Unit I

CONVENTIONAL POWER GENERATION

1.1 INTRODUCTION

- Energy plays an important role in our daily life and economic growth. There is a close relation between the availability of energy and growth of a nation. The development and civilization of a country depends on the utilization of energy by human beings for their needs.
- India is the second largest populated nation in the world with more than a billion people has an economy which is growing about 6% on the average since independence of India. It is expected that India's economy will go at more or less the same rate even till 2050, naturally this demand enormous amounts of energy. This is also highlighted by the fact that globally, the nations with improved quality of life, as reflected by the larger value of the human development index, consume more amount of energy per capita.
- Though India is presently the fourth largest electricity producing country in the world, India's per capita energy consumption (500 kWh) is rather small, which is only about one half of China, one fourth of World average and about one thirteenth of developed nations. This is also reflected by the low life expectancy in India and other similar nations.
- However, India aspires to reach at least the global average by 2050, which would require India to produce about 1300 GW of electricity, ten times more than the present value of about 130 GW. Of the present electricity generation, about 80% of the resources is fossil fuels, Hydro about 15%, renewable about 2% and nuclear about 3%.
- The per capita energy consumption directly relates with the standard of living of a given country. The energy consumption is increasing rapidly day by day and the supply of energy is depleting resulting in the energy crisis. This Energy crisis is mainly because of two reasons; firstly the population of the world has increased rapidly and secondly the standard of living of human beings has increased.
- The energy is available in different forms like heat energy, mechanical energy, electrical energy, nuclear energy etc.

1.2 CLASSIFICATION OF ENERGY SOURCES

The energy needs are drawn from a variety of sources.

(a) Commercial and non-commercial Energy Resources

(b) Conventional or non-renewable Energy Resources

(c) Non-Conventional or Renewable Energy Resources

(a) Commercial and Non-Commercial Energy Resources

Fossil fuels (coal, oil and natural gas), Hydroelectric Power, Nuclear power are commercial energy resources while wood, animal waste and agriculture wastes are non-commercial sources. In the world most of the energy requirements are met from the commercial sources.

(b) Conventional or Non-Renewable Energy Resources

- Fossil Fuels
- Nuclear Fuel
- Potential energy of water (stored at certain head height)

(i) Fossil Fuels **[May 18]**

Fossil fuels are of three types:

1. Solid Fuels: Coal, coke, bituminous, etc.
2. Liquid fuels: Petrol, diesel, kerosene, biodiesel, jatropa oil etc
3. Gaseous Fuels: Natural Gas, producer gas etc.

(ii) Nuclear Fuels

Uranium ($_{92}U^{235}$), Thorium ($_{90}Th^{232}$)

It took millions of years to build up these conventional energy resources. Relying on fossil fuels alone to increase the energy production is both impractical and impossible, first because of lack of access to required resources and second, even if resources are available, it would produce irreparable damage to the environment through global warming. Renewable resources are solar energy, wind energy, water energy and biomass.

(iii) Potential Energy of Water

Potential energy of rain falling on the earth's surfacewith respect to sea level is converted into mechanical energy by using suitable prime mover

(c) Non-Conventional or Renewable Energy Resources

- Solar energy
- Wind energy
- Tidal energy
- Ocean thermal energy
- Biogas and Biomass
- Fuel cell
- Geothermal energy

These energies are indirect effect of the solar energy reaching the earth's atmosphere. These sources are considered as renewable sources because these are generated again and again due to solar heating.

1.3 STEAM POWER STATION

- Steam is working fluid in steam power plant for generating mechanical power which subsequently converted into electricity. Steam obtained from water has many advantages as a working media. It does not react with the material of the equipment. Latent heat of evaporation of water is very high.
- Steam is used to drive the steam turbines. Steam power station is the most suitable where coal is available in abundance. This power plant is the important source to produce the electricity which converts the energy stored in fossil fuels into shaft work. The major portion of electricity demand of the world is fulfilled by the steam power plant. It is also called as thermal power plant.
- The simple block diagram showing the main components of steam power plant are shown in Fig. 1.1.

