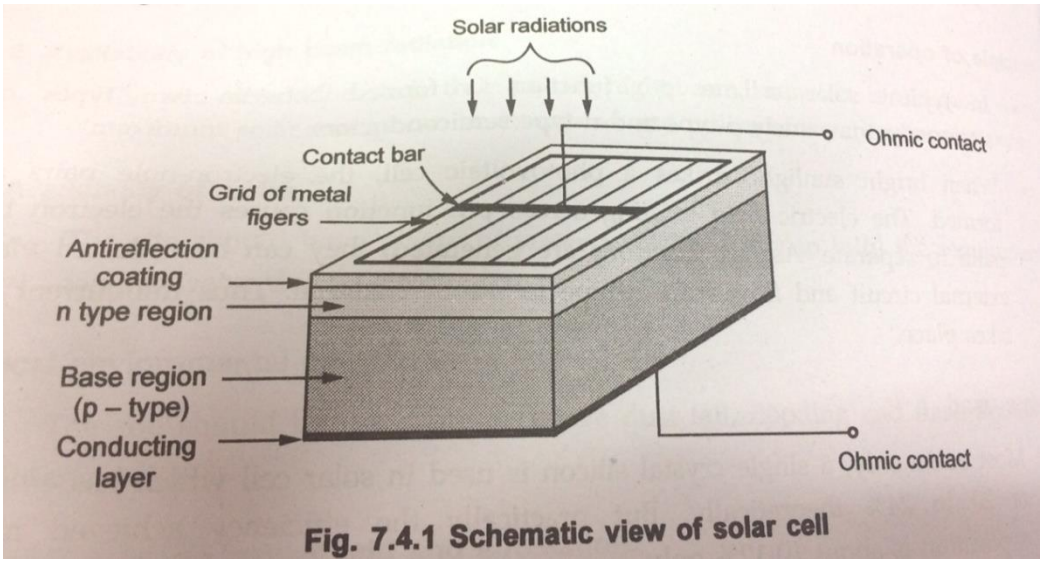


Fig. 7.4.1 Schematic view of solar cell

When a bright sunlight strikes the photovoltaic cell, the photons of the sunlight penetrate the junction and create electron-hole pairs. The barrier field existing across the **pn** junction causes the electron hole pair to separate. The free electrons thus created move towards the n-side and the holes move towards the p-side. So a voltage is set up which is known as photo voltage. When the cell is connected to an external circuit, the free electrons diffuse from n-side to p-side causing the electric current to flow.

Construction of Solar Cell

Solar photovoltaic module:

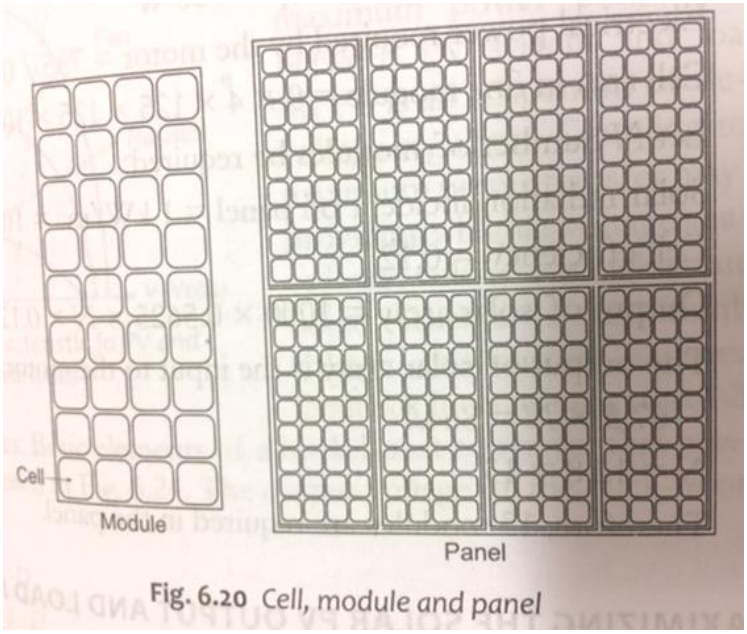


Fig. 6.20 Cell, module and panel

Note: This is only Basic Information for students. Please refer "Reference Books" prescribed as per syllabus

The output voltage of a single cell is very small and is about 0.3 to 0.5V. To increase the voltage level, several cells are interconnected to form a photovoltaic module. The number of cells in a module depends on the module voltage. A 12V solar module consists of 33 to 36 cells. These cells are mounted on a durable back cover and are sealed with a transparent top cover to protect against dust, moisture, mechanical shocks and other outdoor conditions.

Solar photovoltaic array:

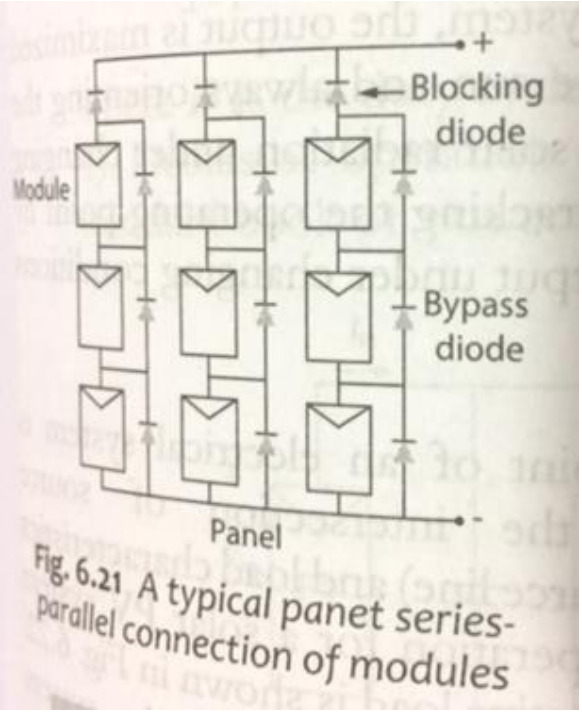


Fig. 6.21 A typical panet series-parallel connection of modules

Several solar modules are interconnected in series and parallel to form solar arrays. These modules are connected in series to increase the voltage and they are connected in parallel to increase the current output. There are two types of solar arrays namely :

- Tracking arrays
- Fixed arrays

Tracking arrays are movable type and they are always aligned perpendicular to the direction of sun rays to receive maximum solar radiation.

A fixed array is placed east-west and tilted at an angle equal to the latitude of that place.

Construction of Photovoltaic Panel

Materials Used in Solar Cell:

The materials used for the solar cells must have the following properties:

- They must have an energy band gap of 1ev to 1.8ev.
- They must have high optical absorption.
- They must have high electrical conductivity.

- The raw material for solar cell must be available in abundance and the cost of the material must be low

Based on these criteria, the following are the commonly used materials for solar cells.

- Silicon.
- GaAs (Gallium Arsenide)
- CdTe (Cadmium Telluride).
- $CuInSe_2$ (Copper Indium Diselenide)

Types of photo voltaic power system:

There are three types of photovoltaic power systems namely:

- Stand alone solar photovoltaic system
- Grid interactive solar photovoltaic system
- Hybrid solar photovoltaic system

Stand alone solar photovoltaic system:

Fig shows the block diagram of standalone solar photovoltaic system. It consists of photo voltaic array, charge regulator, battery, inverter, DC load centre and AC load centre. The DC output of the PV array is connected to the battery through the charge regulator unit. The charge regulator consists of a blocking diode in series with the photovoltaic array. It prevents the battery from being discharged through the PV array at night when there is no sunshine.

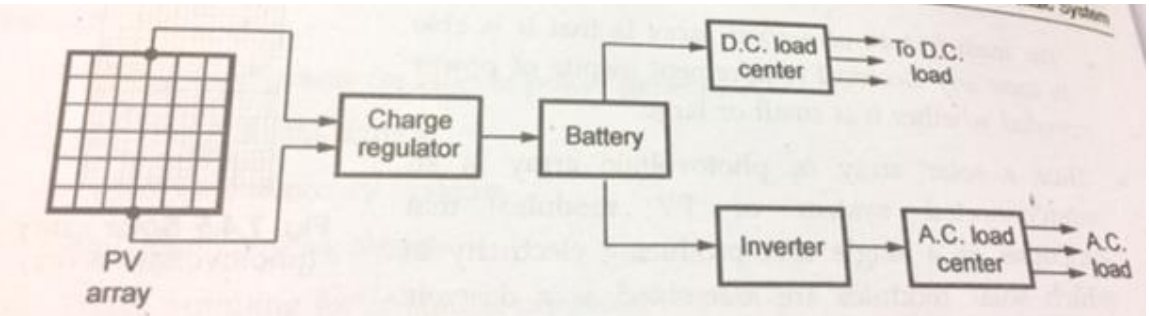


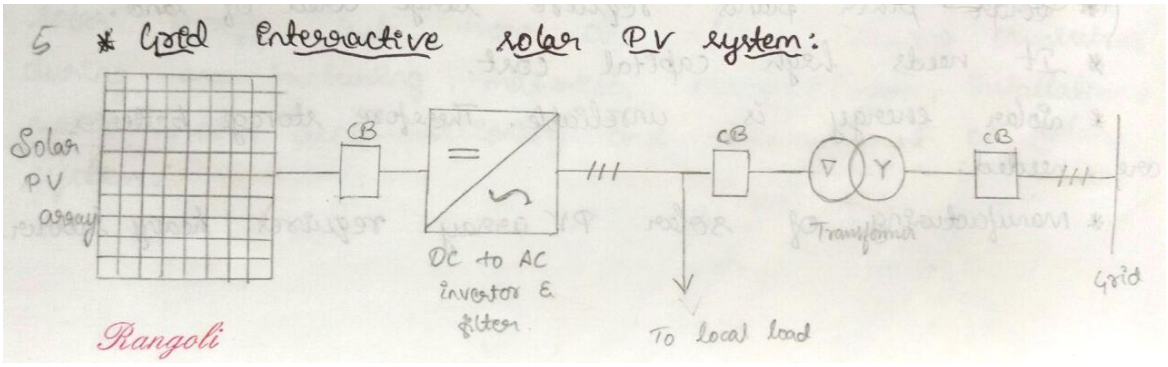
Fig. 7.5.1 Block diagram of stand alone system

The blocking diode also prevents overcharging and discharging of battery and also protects the battery from short circuits.

The battery gets charged from the DC output of the PV array. Battery output can be directly connected to the DC loads. For AC loads, the battery output is first connected to an inverter which converts DC to AC and then it is connected to AC load centre.

Stand Alone Solar PV System

Grid interactive solar photovoltaic system:



In grid interactive solar photovoltaic system, all the excess power is fed to the central power grid. Fig shows the block diagram of grid interactive solar photovoltaic system. In this system, battery is not required because the supply of power is maintained from the grid during night when there is no sunshine. The DC power from the PV array is first converted to AC by the inverter and then the harmonics are filtered. The filtered AC power is fed to the grid after adjusting the voltage level using transformer. The circuit breakers are provided to disconnect the PV system from the grid during failure of utility supply.

Grid Interactive solar PV System

Merits of solar photovoltaic system:

- Solar energy is freely available in nature
- Direct conversion of sun light into electricity
- Absence of moving parts
- Low maintenance cost
- No environmental pollution
- Long life and highly reliable
- It can be easily started as no starting time is required
- It can be installed at load centers and hence saves cost of transmission and distribution

Demerits of solar photovoltaic system:

- Solar power plants require large area of land
- It needs high capital cost
- Solar energy is unreliable and therefore storage batteries are needed
- Manufacturing of solar array requires heavy labour

Applications of Solar PV System:

1. Terrestrial Applications

- Water pumping sets for irrigation and drinking water supply.
- Rural electrification.
- Radio beacons for ship navigations at ports.
- Weather monitoring
- Railway signaling equipment
- Battery charging
- Street lighting

2. Agricultural applications

- Heating and cooling of commercial green houses.
- Drying grains, soybeans, peanut, tobacco, onions, fruits.

3. Industrial applications

- Distillation of water.
- Laundries, fabric drying, textile dying, paper industries, etc.,
- Food processing.
- Laminating and drying glass fibers.
- Picking in steel industries.
- Generation of electric power.

Environmental impacts of solar photovoltaic system:

Unlike fossil fuel power generating systems, solar power systems have very low emissions of air pollutants such as sulphur dioxide, nitrogen oxides, carbon monoxide and carbon dioxide during their operations. However, there are some negative impacts of solar power plants on the environment associated during construction, operation, and decommissioning. The following are the negative impacts of solar power plants:

Land Use Impacts: Solar power plants require relatively large area of land to generate electricity at utility scale. Such solar power plants result in land degradation. They may also affect vegetation, wildlife and result in habitat loss.