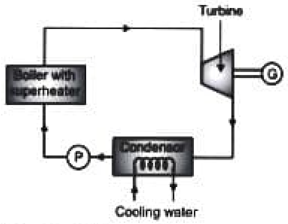


Fig. 1.1 : Block diagram of steam power plant

- Fig. 1.2 shows a schematic arrangement of devices of a steam power station in details. Steam power plant either works on simple Rankine cycle or modified Rankine cycle. The Rankine cycle used for steam power plant is shown in Fig. 1.3 (a) and (b) on P-v and T-s diagram respectively.

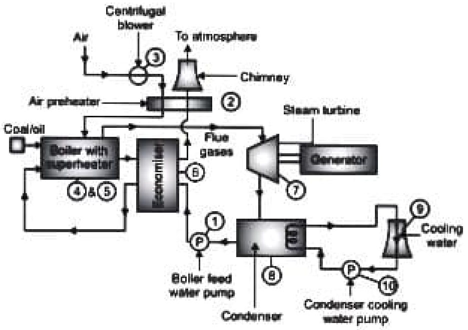
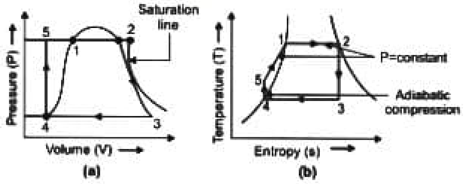


Fig. 1.2 : Schematic arrangement of steam power plant



Operations :

4-5 : Adiabatic pressurizing of water by feed pump

5-1 : Sensible heating of water in boiler.

1-2 : Evaporation of water at constant pressure in boiler.

2-3 : Isentropic expansion of steam in the turbine.

3-4 : Constant temperature heat rejection from steam to water in the condenser.

Fig. 1.3 : P- V and T-s diagram

The major components of this power plant are (i) boiler, (ii) steam turbine, (iii) condenser , (iv) water feed pump, (v) electrical generator, (vi) cooling tower, etc.

In steam power plant the thermal energy is converted to electric energy.

- The water supplied to the boiler through feed water pump (1) from the water tank.
- The water in the boiler (4) is heated by transferring heat of combustion by burning the fossil fuel in the furnace. The boiler consist of economiser (6), superheater (5).
- Coal received in coal storage yard of power station is transferred in the furnace by coal handling unit.
- Heat produced due to burning coal is utilized in converting water contained in boiler drum into steam at suitable pressure and temperature.

- The steam is further heated to superheat state in the unit superheater.
- In order to recover heat from the flue gases to the maximum possible, flue gases are passed through the economiser to preheat the water supplied to the boiler.
- The economiser raises the temperature of water before supplying it to the boiler. So the amount of fuel required is less when the boiler is coupled with the economiser.
- The flue gas from boiler chimney is also circulated through air pre-heater (2) where flue gases dissipate heat to the air supplied to the combustion chamber.
- From the super-heater the high pressure high temperature steam strikes the turbine (7) blades with a high speed and the turbine blades starts rotating to a high speed. Here the pressure energy of the steam gets converted into mechanical energy. Steam turbines are of various types, but mainly these are divided into impulse and reaction turbines.
- A generator is coupled with the turbine rotor. As the turbine rotates, the generator also rotate with same speed and mechanical energy of the turbine gets converted into electrical energy.
- After hitting the turbines blades the steam loses its most of the energy and leaves the turbine with low pressure steam.
- This low-pressure steam enters into the condenser (8). Cold water circulates in the condenser from the cooling tower (9).
- In the condenser the low pressure steam is converted into condensate i.e. water. Basically, there are two types of condensers: jet condenser and surface condenser.
- This condensed water is then again feed to boiler through economizer. Finally, the feed water enters into the boiler by a feed water pump to repeat the cycle. The feed pump increases the pressure of water (condensate) to the boiler pressure.
- There is separate water treatment plant to purify the water supplied to the boiler. Also one can see a separate coal handling unit in which reconditioning of coal is done before being supplied to the furnace. Apart from these coal handling unit, water treatment plant, there is ash handling and carrying system.

Steam Turbine : The high pressure superheated steam is expanded through this unit, to generate the shaft power. The turbine shaft is coupled to the electric generator, where mechanical power is converted into electrical energy.

Steam turbines are mainly divided into two groups :

1. Impulse turbine and
2. Impulse reaction turbine.

1. Impulse Turbine : In simple impulse turbine, steam coming out at a very high velocity through the fixed nozzle strikes the blades fixed on the periphery of a rotor. The blades change the direction of the steam flow without changing its pressure. The force due to change of momentum causes the rotation of the turbine shaft. The examples of simple impulse turbine are De-Laval, Curties and Rateau.

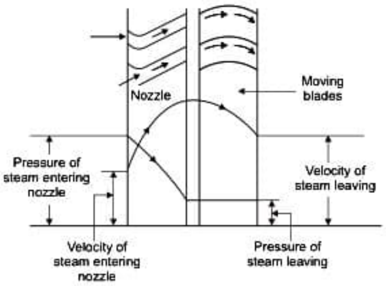


Fig. 1.4 : Diagrammatic sketch of a simple impulse turbine

Simple impulse turbine consists of one set of nozzles and a set of moving blades as shown in Fig. 1.4.

The expansion of steam from its initial pressure to final pressure takes place in one set of stationary nozzles. Due to high drop in pressure in the nozzles, the velocity of the steam increases in the nozzle.

The steam leaves the nozzle with a very high velocity and strikes the blades mounted on a wheel with this high velocity. The pressure of the steam when it moves over the blades remains constant but the velocity decreases. But this turbine is not commonly used due to :

(a) The pressure reduction from boiler pressure to turbine outlet pressure takes place in single stroke in the nozzle. Therefore, the velocity of the steam striking the blades of the moving rotor is very higher. Subsequently, the turbine rotates at very high speed of the order of 30,000 r.p.m., which is not desirable for practical purposes.

(b) Considerable amount of energy is wasted due to high exit velocity of the steam from the turbine.

The rotor speed can be reduced by the following methods of compounding at turbine :

- Velocity compounding.
- Pressure compounding.
- Pressure velocity compounding.

2. **Reaction Turbine :** In an impulse reaction turbine, steam expands both in fixed and moving blades continuously as the steam passes over them.

   It consists of large number of stages, each stage consisting of set of fixed and moving blades. The pressure drop takes place throughout in both fixed and moving blades.

   No nozzles are provided in reaction turbine. The fixed blades act both as nozzles in which velocity of steam increases and direct the steam to enter the ring of moving blades.

   As the pressure drop takes place both in the fixed and moving blades, all blades are nozzle shaped. The steam expands while flowing over the moving blades and thus gives reaction to the moving blades. Hence, the turbine is known as reaction turbine. The fixed blades are attached to the casing whereas moving blades are fixed with rotor. It is also called Pearson's Reaction Turbine.

Difference Between Impulse and Reaction Turbine :

- In impulse turbine, steam completely expands in the nozzle and its pressure remains constant during its flow through the blade passages.

  In reaction turbine, in the nozzle as well as in the moving blades.

- The relative velocity of steam passing over the blades of impulse turbine remains constant (assuming there is no friction).

  The relative velocity of steam passing over the blade of reaction turbine increases as the steam passing over the blade expands.