Impacts to Soil and Water Resources: Construction of solar power plants requires clearing of large area of land. This results in alteration of drainage facilities, soil erosion and increased runoff.

Other Impacts: The PV cell manufacturing process includes a number of hazardous materials. Workers in the manufacturing unit face risk of inhaling silicon dust. There can also be environmental contamination if the solar panels get damaged or improperly disposed upon decommissioning.

Global Warming Emissions: Though there are no global warming emissions associated with generating electricity from solar energy, but there are global warming emissions during

manufacturing, materials transportation, installation, maintenance, decommissioning and dismantlement of solar system.

Solar Impacts on Environment

Unit - 4 WIND POWER PLANT

Importance of wind energy

- Wind energy is the kinetic energy associated with the movement of large masses of air. The movements of air result from uneven heating of the atmosphere by the sun creating temperature, density and pressure difference. Thus it is an indirect form of solar energy.

- Wind energy is clean, cheap and eco friendly renewable source of energy. The only disadvantage of wind energy is that, it is dispersed, erratic and location specific.

- Wind energy is converted into mechanical energy with the help of wind turbine. The mechanical energy thus obtained can be used to operate farm appliances and water pumps. It can also be converted into electrical energy by coupling a generator to the wind turbine. A generator coupled to the wind turbine is known as aero-generator.

- Wind speeds ranging from 20km/h to 25km/h are required for power generation using wind turbines.
- With modern blade materials, the life of wind turbine has exceeded 20 years. The installation cost is also comparable with conventional thermal power plant. Due to these reasons, the wind energy is gaining importance and is competing with conventional power sources.
- Global installed capacity by the end of year 2007 has reached 94,123 MW. India has an installed capacity of 8000MW at the end of year 2007.

Origin of winds

There are two sources of winds namely, global winds and local winds.

Global winds:

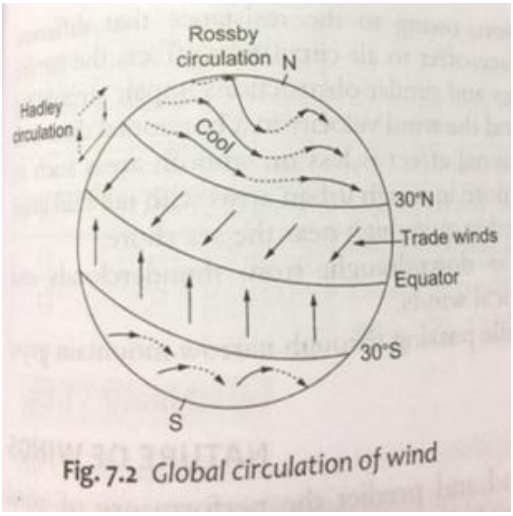


Fig. 7.2 Global circulation of wind

Global winds are produced due to difference in heating of the earth at equatorial and polar regions. The solar radiation causes temperature at equator to be more than that of polar region. Therefore the warmer air over the equator starts moving towards the poles and the cold air from the poles move towards the equator. This exchange of warm and cold air between the equator and the poles produces global wind belts. Earth's rotation about its axis creates a force called 'coriolis' force. This force causes the direction of the winds to bend toward west and causes circulation of global wind.

Origin of Global Wind

Local winds:

Local winds are produced due to uneven heating of land surface, water bodies and the hill slopes during day and night. During the day, land becomes hotter than water. As a result cool heavier air blows from water bodies to the land. At night, land cools rapidly than water. This causes the direction of wind to reverse. This results in local winds.

Similarly there is a differential heating between low land and hill slopes. The hill slopes heat up during the day and cool down at night more rapidly than that of low land. This causes cool air to blow from land to the hill slope during day and from the hill slope to land during night. This also results in local winds.

Origin of Local Winds

Factors affecting the distribution of wind energy on the surface of the earth:

Many factors are responsible for distribution of wind energy on the surface of the earth. Some are global factors and others are local factors. The factors affecting are:

- On the global level, high mountains affect the circulation of wind.
- The friction caused by hills, trees, buildings, etc obstruct the circulation of wind.
- Frictional effect is less on smooth surface of seas and therefore wind speed is high on seashore.
- Climatic disturbances such as rainfall also affect the circulation of wind.
- Turbulence results in wind velocity to get reduced.
- Wind speed increases while passing through narrow mountain gaps where it gets channelized.

Nature of wind:

To predict the performance of wind turbines and for proper designing the supporting structure for wind turbines, it is necessary to study the nature of winds. The beaufort scale gives the description of the nature of the wind. The description of wind based on beaufort numbers is given in table below:

Beaufort number	Wind speed (m/s)	Wind description	Wind effect
1	0.4 – 1.8	Very light	Smoke moves
2	1.8 – 3.6	Light	Leaves move
4	5.8 – 8.5	Moderate	Small branches and turbine vanes start moving

7	14 - 17	Strong	Whole tree moves
8	17 – 21	Very strong	Tree branches break

Factors to be considered for site selection of wind power plants:

- The site selected for wind power plant should have an average wind speed of 20-30km/h.
- It is desirable to install wind power plant at higher altitudes because the wind tends to have higher velocities at higher attitudes.
- The land cost should be low.
- The ground condition of the site should be such that strong foundation for tower is possible.
- Icing problem, salt spray or blowing dust should not be present at the site as they affect the turbine blades.
- The land should be accessible by road or rail.
- The site should be near the load center to reduce transmission cost and losses.

Merits of wind power plant:

- Wind power stations are non-polluting.
- It uses renewable source of energy which is free of cost.
- The energy generated by wind power station is cheaper.
- It avoids fuel transport.
- It is simple in construction and requires less maintenance.

Demerits of wind power plant:

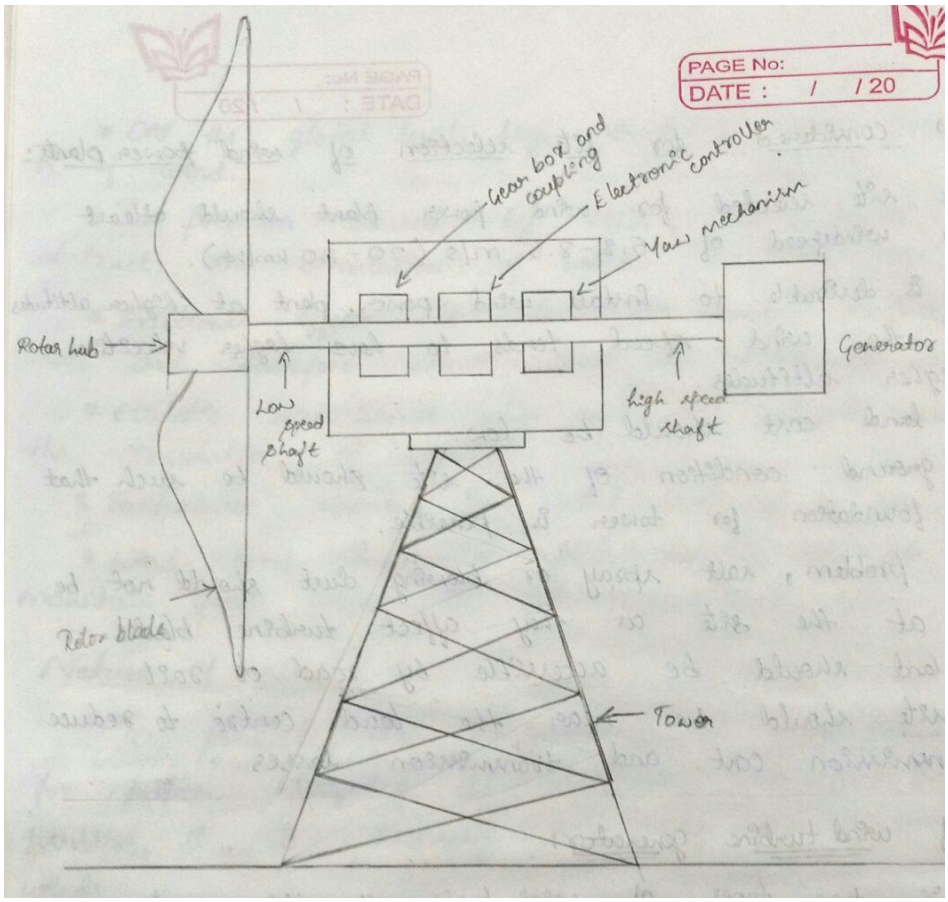
- Wind energy is fluctuating in nature.
- Wind power plant needs storage devices because of irregularity in wind speed.
- It is suitable for only small power generation.
- Its operation is noisy.

Classification of wind turbine generator

- Horizontal axis wind turbine generator.
- Vertical axis wind turbine generator.

Horizontal axis wind turbine generator:

Horizontal axis wind turbine is the commonly used type of wind turbine. In this turbine shaft is mounted horizontally parallel to the ground. All the components are mounted on a tower of about 80m height. The following are the components of the horizontal axis wind turbine generator,



Rotor blades: About 2 or 3 blades are mounted on the rotor hub. These blades capture wind energy and convert it into rotational energy of shaft.

Shaft: Transfers rotational energy from the wind turbine to the electric generator.

Gear box: Increases the speed of the turbine shaft form 30 – 60 rpm so that it matches with generator speed of about 1000 – 1800 rpm.

Electronic controller: Senses wind speed, wind direction and controls the yaw mechanism. It also gives signal to the brakes to shut down the turbine is case of malfunction.

Brakes: Stops the rotation of shaft in case of overload or system failure.

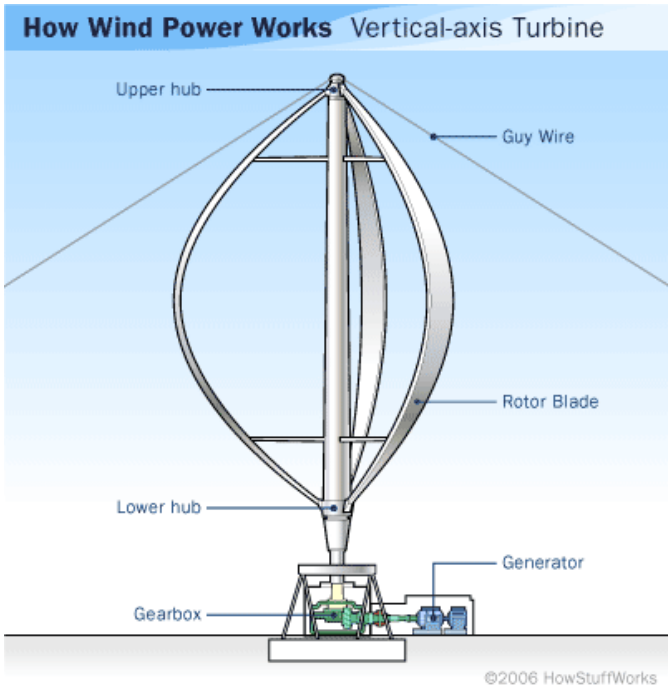
Yaw mechanism: Moves the rotor to align with the direction of wind to capture maximum wind energy.

Generator: Converts rotational energy of the shaft into electrical energy.

Tower: Supports the entire set up at higher elevation so that blades can freely rotate away from the ground.

Horizontal Axis Wind Turbine Generator

Vertical axis wind turbine generator:



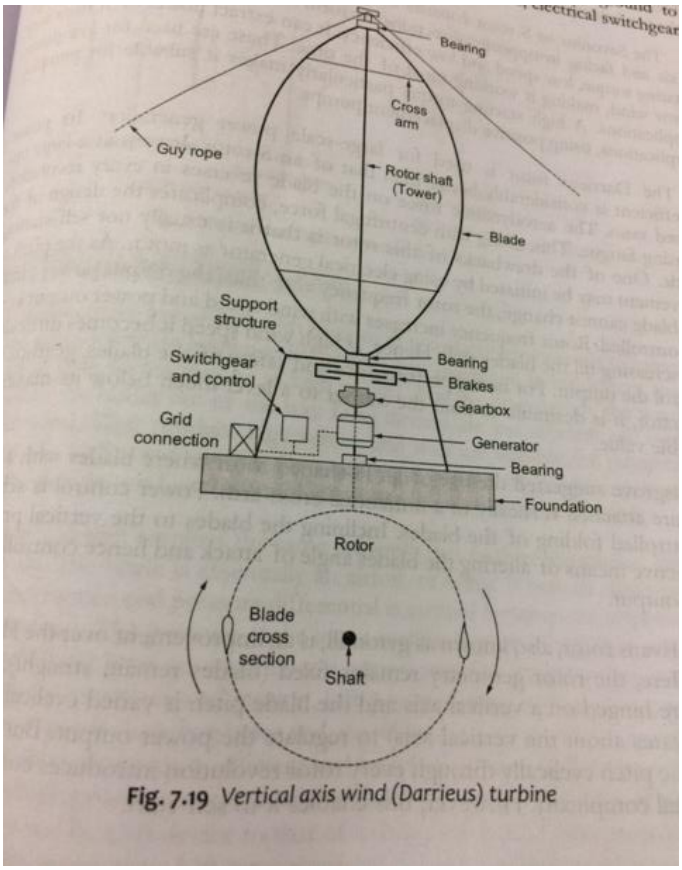


Fig. 7.19 *Vertical axis wind (Darrieus) turbine*

Fig shows the constructional details of vertical axis wind turbine generator. In this turbine, the rotor turbine is perpendicular to the ground. The following are the important components of vertical axis wind turbine generator.