- The pressure on both ends of the moving blade of an impulse turbine is same but it reaction turbine it is different.
- The impulse turbine blades are symmetrical but the reaction turbine blades are asymmetrical.
- The blade efficiency curve for the reaction turbine is more flat compared to that of the impulse turbine.
- The number of stages required for reaction turbines are more compared with impulse turbine for the same power developed as the pressure drop in each stage is small.
- The steam velocity in a reaction turbine is not very high and the speed of the turbine is low as compared to the speed of impulse turbine.

Condenser : A closed vessel in which steam is condensed by removing heat and the pressure is maintained below atmospheric pressure is known as a condenser.

To absorb the heat from the wet steam entering the condenser, a cold water is circulated.

To condense one kg of dry saturated steam at atmospheric pressure requires about 10 kg of cold water at 25°C. It means a huge quantity of water is to be circulated in it. The heated water is supplied in the coding tower.

Following are the Advantages of Installation of Condenser in a Steam Turbine Plant :

- The efficiency of the thermal power plant increases due to the increased enthalpy drop across the turbine, which increases by increasing the vacuum in the condenser to certain extent.
- Reduction in steam consumption per kW power. Increase in vacuum from 70 to 73 cm of Hg gives about 45% reduction in steam consumption.
- The temperature of condensate is always higher than that of the feed water if it is taken from outside source. Therefore, the amount of heat supplied to the boiler per kg of steam generated is reduced.
- The reuse of condensate as feed for boiler reduces the cost of power generation.

The formation of deposits or scales in the boiler is prevented with the use of condensate instead of feed water from outer source.

There are mainly two types of condensers, namely jet condenser and surface condenser. Usually surface condenser is preferred in the steam power plant.

Cooling Tower : A majority of high capacity steam power plants are installed adjacent to rivers where water is available abundantly.

But for many plants, cooling water is procured from the local water supply. In such cases, the same water is recirculated over and over again. It must be cooled before it re-enters the condenser tubes. The water is cooled by means of cooling ponds or cooling towers.

There are different types of cooling towers. The induced draft cooling towers are commonly used in high capacity power plants.

The hot water coming out from the condenser is sprayed at the top of the tower and air is induced to flow through the tower with the help of induced draft fan mounted at the top of the Water.

1.3.1 Advantages and Disadvantages of Steam Power Plant

Advantages

- Fuel cost of thermal power plant is relatively low.
- This plant is economical in initial cost compared to hydro plants and running costs are less compared to gas plants or diesel plants.
- Thermal plants can be placed near load centers unlike hydro and nuclear plants. Hence transmission of power losses can be minimized.
- This power plant has easy maintenance cost.
- Steam power plant can be installed in any area where water sources and transportation facility are easily available.

Disadvantages

- The running cost of steam power plant is comparatively high because of fuel, maintenance etc
- The overall efficiency of steam power plant is about 35 % to 41% which is low.
- Due to the release of burnt gases of the coal or fuel, it contributes to the global warming to a larger extent.
- The heated water that is thrown in the rivers, ponds etc puts and adverse effect on the living organism of water and disturbs the ecology.

1.4 NUCLEAR POWER PLANTS [May 18]

- Nuclear power plants generate electricity in much similar way that other thermal power plants generate electricity.
- The difference with nuclear power plants is that instead of using the combustion of a fuel to generate heat, they use nuclear fission to generate heat.
- Nuclear power stations are usually considered to be base load stations, since fuel is a small part of the cost of production. Nuclear fission in simple terms is the splitting of large atoms into smaller atoms; this process releases vast amounts of energy.
- Nuclear fission can occur either naturally or be induced.
- When it happens naturally the process is known as radioactive decay, and it is a common process. The elements in which this process occurs naturally are known as radioactive isotopes.
- The other type of nuclear decay called fission is a manmade nuclear reaction. This reaction occurs inside the nuclear reactor and generates the heat to produce electricity.
- A nuclear reactor is the steel vessel where the nuclear fuel is contained.
- A nuclear reaction occurs when an atom is induced to split or "fission", and as a consequence, it releases a large amount of energy.
- The nuclear fuel most commonly used for commercial nuclear power plants is uranium (denoted by the chemical symbol U).