Rotor shaft: The vertical rotor shaft is mounted between the top and bottom bearings above the support structure. The upper part of the rotor shaft is supported by guy wires. The height of the rotor shaft is around 100m.

Blades: the rotor shaft has two or three thin curved blades which converts wind energy into mechanical energy. The blades can accept wind from any direction and therefore it does not require yaw control.

Support structure: The support structure is provided at the ground and it has gear box, brakes, generator and switch gear controls. The gear box increases the speed of the turbine shaft from 30-60 rpm to match with generator speed of 1500-1800 rpm. The brakes stop the rotation of shaft in case of overload or system failure. The generator converts rotational energy of the shaft into electrical energy. The electrical energy is fed to the grid through switch gear control.

Vertical Axis Wind Turbine Generator

Comparison between horizontal axis and vertical axis wind turbine generator:

Sl No	Horizontal axis wind turbine	Vertical axis wind turbine
1	In this turbine, the shaft is mounted horizontally parallel to the ground.	In this turbine, the shaft is mounted on a vertical axis perpendicular to the ground.
2	They use tower for support.	They use guy wires for support.
3	Gear box and generator are mounted above the ground on a tower.	Gearbox and generator are mounted at ground level.
4	Installation and maintenance are difficult as the equipments are at height.	Easy installation and maintenance as all the equipments are at ground level.
5	Yaw mechanism is required to align the blades to face the wind.	Yaw mechanism is not needed as the rotor rotates for any wind direction.
6	Turbine rotor is at higher elevation, so higher wind speed and higher efficiency.	Turbine rotor is almost at ground level, so lower wind speed and lower efficiency.
7	They take little ground space.	They take large ground space.
8	Energy output is more.	Energy output is less.

Environmental Impacts of Wind Power Plant:

The environmental impact of wind turbine power plant is very less when compared to the fossil fuel power plants. But there are certain negative impacts of wind power plants on the environment. They are as follows:

Land Use impact: Wind turbine installations use a large area. But the vegetation clearing and ground disturbance is very less when compared with thermal power stations. Less than one acre per megawatt of land is disturbed permanently by wind power plant. The remaining land can be used for other purposes like livestock grazing, agriculture, highways, etc.

Noise impact: Noise from wind turbines is caused from two sources:

- Mechanical noise caused by the gearbox and generator
- Aerodynamic noise caused by interaction of the turbine blades with the wind.

Noise from the wind turbine may result in stress and stress related diseases in human beings. By making design changes, using insulating materials and by using proper sites the noise impacts can be minimized.

Visual Impacts: Due to their height, wind turbines are highly visible structures in any landscape. They may result in aesthetic impacts to the landscape.

Bird and bat mortality: Bird and bat deaths by colliding with rotor blades are one of the most biological impacts of wind turbines. The risk of bird collisions can be reduced by increasing the visibility of rotor blades and by keeping the bird migration paths free.

Other impacts: Wind turbines do not produce global warming emissions during operation. But there are certain emissions produced during manufacturing of turbines, transportation, commissioning, maintenance and decommissioning. Another impact of wind turbines is that they interfere with radar and telecommunication facilities.

Unit-5

Tidal power plant

Tidal energy: Tidal energy is the natural rise and fall of sea waters caused by the interaction of gravitational fields of the sun and the moon .The ocean level difference caused due to tides contains large amount of potential energy. The electricity generated using the potential energy of tides is called tidal power.

The highest level of tidal water is known as Flood tide or high tide. The lowest level is known as Ebb tide or low tide .The level difference between high tide and low tide is known as tidal range .The tidal range varies greatly with location. The tidal range varies from few cm to 8-11 m around the world. Only sites with tidal range of 5m and above are considered suitable for power generation.

Origin and nature of tidal energy:

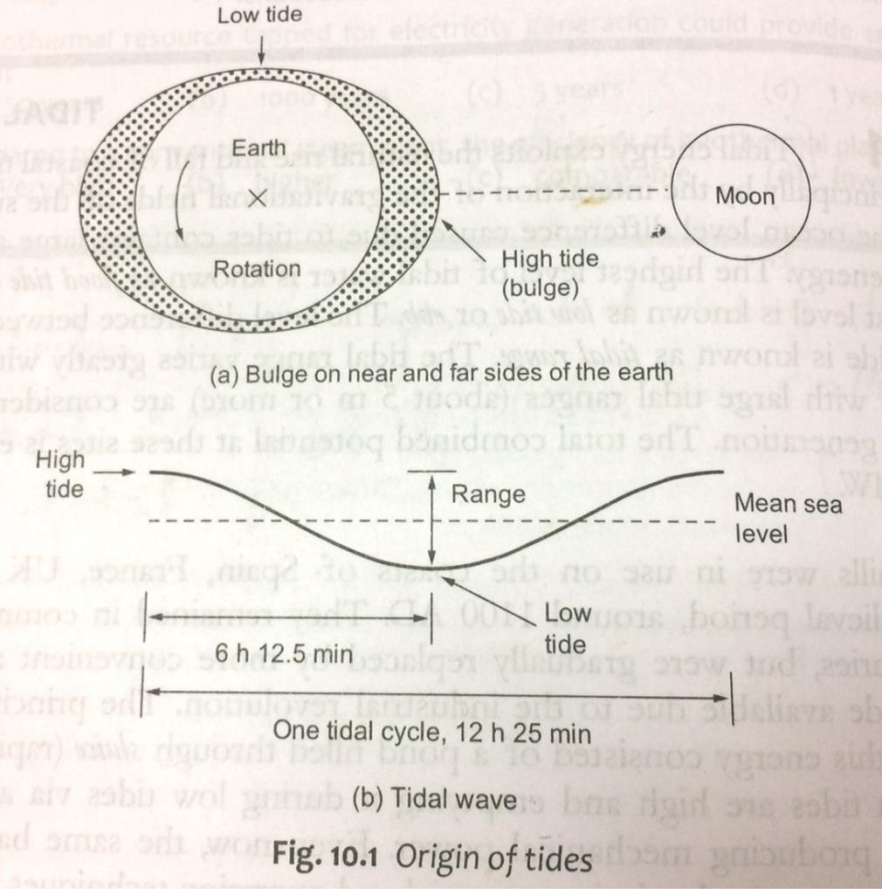


Fig. 10.1 *Origin of tides*

Tides are produced by the gravitational attraction of the moon and the sun acting upon the rotating earth. The tide produced due to gravitational force of the moon is about 70% and that due to sun is about 30%. Due to such gravitational force, the surface water is pulled away from the earth on the side facing the moon, at the same time the earth is pulled away from the water on the opposite side. Thus high tide occurs in these areas and low tides occur at the intermediate areas. As the earth rotates,

the position of the earth with respect to moon changes and hence tidal position also changes. This causes high and low tides to be periodically and continuously produced.

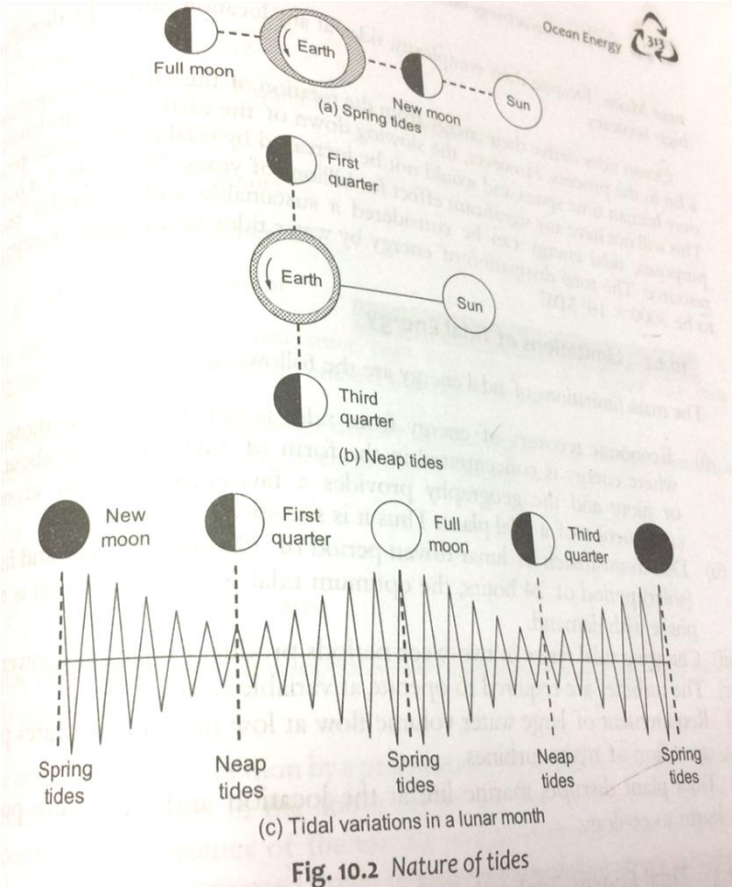


Fig. 10.2 Nature of tides

The nature of tidal energy depends on the position of the sun, earth and the moon. When the sun, earth and moon are aligned in a line, the lunar and solar tides will be in phase producing maximum tidal range. These are called spring tides and they occur on full moon day and new moon day.

When sun- earth and moon-earth are at perpendicular directions, the solar and lunar tides out of phase producing minimum tidal range. These tides are called neap tides and they occur at first and third quarter of moon cycle.

https://youtu.be/oewqNVNanak

Factors to be considered for site selection of tidal power plant:

- The tidal range at the selected site should be at least 5m and above.
- There should not be appreciable change in tidal pattern at the proposed site.
- The site selected for the tidal power plant should be free from wave attack of the sea.
- The selected site should not have excessive sediment load.

Types of tidal power plant:

There are two types of tidal power plant, namely:

- Single basin type tidal power plant
- Double basin type tidal power plant

Important components of tidal power plant:

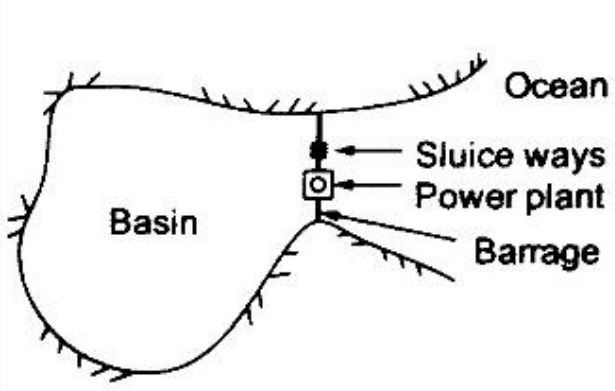
Dam: It is a barrier constructed to hold water.

Basin: It is a vast area of land where water gets collected.

Sluice ways: These are the controlled gates used to fill the basin during high tide and empty the basin during low tide .

Turbine-Generator set: Whenever the water is filled in the basin or emptied from the basin, the turbine installed in the sluice ways rotate. This in turn rotates the generator to generate electricity.

Single basin type tidal power plant:



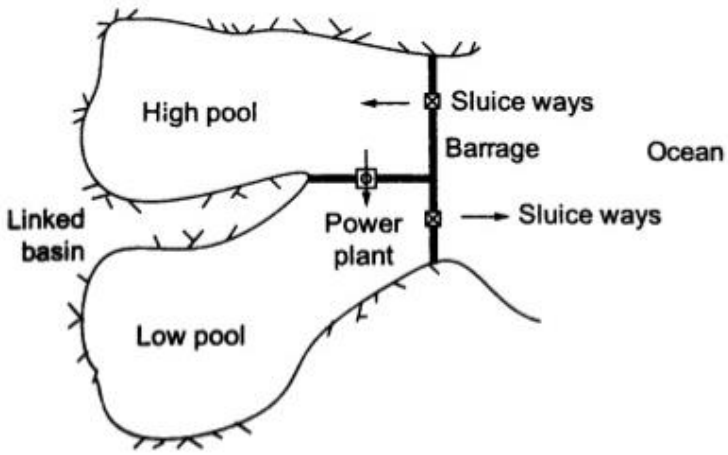
In a single basin type tidal power plant, there is one basin behind the dam. The basin is filled from the ocean at high tide (flood tide) and is emptied at low tide (Ebb tide).

When the ocean is at high tide, the water level in the basin is at low level and there is a filling process. When the ocean is at low tide, the water level in the basin is at high level and the basin gets emptied .The flow of water in both the directions is used to drive a reversible water turbine installed in the dam. This turbine in turn rotates the generator to generate electricity.

https://youtu.be/qRUl1mJQHmc

Double basin type of tidal power plant:

- **HIGH POOL**
  - FILLED DURING HIGH TIDE
- **LOW POOL**
  - EMPTIED DURING LOW TIDE



In this system, an inland basin is created by dam-A. Dam-B divides this basin into two pools namely high pool and low pool. The sluice ways located in the dam-A are such that, the high pool gets filled during high tide and low pool gets emptied during low tide. The water flows from high pool to low pool through the turbine generator set located in dam B. This causes the turbine to rotate which in turn rotates the generator to generate electricity. In this type of power plant, the fluctuation in the water head is minimum. Therefore continuous uniform power is generated.

https://youtu.be/3XQKzC9BpRA

Advantages of tidal power plant:

- Tidal power plant is free from pollution.
- It uses renewable source and does not depends on rain.
- It does not produce any waste and hence it does not cause pollution.
- It does not require large area of valuable land because it is located on sea shore.
- Tidal power plant has the capacity to meet the peak load demand when it works in combination with hydel or thermal power plant.
- Efficiency of tidal power plant is about 80% which is considerably high as compared to fossil fuels which have almost 30% efficiency.

Disadvantage of tidal power plant:-

- Tidal power can be generated only in the area where tidal range is 5m and above.
- The output power of tidal power plant varies because of variation in tidal range.
- The turbines in the tidal power plant are required to operate at variable load.
- Tidal power plant disturbs the marine life and hence it causes harm to the ecology.
- Sedimentation of the basin is a problem associated with tidal power plant.
- Power transmission cost is high because tidal plants are located away from the load centres.
- Capital cost of tidal plant is high.
- Construction of plant in sea is difficult

WAVE ENERGY

Introduction:

Waves are caused by the transfer of wind energy to the water on the ocean surface. The rate of transfer of energy depends on the wind speed the distance for which the wind interacts with water. Compared to other renewable energy sources like solar, wind, etc, the wave contains enormous energy. The power in the wave is directly proportional to its amplitude and period of motion. Larger waves in deep ocean can store their energy for many days and can carry for great distances.

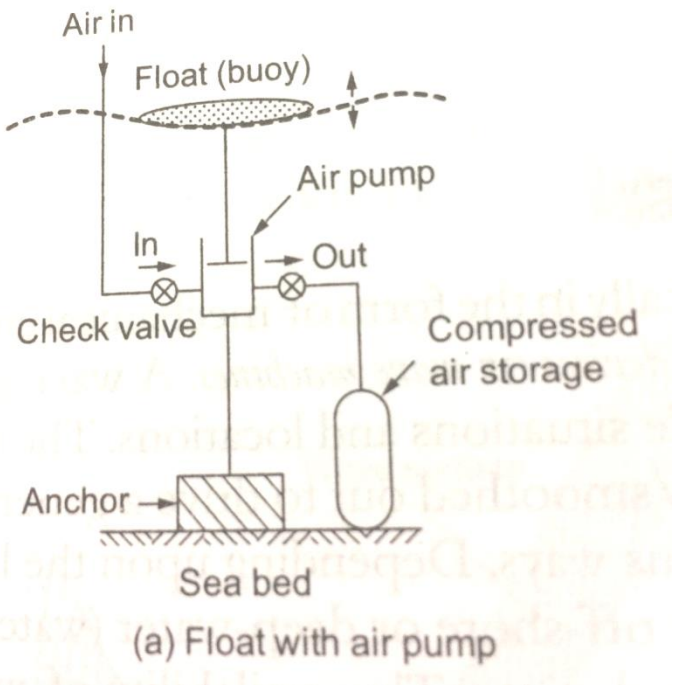
Wave energy conversion devices:

Energy in the wave is converted into mechanical energy using wave energy converters, also known as wave devices or wave machines. A wave device may be placed in the ocean at suitable locations. The fluctuating mechanical energy obtained from the wave device is smoothened out to drive an electrical generator to generate electricity.

Depending on the actuating mechanism used in the wave devices to capture wave energy, they are classified as:

- Heaving float type
- Pitching type
- Heaving and pitching float type

Heaving float type:

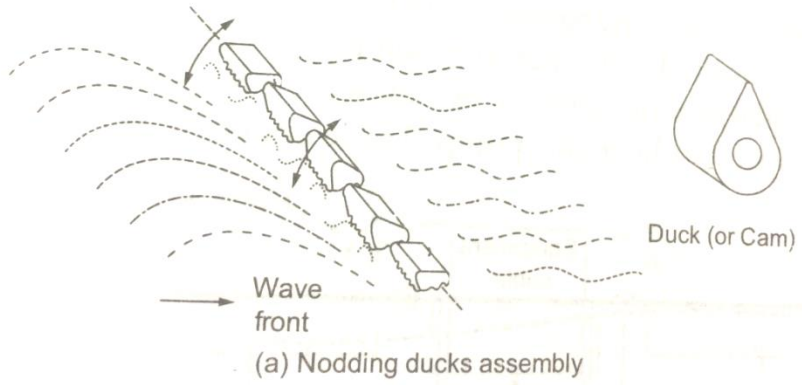


(a) Float with air pump

This type of device uses a float placed on the surface of the water. As the wave water rises and falls, the float also moves up and down. The float is coupled with the piston of the air pump. Thus with the movement of float, the piston also moves up and down. The air pump stores energy in the form of compressed air in the storage cylinder. Many such float operated air pumps are anchored in the sea bed. This compressed air in turn operates the air turbine-generator set to generate electricity.

https://youtu.be/EsRzTl6Q24E

Pitching type:



In pitching type, several cam shaped floating pieces (also known as nodding ducks) are hinged to a common flexible linkage to form a nodding duck assembly. The duck swings forward when the wave enters and swings backward for the trough of the wave. The oscillatory motion of the duck assembly is converted into rotating motion of the shaft using ratchet and wheel mechanism. The power of the rotating shaft is transferred to the generator through linkages and gears. The generator rotates to generate electricity.

https://youtu.be/NTUFPSs5hAI

Heaving and pitching float type:

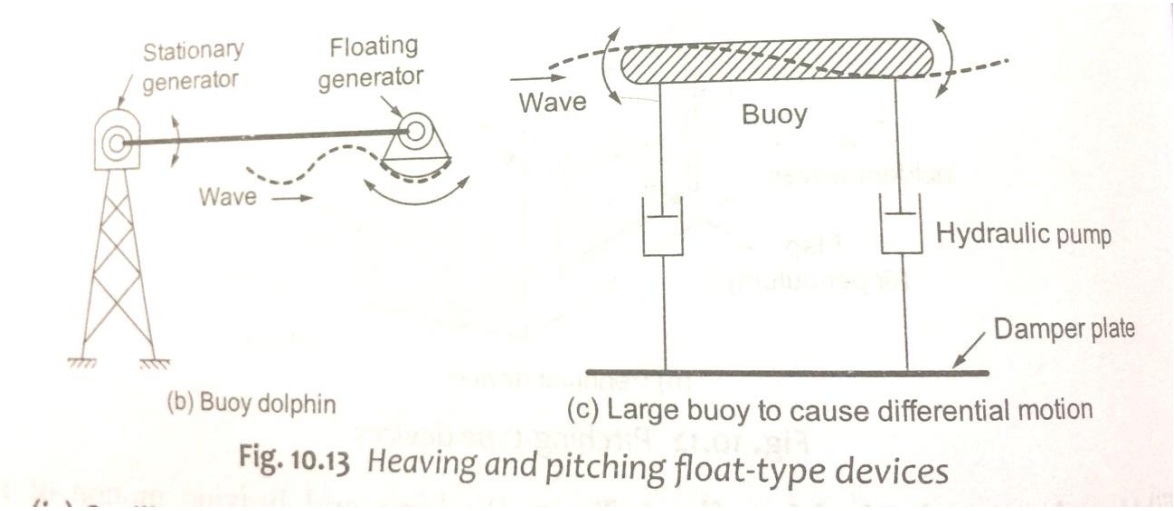


Fig. 10.13 *Heaving and pitching float-type devices*

In this type both heaving and pitching motion of the float is used to extract wave energy. A specially shaped float known as dolphin is used for this purpose. When the wave passes over the dolphin, it rolls

and also heaves as shown in the figure. The two motions of the dolphin are converted into unidirectional motion using ratchet wheel arrangement. This in turn operates the stationary generator and floating to generate electricity.

In some other devices, a large float is used. The wave produces a differential motion between the two ends of the float. This motion can be used to operate a hydraulic pump as shown in the figure.

https://youtu.be/_bdeNuRF-yE

Advantages of wave energy:

- It is a free and renewable energy source.
- No wastes or greenhouse gases are produced and hence it is pollution free
- The amount of energy concentrated in the wave is very much greater than that of solar and wind energy.
- Wave devices do not need huge land masses like solar energy and wind energy.
- Wave energy is easily predictable and can be used to calculate the amount of energy it can produce.
- Wave devices can be installed far from the shore or can be entirely submerged in the water. Therefore the devices produce minimum visual impact.

Disadvantages of wave energy:

- Irregularity in wave patterns in amplitude, phase and direction makes it difficult to extract wave energy efficiently.
- Wave energy converters must be capable of withstanding severe stresses due to storms.
- Due to corrosive nature of sea water, the life of wave devices is limited.
- Wave devices are very complicated and expensive to construct.
- The maintenance, repair and replacement of wave devices are also expensive.
- The wave devices may obstruct ships and also disturb marine life.
- The slow and irregular motion of the wave is required to be coupled to a generator requiring high and constant speed of motion.

OCEAN THERMAL ENERGY

Introduction:

Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm surface water.

The sun's heat warms the surface water a lot more than the deep ocean water, which creates the ocean thermal energy. The oceans cover more than 70% of Earth's surface and capture a large part of the sun's heat in the upper layers, making them the world's largest solar collectors and energy storage system. Utilizing just a small portion of this energy, can cover the global energy need.

Ocean Thermal Energy Conversion is based on the thermodynamic principle where heat flows from high temperature surface water (heat source) to the low temperature deep water (heat sink) through an engine converting a part of this heat into mechanical energy and in turn electrical energy. A minimum temperature difference of 20^0C is required for energy conversion.

There are two methods ocean thermal energy conversion,

- Open cycle OTEC system or Claude cycle
- Closed cycle OTEC system or Anderson cycle

Open cycle OTEC system or Claude cycle

In open cycle OTEC system, the warm ocean water is directly used as working fluid. Figure shows the block diagram of open cycle OTEC system.

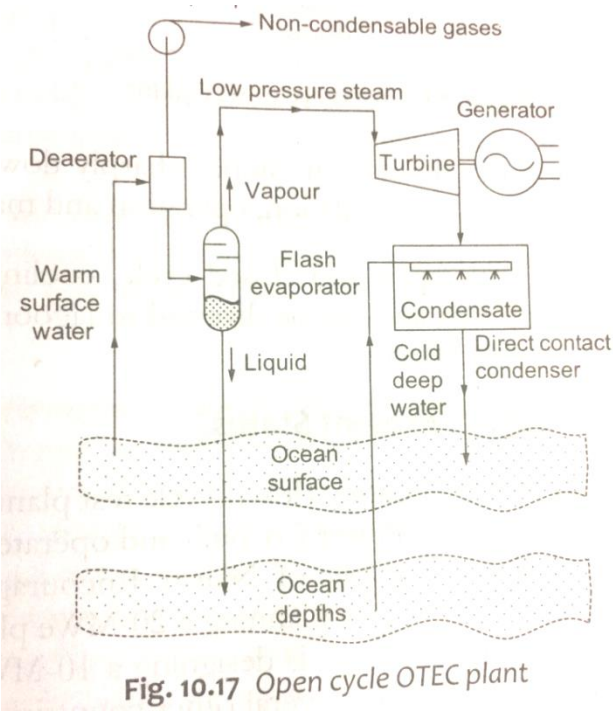


Fig. 10.17 *Open cycle OTEC plant*

The warm water from the ocean surface is fed to the flash evaporator. Here the warm water is evaporated under partial vacuum. The low pressure steam thus obtained is used to run a steam turbine. The turbine in turn runs a generator to generate electricity.