1.4.1 Nuclear Power Plants Elements

The basic elements of nuclear power plant are Nuclear reactor, coolant and coolant pump, heat exchanger, steam turbine, condenser and generator.

A nuclear reactor is a device in which nuclear chain reactions are initiated, controlled, and sustained at a steady rate.

The heat energy is generated in the nuclear reactor by splitting the atom of the nuclear fuel. This heat energy from the nuclear reactor is used in the heat exchanger for formation of steam which is used for power generation in similar manner as conventional power plant.

- The fission in a nuclear reactor heats the reactor coolant.
- The coolant may be water or gas or even liquid metal depending on the type of reactor.
- The reactor coolant then goes to a steam generator and heats water to produce steam.
- The pressurized steam is then usually fed to a multi-stage steam turbine.
- After the steam turbine has expanded and partially condensed the steam, the remaining vapor is condensed in a condenser.
- The condenser is a heat exchanger which is connected to a secondary side such as a river or a cooling tower. The water is then pumped back into the steam generator and the cycle begins again. The water-steam cycle corresponds to the Rankine cycle.

Nuclear Fuel

Nuclear fuel is any material that can be consumed to derive nuclear energy. The most common type of nuclear fuel is fissile elements that can be made to undergo nuclear fission chain reactions in a nuclear reactor. The most common nuclear fuels are 235U and 239Pu. Not all nuclear fuels are used in fission chain reactions.

Nuclear Fission

When a neutron strikes an atom of uranium, the uranium splits into two lighter atoms and releases heat simultaneously.

Fission of heavy elements is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments.

Nuclear Chain Reactions

A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. If the process is controlled it is used for nuclear power or if uncontrolled it is used for nuclear weapons.

$$U235 + n \rightarrow \text{fission} + 2 \text{ or } 3\, n + 200 \text{ MeV}$$

If each neutron releases two more neutrons, then the number of fissions doubles each generation. In that case, in 10 generations there are 1,024 fissions and in 80 generations about 6 × 10 23 (a mole) fissions. Fig. 1.5 shows the schematic of nuclear power plant.

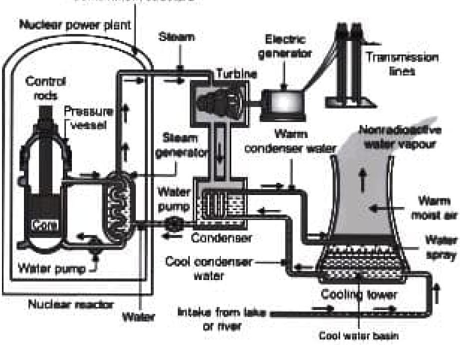


Fig. 1.5 : Nuclear power plant

1.4.2 Components of Nuclear Reactors and their Functions

A nuclear reactor is a device in which nuclear chain reactions are initiated, controlled, and sustained at a steady rate, as opposed to a nuclear bomb, in which the chain reaction occurs in a fraction of a second and is uncontrolled causing an explosion.

Components:

- **Control Rods :** The control rods are used to control the reaction rate, starting and shutting down of the reactor. Control rods made of a material that absorbs neutrons are inserted into the bundle using a mechanism that can rise or lower the control rods. The control rods essentially contain neutron absorbers like, boron, cadmium or indium.
- **Moderators :** The fast moving neutrons are slow down by using moderators. The neutrons lose their kinetic energy by collision with the nuclei of moderator material. The moderator can be in the form of solid, liquid or gas. The material used as moderator are water (H_2O), Deutoriumor Heavy Water (D_2O), graphite and beryllium. The moderator material should possess the following properties

  (i) It should not react with the neutrons.

  (ii) It should be inert and chemically stable.
- **Coolant:** The medium used to take heat from the reactor is called as a coolant. This heat is then transferred to the water for generation of steam in the heat exchanger. The coolant should not absorb the neutrons. The coolant should have good heat transfer coefficient.

  It should be free from the radiation damage. It should be non-corrosive, non-toxic, non-oxidising.

  The coolants used are H_2O, D_2O, gas, liquid sodium. If the water is used as the coolant then water itself acts as the working fluid. It directly generates the steam in the reactor and this steam is directly sent to steam turbine for power generation.
- **Fuel Rods:** Nuclear fuel is the material that can be consumed to derive nuclear energy. The most common type of nuclear fuel is fissile elements that can be made to undergo nuclear fission chain reactions in a nuclear reactor. The most common nuclear fuels are 235U and 239Pu. The fuel material is fabricated in various shapes like rods, plates, tins, pallets etc.

- **Steam Generator:** Steam generators are heat exchangers used to convert water into steam from heat produced in a nuclear reactor core. Either ordinary water or heavy water is used as the coolant.
- **Steam Turbine:** A steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts it into useful mechanical
- **Coolant Pump:** The coolant pump pressurizes the coolant to pressures of the order of 155bar.The pressure of the coolant loop is maintained almost constant with the help of the pump and a pressurizer unit.
- **Feed Pump:** Steam coming out of the turbine, flows through the condenser for condensation and recirculated for the next cycle of operation. The feed pump circulates the condensed water in the working fluid loop.
- **Condenser:** Condenser is a device or unit which is used to condense steam coming out from turbine into liquid. The objectives of the condenser are to reduce the turbine exhaust pressure to increase the efficiency and to recover high quality feed water in the form of condensate and feedback it to the steam generator without any further treatment.
- **Cooling Tower:** Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Water circulating through the condenser is taken to the cooling tower for cooling and reuse.

1.4.3 Types of Nuclear Reactors

Thermal Reactors :

- Pressurized water reactor
- Boiling water reactor
- Pressurised heavy water reactor
- Gas cooled reactor

Fast Breeder Reactor :

- Liquid metal fast breeder reactor
- Gas cooled fast breeder reactor

1. Pressurized Water Reactor – PWR

Fig. 1.6 shows the schematic of the pressurized water reactor.

- A pressurized water reactor power plant consists of two loops in series, the coolant loop called primary loop and the secondary loop as water steam or working fluid loop.
- As the name suggests the PWR, the water is used as coolant. The water also acts as a moderator in PWR.
- The coolant picks up heat in the reactor and transfers it to the working fluid in the steam generator.
- The steam is then used to produce electricity by using Rankine cycle.

The fuel in PWR is slightly enriched uranium in the form of thin rods or plates.

- The coolant leaving the reactor enters the steam generator which can be either shell and tube type.
- Pressure is maintained by steam in a pressurizer.
- In the primary cooling circuit, the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type.
- The secondary shutdown system involves adding boron to the primary circuit. The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators.
- The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.

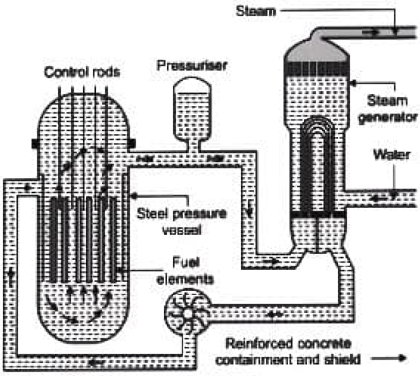


Fig. 1.6 : Pressurized water reactor (PWR)

2. Boiling Water Reactor (BWR)

Fig. 1.7 depicts the schematic of boiling water reactor (BWR). The design of boiling water reactor is similar to PWR except that the steam produced in the reactor core is directly supplied to the turbine to produce power. So there is only one loop.

- As compared to PWR the water is at lower pressure so that it boils in the core at about 285°C.