The exhaust steam from the turbine is condensed in a direct contact condenser. The direct contact condenser uses cold water drawn from the ocean at a depth of 1000m as cooling water. The resulting mixture of used cooling water and condensate is disposed in the ocean.

Note: If surface contact type of condenser is used, the condensate can be used as desalinated water.

https://youtu.be/wriS0ZM9IJM

Closed cycle OTEC system or Anderson cycle

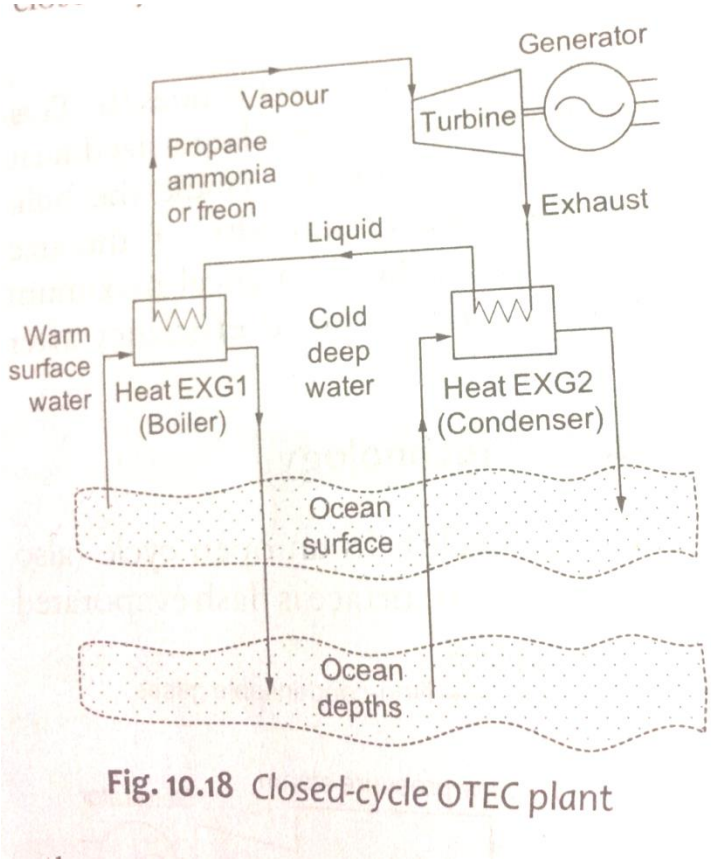


Fig. 10.18 Closed-cycle OTEC plant

In closed cycle OTEC system, low boiling point fluid such as ammonia, Freon or propane is used as working fluid. Figure shows the block diagram of closed cycle OTEC system.

The warm surface water is drawn and is used to evaporate low boiling point fluid such as ammonia, Freon or propane in the heat exchanger. The high pressure vapour of ammonia, Freon or propane is passed through the turbine which converts thermal energy into mechanical energy. The generator coupled to the turbine converts mechanical energy into electrical energy.

The low pressure exhaust vapour from the turbine is condensed in the condenser. The condenser uses cold water drawn from the ocean at a depth of 1000m for condensing. The condensate is again pumped back to the heat exchanger for next cycle of operation.

The working fluid used in closed cycle system has higher operating pressure and lower specific volume than that of water in open cycle system. Hence the size and cost of the turbine that is used in closed cycle system is much less when compared to that of open cycle system.

https://youtu.be/Wde22EbZt50

Advantages of OTEC system

- OTEC Generates electricity with no greenhouse emissions.
- It is totally a renewable source of energy.
- OTEC produces continuous energy with very little daily or seasonal variation.

- It creates useful by products like desalinated water.
- It is an unlimited source of free energy especially in tropical waters.

Disadvantages of OTEC system

- Capital investment is very high.
- Due to small temperature difference in between the surface water and deep water, conversion efficiency is very low about 3-4%.
- Low efficiency, high capital cost and maintenance cost makes them uneconomical for small plant
- Needs a large difference in temperature between surface and deep water for best results.
- Suitable only for tropical locations.
- Plant needs safe location from storms and surf.

Urban waste to energy conversion

Municipal Solid Waste (MSW) is a solid waste generated by households, commercial and industrial operations. Disposal of MSW is major problem in big cities, where large quantity of waste has to be disposed far away from city centres. The solution for this problem is to use MSW incineration plant. Here the waste biomass is used as an energy source for electricity generation for the city itself. The small residue of used biomass (ash) can be disposed in the landfills.

MSW incineration plant

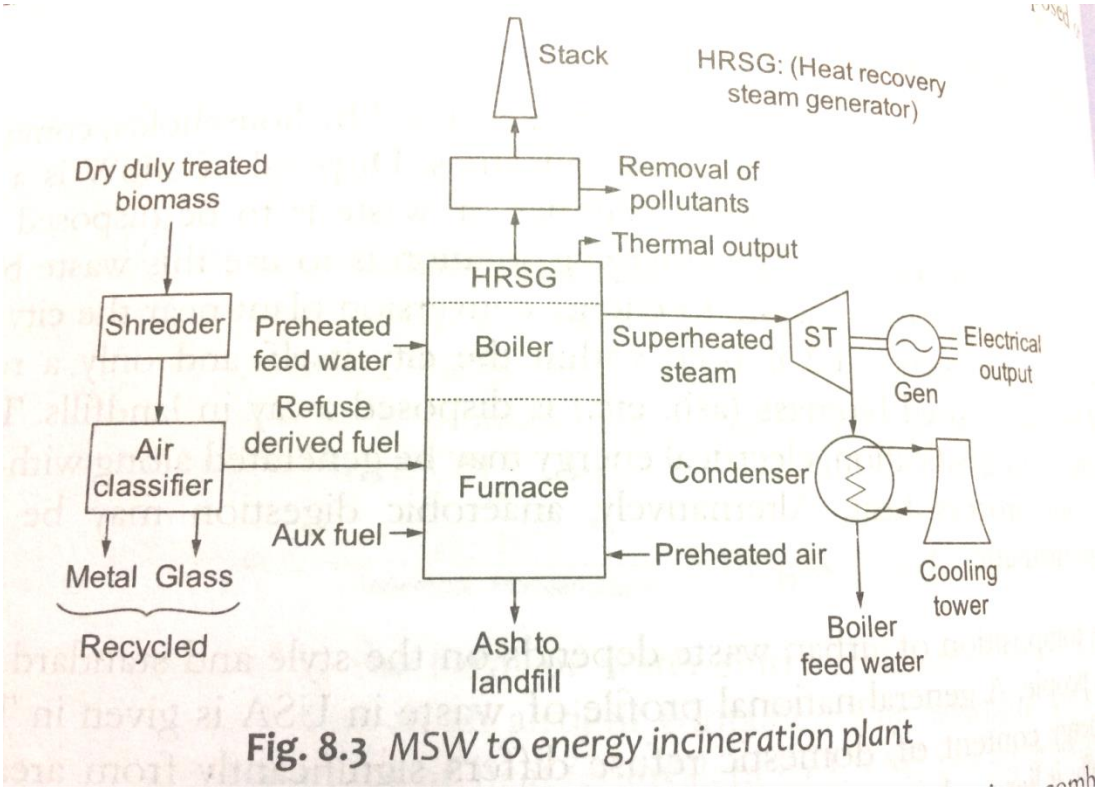


Fig. 8.3 *MSW to energy incineration plant*

Figure shows the block diagram of MSW to energy incineration plant. The dry biomass is torn (shredded) into small pieces of 2.5 cm in diameter. The air stream separates the lighter refuse derived

fuel (RDF) from the heavier metal and glass pieces. These glass and metal pieces can recycled and reused. The RDF thus obtained is burnt in a furnace at about 1000^0C to produce steam in the boiler. The combustion process may be assisted by using auxiliary fuel if needed. The superheated steam thus obtained from the boiler is used to run steam turbine coupled with an alternator to generate electricity. The heat recovery steam generator extracts maximum possible heat from the flue gases to form thermal output. The flue gases are then discharged in to atmosphere through the stack after removing pollutants such as particulate matter and oxides of nitrogen and sulphur. The ash is removed and disposed in the landfills.

https://youtu.be/67Z10YpC6DU

BIOMASS POWER PLANT

Importance and Scope:

Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities. It is derived from numerous sources, including the by-products from the timber industry, agricultural crops, raw material from the forest, major parts of household waste and wood.

Biomass is a renewable energy resource and it does not add carbon dioxide to the atmosphere. It can be used to generate electricity with the same equipment or power plants that are now burning fossil fuels. In India, biomass fuel is the most important fuel used in over 90% of the rural households and about 15% of the urban households. Biomass can be used directly as fuel instead of coal in the traditional furnaces or it can also be converted into a more convenient-to-use gaseous form of fuel called biogas.

Biogas is produced by the anaerobic digestion or fermentation of biomass in the presence of microorganisms and moisture and in the absence of oxygen at temperature of $35\text{-}70^0$C. Biogas mainly contains methane (CH_4) and carbon dioxide (CO_2) and small amounts of hydrogen sulphide (H_2S). Biogas can be used as a fuel for any heating purpose, such as cooking or it can also be used to produce electricity.

Factors to be considered for site selection of biogas plants

- **Distance:** The distance between the plant and the site of gas consumption should be less in order to pump the gas economically and to minimize gas leakage. For a gas plant capacity of $2m^3$, optimum distance is 10m.
- **Minimum gradient:** For conveying the gas a minimum gradient of 1% must be available in the line.
- **Open space:** The sunlight should fall on the plant as temperature between 15^oC and 30^oC is essential for the gas generation at good rate.
- **Distance from wells:** The seepage of fermented slurry may pollute the well water. Hence a minimum of 15m should be maintained from the wells.
- **Space requirement:** Sufficient space must be available for day to day operation and maintenance.

- **Availability of water:** Plenty of water must be available as cow dung slurry with a solid concentration of 7% to 9% is used.
- **Source of cow dung:** The distance between the cow dung source and the gas plant should be less to reduce the transportation cost.

Line diagram of biogas plant

Figure shows the line diagram of biogas power plant. The different components of biogas plant include:

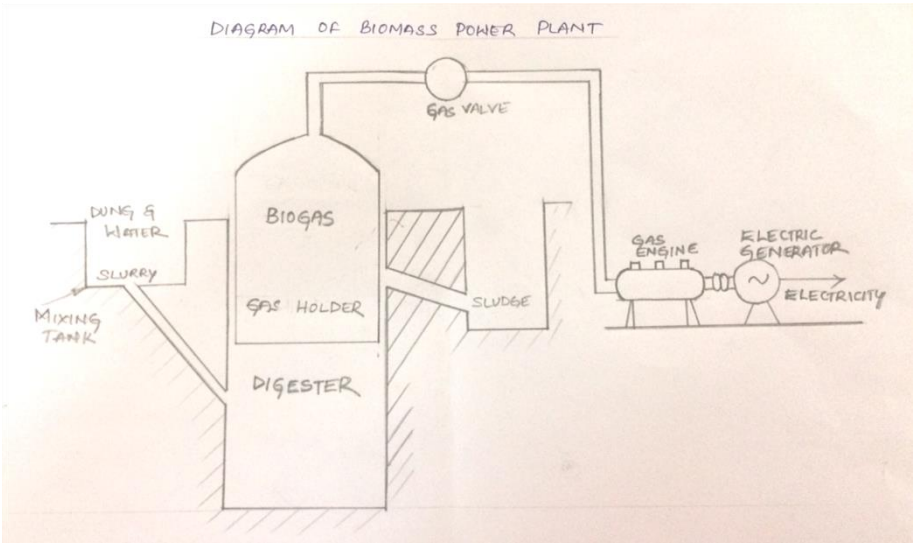
Mixing Tank: It is used to mix dung and water to produce slurry to the digester

Digester: Digester is an underground chamber where anaerobic digestion of slurry takes place to produce biogas. In this area, the bacteria and other microorganisms transform the slurry into compost and this slowly decays over time to produce biogas. The entire process takes place in the absence of oxygen, at atmospheric pressure and temperature of 35 to 70^0C.

Gas holder: After the required amount of biogas has been produced, the biogas digester moves the gas into a chamber known as gas holder. This holds the biogas and makes it available for further use.

Sludge holder: The waste sludge after digestion of slurry is fed to the sludge holder.

Gas Engine and Generator: The gas from the gas holder drives the gas engine. The gas engine inturn drives the electrical generator to generate electricity.



https://youtu.be/3UafRz3QeO8

https://youtu.be/Zu8Wr-AGgNU

Types of biogas plants:

Biogas plants are classified i) Batch type and ii) Continuous type. Continuous type plants are further classified as a) fixed dome type and b) floating drum type

The batch type: In batch type plant, digester is charged and allowed to produce gas for 40-50 days. Once charged, it starts supplying gas after 8-10 days and continuous to do so for about 40-50 days. After the digestion is complete, the residue is emptied and digester is filled again. A battery of digesters is used and they are charged and emptied one by one so that continuous supply of gas is maintained in common gas holder.

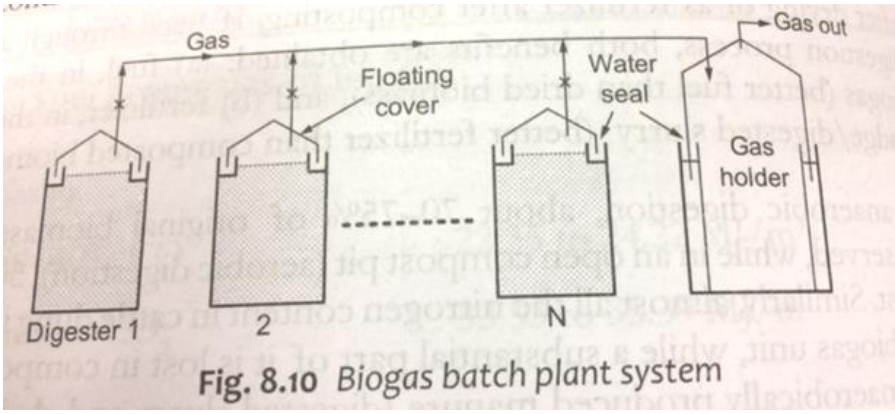


Fig. 8.10 *Biogas batch plant system*

Continuous type: In continuous type biogas plant, the supply of the gas is continuous and the digester is fed with biomass regularly. The gas produced is stored in a gas holder which can be drawn out when required. The digested slurry is removed out through an outlet.

Continuous biogas plants may be single stage or two stage. In single stage, acid production and methane production are carried out in the same chamber without barrier. In two stage, acid production is carried out in a separate chamber and only diluted acids are fed into the second chamber where biogas production takes place. Single stage plants are economical, simple and easy to operate and they are generally used for small and medium size biogas plants. However, the two stage biogas plants are costlier, difficult in operation and maintenance but they produce more gas.

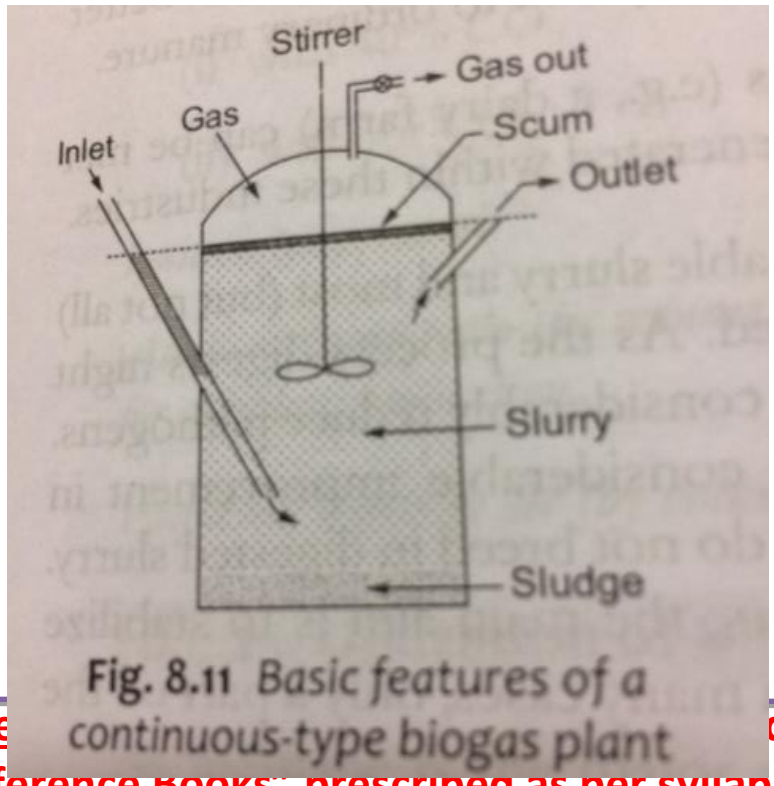


Fig. 8.11 *Basic features of a continuous-type biogas plant*

Floating Drum type (movable drum type): The movable drum type consists of a digester with an inlet on one side for feeding slurry and an outlet on the other side for removing digested slurry. The gas collects in a steel drum which is inverted over the slurry. The drum floats as the gas gets collected and it sinks when the gas is taken out from the top.

Fixed dome type: A fixed-dome plant consists of a digester with a fixed, non-movable gas holder, which sits on top of the digester. When gas production starts, the pressure inside the digester increases and the spent slurry is displaced into the displacement tank. Gas pressure increases when the volume of gas stored in gas holder increases. If there is a little gas in the gas holder the gas pressure is low.

Floating/Movable drum type biogas plant:

The floating gas holder type of biogas plant has the following chambers/ sections:

- **Mixing pit**- It is present above the ground for preparing slurry.
- **Digester** - Deep underground well-like structure. It is divided into two chambers namely inlet chamber and outlet chamber by a partition wall in between. It has two long cement pipes namely
    - **Inlet pipe** opening into the inlet chamber for introduction of slurry.
    - **Outlet pipe** opening into the outlet pit for removal of spent slurry.
- **Gas holder** – It is an inverted steel drum resting above the digester.
- **Outlet pit**- It is present above the ground for storing spent slurry

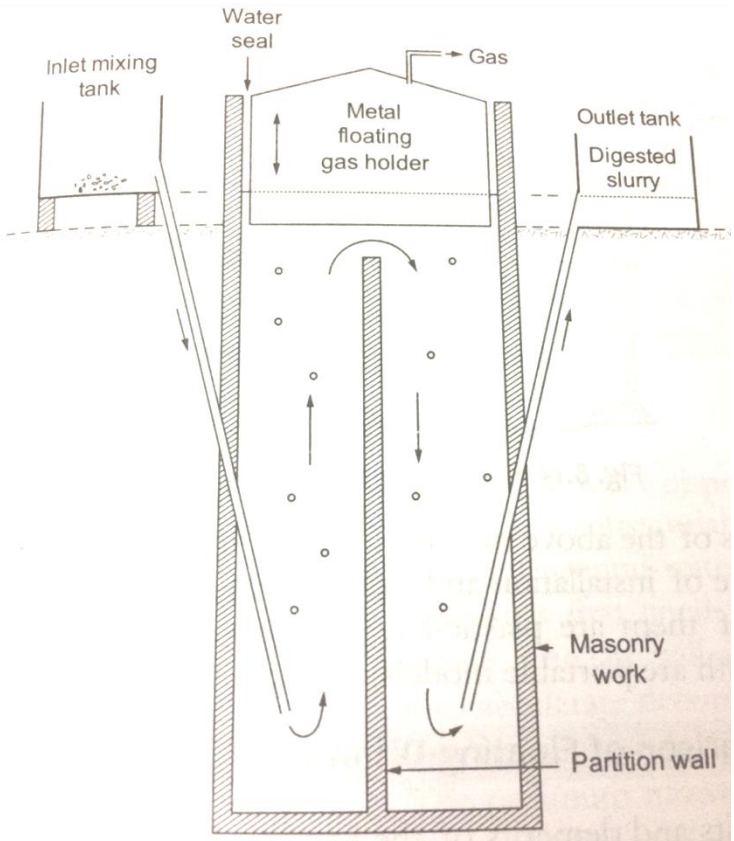


Fig. 8.12 *Floating-drum-type biogas plant*

Working of floating drum type biogas plant:

Slurry (mixture of equal quantities of biomass and water) is prepared in the mixing tank.
The prepared slurry is fed into the inlet chamber of the digester through the inlet pipe.
The plant is left unused for about two months and introduction of slurry is stopped.
During this period, anaerobic fermentation of slurry takes place in the presence of water and produces biogas in the digester.
Biogas being lighter rises up and starts collecting in the gas holder. The gas holder now starts moving up.
When the outlet chamber gets filled with the spent slurry, the excess slurry is forced out through the outlet pipe into the outlet pit. This is later used as manure for plants.
The gas valve of the gas outlet is opened to get a supply of biogas.

Fixed dome type biogas plant:

The fixed dome biogas plant is a brick and cement structure having the following sections:

- **Mixing tank:** It is present above the ground level where slurry is prepared.
- **Inlet pipe:** The slurry is fed into digester through a sloping inlet pipe.
- **Digester:** The digester is a huge tank with a dome like ceiling. The ceiling of the digester has an outlet with a valve for the supply of biogas.
- **Displacement tank:** The digester opens from below into a displacement tank where spent slurry is stored.

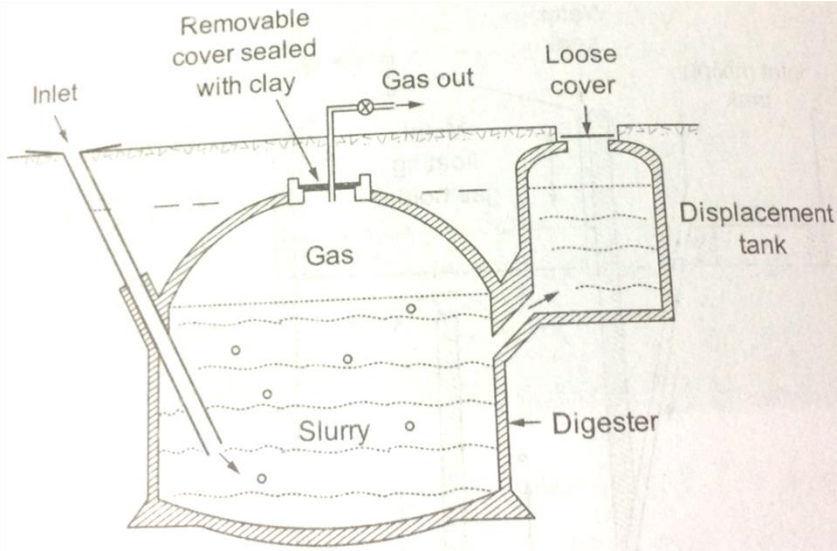


Fig. 8.13 *Fixed-dome-type biogas plant*

Working of fixed dome type biogas plant:

- Slurry (mixture of equal quantities of biomass and water) is prepared in the mixing tank.
- The slurry is fed into the digester through the inlet pipe.
- When the digester is partially filled with the slurry, the introduction of slurry is stopped and the plant is left unused for about two months.
- During these two months, anaerobic fermentation of slurry takes place in the presence of water and produces biogas in the digester.
- The biogas starts collecting in the dome of the digester.
- As more and more biogas starts collecting, the pressure exerted by the biogas forces the spent slurry into the displacement chamber which can be used as manure for plants.
- The gas valve is opened whenever a supply of biogas is required.

https://youtu.be/H31zuGZ0_GY

Comparison between movable drum type and fixed dome type:

Floating/Movable drum type	Fixed dome type
Digester and gas holder are separate units	Digester and gas holder is a single unit
Gas holder is floating and is above the ground	Gas holder is fixed and is under ground
Gas produced per unit volume of digester is more	Gas produced per unit volume of digester is less
It has corrosion problem	No corrosion problem
Needs more maintenance because of movable parts	Needs less maintenance
Cost of construction and maintenance is more	Low cost of construction and maintenance
It has constant gas pressure	It has variable gas pressure
Gas leakage is less likely	Gas leakage is more likely

Advantages of biogas plant

- Biogas is a renewable fuel that can be used to produce heat, power and as a vehicle fuel
- Biogas plants use waste to generate energy.
- Biogas plants considerably reduce the greenhouse effect by recycling waste.
- Digested slurry of the biogas plant can be used as fertilizer.
- They do not cause pollution.
- Running cost is low because they use biological waste as fuel which is free of cost.

Disadvantages of biogas plant

- They produce a limited quantity of energy.
- There is little or no control on the rate of gas production.
- Gas generation needs sufficient time.
- They affect well water when placed near the wells.
- Experts are required for the design and construction
- Sulphurous compounds of the biogas can produce foul smell.

Fuel cell

Definition: Fuel cell is an electrochemical energy conversion device that converts chemical energy of the fuel directly into DC electrical energy.

Fuel cell mainly uses hydrogen as fuel. Sometimes hydro-carbons such as natural gas are also used as fuel. Similar to a primary cell, the fuel cell consists of two electrodes with an electrolyte between them. The fuel is supplied to the negative electrode called anode and the oxidant is supplied to the positive electrode called cathode. Each fuel cell generates an average DC voltage of about 0.7V. Several cells are connected in series- parallel combination to increase the current and voltage.

Classification of fuel cell

Based on the type of electrolyte used, fuel cells are classified as:

- Phosphoric Acid Fuel Cell (PAFC)
- Alkaline Fuel Cell (AFC)
- Polymer Electrolytic Membrane Fuel Cell (PEMFC)
- Molten Carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)

Phosphoric Acid Fuel Cell (PAFC)

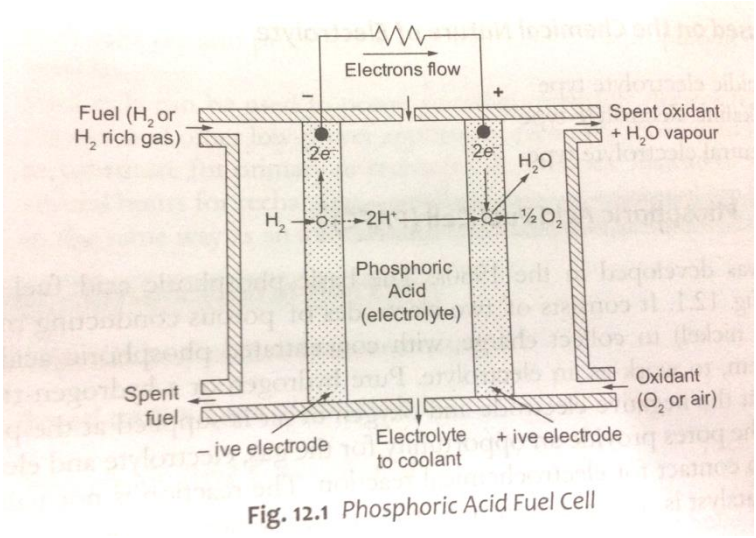


Fig. 12.1 *Phosphoric Acid Fuel Cell*

Fig. shows the schematic diagram of phosphoric acid fuel cell. It consists of two porous nickel electrodes immersed in the concentrated phosphoric acid working as an electrolyte. The anode has fine platinum powder as catalyst and cathode has nickel as catalyst. These catalysts accelerate the chemical reactions taking place at the electrodes.

The hydrogen fuel is fed to the anode of the fuel cell and oxygen is fed to the cathode of the fuel cell. At the anode, the hydrogen atom is split into positively charged H^+ ion and negatively charged electron.

$2H_2 \rightarrow 4H^+ + 4e^-$

The electrons originating at the anode travel thought the external wire to reach cathode creating direct electric current. The positive H^+ ions travel through the electrolyte to reach cathode. In the cathode, the

H^+ ions combine with electrons and oxygen atom to create water. This water created at the cathode is the waste product of the fuel cell.

$4H^+ + 4e^- + O_2 \rightarrow 2H_2O$

Combining the above equations indicates that, the fuel cell combines H_2 and O_2 to produce water and electrical energy. Therefore the overall reaction is,

$$2H_2 + O_2 \rightarrow 2\ H_2O$$

The operating temperature of PAFC is 150^0C to 200^0C. The average voltage generated by PAFC lies between 0.7 to 0.8V.

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Alkaline Fuel Cell (AFC)

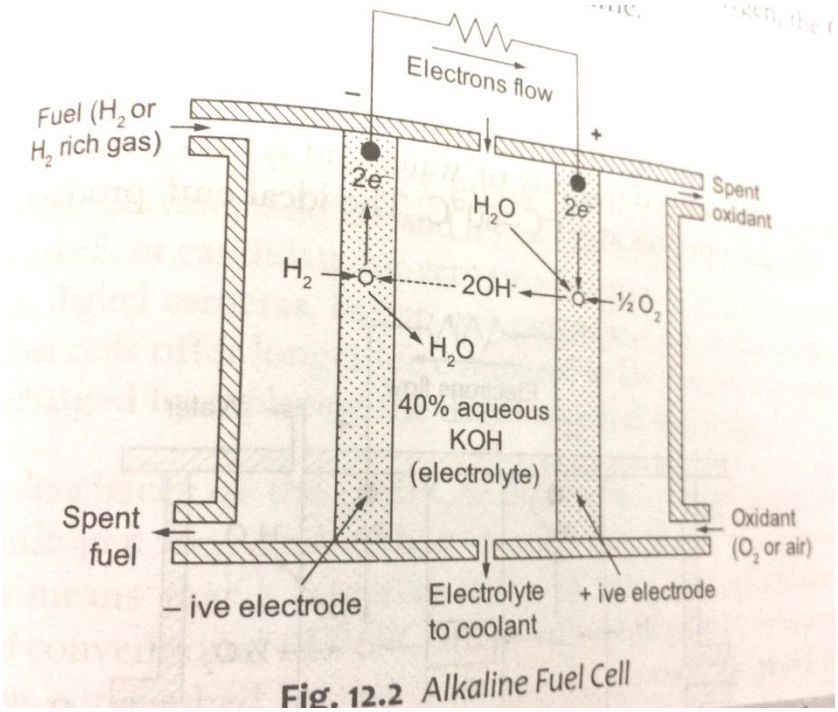

Fig. 12.2 Alkaline Fuel Cell

Fig. shows the schematic diagram of alkaline fuel cell. It consists of two porous nickel electrodes immersed in 40% aqueous solution of potassium hydroxide (KOH) working as an electrolyte. The nickel or silver powder is used as catalyst. The catalyst accelerates the chemical reactions taking place at the electrodes.

The hydrogen fuel is fed to the anode of the fuel cell and oxygen is fed to the cathode of the fuel cell. At the cathode, the oxygen, water from electrolyte and the electrons returning from the external circuit combine to produce OH^- ions.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

These OH^- ions migrate from cathode to the anode through the electrolyte. On reaching the anode, the OH^- ions combine with H_2 to produce water and electrons. The electrons originating at the anode travel thought the external wire to reach cathode creating direct electric current.

$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Combining the above equations indicates that, the AFC also combines H_2 and O_2 to produce water and electrical energy. Therefore the overall reaction is,

$2H_2 + O_2 \rightarrow 2H_2O$

The operating temperature of AFC is about 90^0C. The average voltage generated by AFC lies 1.1V

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Polymer Electrolytic Membrane Fuel Cell (PEMFC)

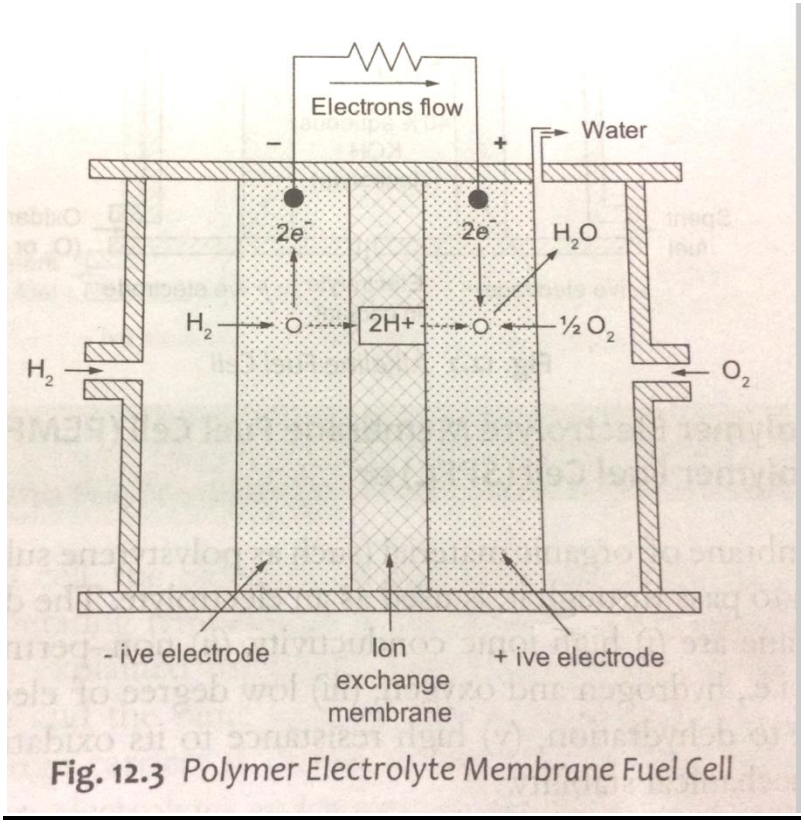


Fig. 12.3 Polymer Electrolyte Membrane Fuel Cell

Fig. shows the schematic diagram of Polymer Electrolytic Membrane Fuel Cell (PEMFC). It uses solid membrane of organic material such as polystyrene sulphonic acid as an electrolyte and porous carbon electrodes with platinum catalyst.

The hydrogen fuel fed to the fuel cell interacts with anode and gets converted into H+ ions and electrons.

$2H_2 \rightarrow 4H^+ + 4e^-$

The electrons originating at the anode travel thought the external wire to reach cathode creating direct electric current. The positive H^+ ions travel through the membrane to reach cathode. In the cathode, the H^+ ions combine with electrons and oxygen atom to create water. This water created at the cathode is the waste product of the fuel cell.

$4H^+ + 4e^- + O_2 \rightarrow 2H_2O$

Combining the above equations indicates that, the PEMFC combines H_2 and O_2 to produce water and electrical energy. Therefore the overall reaction is,

$$2H_2 + O_2 \rightarrow 2\ H_2O$$

The operating temperature of PEMFC is very low 40^0C to 60^0C. The ideal voltage generated by PEMFC is about 1.23V at 25^0C. They have less weight and volume and also deliver high power. Hence they are mainly used in vehicles such buses and cars.

https://youtu.be/_MsG9REFN3s

Performance limiting factors of fuel cell:

Fuel cells are designed to operate in specific types of conditions as stated below:

Oxygen is a key element required to complete the reaction, as it removes spent hydrogen from the system as water. If no oxygen is present, or not in enough quantity, the reaction will either slow down or stop completely.

Water management is important as it helps move hydrogen protons from the anode side across the membrane to the cathode side. If too much water moves across, then the cathode side can be easily "flooded'. Not enough water, then the membrane cannot transfer enough protons to facilitate the reaction.

Electrolytes in fuel cells are chemical compounds in liquid, molten or solid forms which transmit a specific ion or reactant from one electrode to another while preventing the protons from passing through them. The electrolyte of a fuel cell determines the operating temperature and the catalyst of the cell and these two factors determine the overall cost of the fuel cell.

In the chemical reaction of the fuel cell, the catalyst is required for the reaction to proceed faster and at a lower temperature. So far, the most excellent catalyst of fuel cell is the platinum. Platinum is a very expensive and scarce metal and several techniques are being developed to replace the use of precious metal like platinum.

Finally, the fuel used has an impact, both on the power of the system as well as its operating conditions. In the case of solid oxide fuel cells, the reaction needs to occur within 600ºC - 1000ºC, while alkaline fuel cells operate best between 40º -80ºC. Thus, balance between air, water and heat management determines the overall performance of a fuel cell system.

Losses in fuel cell

The actual voltage of a fuel cell is much less than the theoretical voltage. This voltage difference is caused by four major losses taking place in a fuel cell. They are as follows:

i) **Activation losses:** These are caused by the slowness of the reactions taking place on the surface of the electrode.

ii) **Fuel crossover and internal current:** From the concept of fuel cell, the electrolyte should only transports ion through the cell. However, a certain fuel diffusion and electron flow will also occur. It results the voltage losses of the fuel cell.

iii) **Ohmic losses:** The voltage losses are caused by the resistance to the flow of electrons through the material of the electrodes and various interconnections. This voltage drop is proportional to current density.

iv) **Mass transport or concentration losses:** The reactants cannot be delivered to the catalyst sites quickly either due to the low porosity of the electrode, or due to water flooding, or anything that prevents the reactant flows. This results in Mass transport or concentration losses.

Merits and demerits of fuel cell

Merits:

i. Fuel cells do not have any moving parts. Hence their operation is noise less and also they require less maintenance.
ii. Since chemical energy is directly converted into electrical energy the conversion efficiency is high.
iii. They do not cause emission pollution.
iv. Fuel cells can be installed near load centers. Hence transmission cost and losses are avoided.
v. No cooling water is needed as there is no use of condenser
vi. Water is the byproduct of the reaction taking place is fuel cell. This is useful in space and remote application.
vii. The efficiency of fuel cell can be raised up to 80% if the heat generated in fuel cell is utilized in co-generation plants.

Demerits:

i. High capital cost.
ii. Low life span due to heavy corrosion of electrodes.

Applications of fuel cell

i. They are used for central power generation.
ii. They are used for residential power of 5 to 10 KW
iii. They are used in space flights and in remote site applications.
iv. They are used to power electric vehicles for road and rail transport.
v. They are used in communication systems.
vi. They supply combined heat and power to commercial buildings, hospitals, military installation and airports.

Environmental Impact of fuel cells

Ideally the hydrogen fuel cell does not produce harmful emissions or pollutants because its exhaust contains only water vapour. But, the hydrogen used in the fuel cell comes from the reformation of hydro carbons such as methane and methanol. These hydro carbons are produced through harmful processes which can impact the environment.

When air is used as oxidant, the exhaust contains a small amount of nitrogen which is not a pollutant. It does not produce other pollutants such as particulate matter and oxides of nitrogen and sulphur. The heat generated in the fuel can be used in cogeneration plant. Hence cooling water is also not required.

In case of fuel cells employing hydrocarbons as fuel, the exhaust contains CO_2 which can impact the environment. But the amount of carbon dioxide emission is relatively less when compared to conventional power plants.

HYBRID PV SYSTEM

Solar photo voltaic system is unreliable source energy because it can supply energy only when there is solar radiation. The intensity of solar radiations gets affected during cloudy conditions. Hence to maintain the continuity of power supply, other sources such as diesel generators, wind generators or fuel cells are operated in conjunction with solar PV system. Such systems are known as hybrid PV systems.

Types of Hybrid PV System

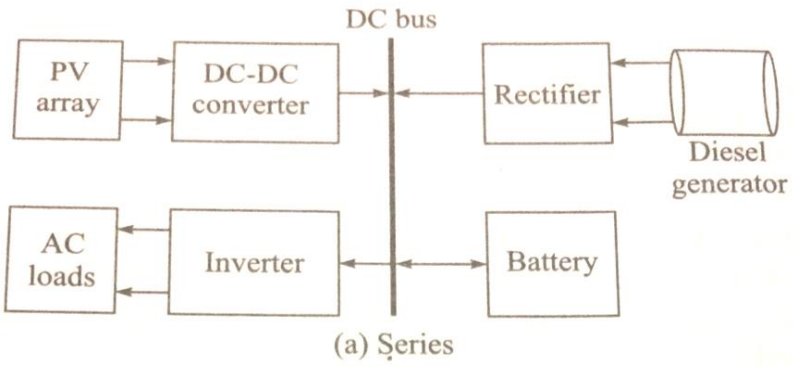
Hybrid PV systems are classified depending on the type of source used in conjunction with PV system. Accordingly, the following are the different types of hybrid PV systems:

- PV-diesel hybrid system
- PV-wind hybrid system
- PV-fuel cell hybrid system

PV-diesel hybrid system

The PV-diesel hybrid system is further classified as series hybrid, parallel hybrid and switched hybrid depending on the way in which diesel source is connected to the PV source.

Series hybrid: Figure shows the arrangement of series hybrid system. In this, the output of diesel generator is converted into DC using rectifier and then converted back to AC using an inverter. The inverter converts the DC to AC and feeds the AC load. The output of the PV array is also connected to the DC bus through DC-DC converter. The battery which is connected to the DC bus stores the excess power and also supplies power during starting of diesel generator.

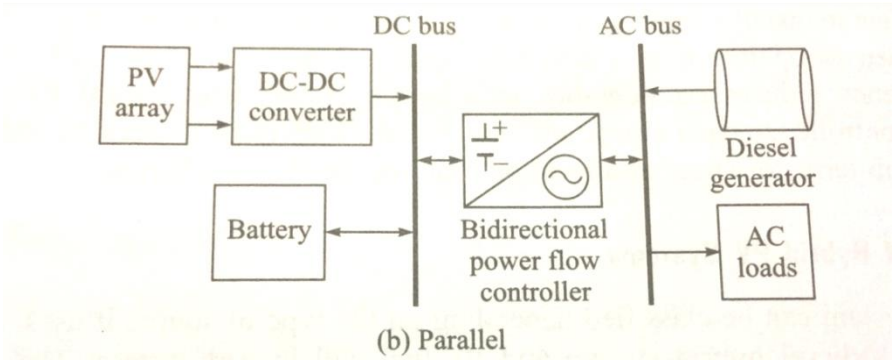


(a) Series

This configuration is known as series hybrid because the diesel generator is not directly connected in parallel with the inverter. Hence the inverter should be designed to take maximum load requirement. Also this system has low efficiency since diesel generator supplies power through series of rectifiers.

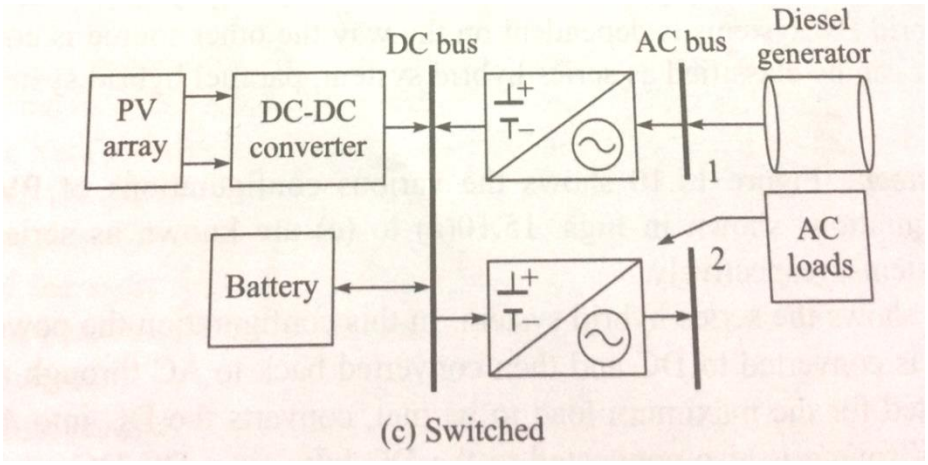
Parallel hybrid: Figure shows the arrangement of parallel hybrid system. The PV array is connected to the DC bus to which the battery is connected. The diesel generator and the inverter are connected in parallel to the AC bus. Bidirectional power flow controller is used for this purpose. As a result, the power

rating of the inverter is less and the efficiency of the system is more. But this system needs synchronization between the output voltage of the inverter and that of the diesel generator.



(b) Parallel

Switched hybrid: Figure shows the arrangement of switched hybrid system. The main feature of this system is that, at a given instance either diesel generator or inverter is connected to the load. But during switching between two sources the power is interrupted. The advantages of this system are: i) diesel generator can be directly connected to the load ii) efficiency of the system is more and iii) synchronization is not needed.



(c) Switched

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PV-wind hybrid system:

Figure shows the arrangement of PV-wind hybrid system. The variation of the wind velocity results in large changes in the frequency and output voltage of the generator. Hence the AC output of the wind generator is first converted to DC and then converted back to AC through the inverter. The DC output of the PV array and the rectified output of wind generator are connected in parallel to the DC link.

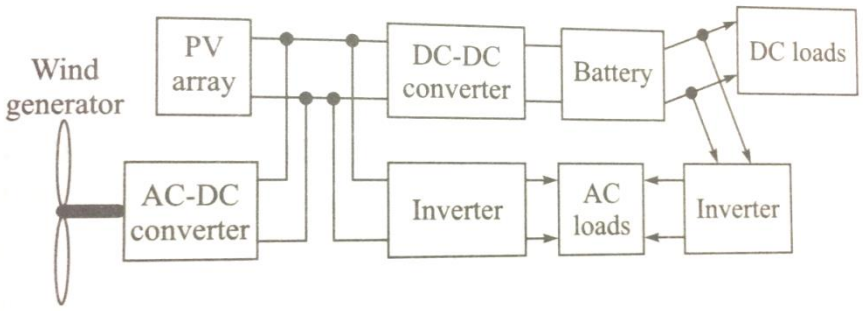

Fig. 15.11 PV-wind hybrid system.

The main drawback of this system is that both PV array and wind generator are unreliable sources and hence in the absence of sun and wind, a large battery bank is needed to meet the load demand.

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PV-fuel cell hybrid system:

The reliability problem of PV-wind hybrid system is eliminated by using weather independent source such as fuel cell. Figure shows the arrangement of PV-fuel cell hybrid system. This system uses two DC-DC converters, one fed from PV array and the other fed from fuel cell. Both of these DC-DC converters are connected in parallel to the DC bus. The DC output generated from the PV array and the fuel cell is converted back to AC using inverter and fed to the AC load. The DC-DC converter is operated such that it extracts maximum power from the PV array.

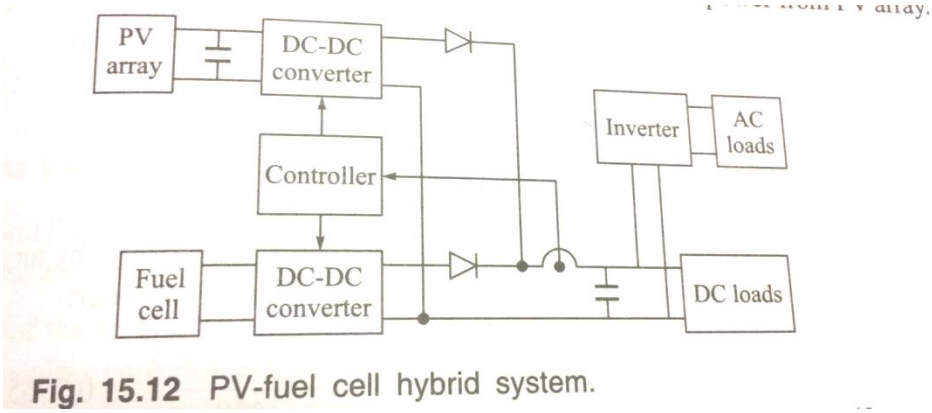


Fig. 15.12 PV-fuel cell hybrid system.

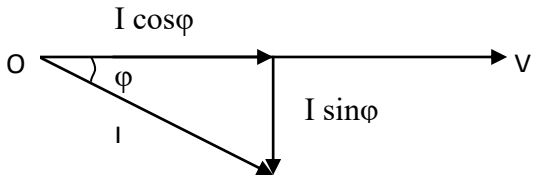
The main advantages of this system are:

- High reliability
- Easy synchronization of two DC sources as compared to synchronization of two AC sources

POWER FACTOR IMPROVEMENT

Power factor: It is the cosine of the angle between the voltage and the current in an AC circuit.

Significance of power factor: Consider an inductive circuit where current I lags the supply voltage V by an angle φ. Fig shows the phasor diagram of the circuit. In this phasor diagram, the inphase component of the current (I cosφ) is known as watt full component or active component where as the perpendicular component (I sinφ) is known as watt less component or reactive component.



The reactive component is the measure of the power factor. If the phase angle φ is small, power factor cosφ will be high and the reactive component or the watt less component or waste full component is small. Hence to minimize the reactive component of the current, the power factor should be high.

Causes of low power factor:

1. Most of the AC motors are induction type which have lagging power factor. These motors work at extremely low power factor of 0.2-0.3 at light loads.
2. Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.
3. Load on the power system is varying. During low load period, the supply voltage is increased which increases the reactive current. This results in decreased power factor.

Effects of low power factor:

1. **Large KVA rating of the equipments:** All electrical equipments are rated in KVA. But KVA = KW/cosφ. Therefore at low power factor, the KVA rating of the equipment has to be made more making the equipment large and expensive.
2. **Greater conductor size:** The conductors will have to carry more current at low power factor. This requires large conductor size.
3. **Large copper loss:** Large current at low pf causes more copper loss and hence results in poor efficiency and poor voltage regulation.
4. **Reduced handling capacity of the system:** Large reactive current at low power factor prevents full utilization of installed equipments. This results in reduced capacity of equipments.

Methods of power factor improvement:

Power factor can be improved by using the following equipments:

a) Static capacitor
b) Synchronous condenser
c) Phase advancer

Selection of capacitor bank to improve power factor

Shunt capacitors are used in the ratings of 15KVAR to 10000 KVAR for power factor improvement in various applications. Small banks upto few hundred KVAR are used for individual distribution circuits of

consumers. Capacitor banks of 500 to 3000 KVAR are used in small distribution substations. Capacitor banks of rating above 3000 KVAR are used in large substations.