- The steam is separated and dried by mechanical devices located in the upper part of the pressure vessel assembly.
- Then the dry steam is sent directly to the high pressure turbine. The coolant here serves the triple function of coolant, moderator and working fluid.
- Since the water around the core of a reactor is always contaminated with traces of radionuclides, it means that the turbine must be shielded and radiological protection provided during maintenance. The cost of this tends to balance the savings due to the simpler design.

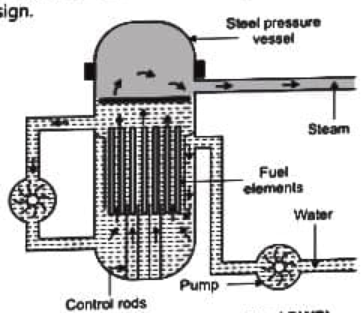


Fig. 1.7 : Boiling water reactor (BWR)

3. **Pressurized Heavy Water Reactor (PHWR)**

As the name suggest the pressurized heavy water reactor used the coolant as pressurized heavy water ie. D_2O.

Fig. 1.8 shows the pressurized heavy water reactor (PHWR). PHWR generally use natural uranium (0.7% U-235) oxide as fuel.

- The PHWR produces more energy per kilogram of mined uranium than other designs, but also produces a much larger amount of used fuel per unit output.

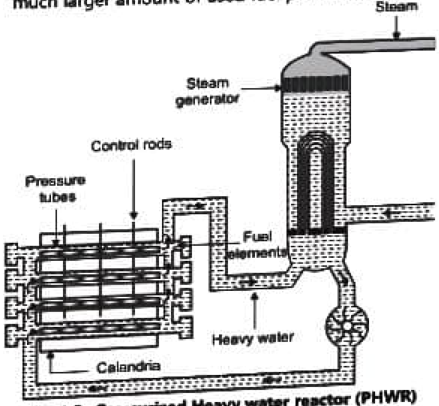


Fig. 1.8 : Pressurized Heavy water reactor (PHWR)

- The Heavy water moderated and cooled reactors have been extensively developed in Canada.
- They are called CANDU-PHW. The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure in the primary cooling circuit, reaching 290°C.

4. **Gas-Cooled Reactor (GR)**

In gas cooled reactor the coolant is used as gas.

Fig. 1.9 shows the gas cooled reactor.

- In Britain in 1965-69 the first gas cooled reactors with CO_2 gas as coolant and graphite as moderator were developed.
- The fuel used in this this reactor was a natural uranium, clad with an alloy of magnesium called magnox.
- The carbon dioxide circulates through the core, reaching 650°C and then past steam generator tubes outside it, but still inside the concrete and steel pressure vessel.
- Control rods penetrate the moderator and a secondary shutdown system involves injecting nitrogen to the coolant.

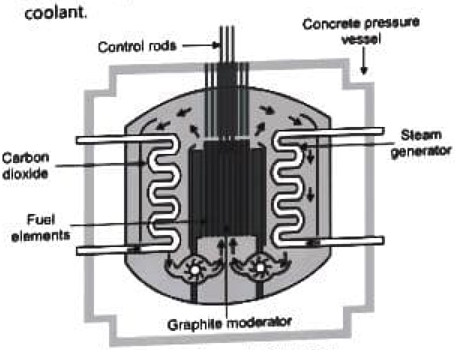


Fig. 1.9 : Gas cooled reactor

1.4.4 Advantages of Nuclear Power Plant

- The nuclear power plant produce electricity without generating greenhouse gas emissions.
- The space requirement of nuclear power plant is less than the thermal power plant.
- Requirement of fuel is much less compared to coal.
- Cost of fuel transportation, storage and handling is small.
- Gives better performance at high load factors, hence suitable for high power demand.
- The nuclear power plants are more reliable in operation.
- The problem of ash handling is avoided.

1.4.5 Disadvantages of Nuclear Power Plant

- Nuclear power plant requires high level of technology and also requires major initial investment cost.
- For variable load requirements these plants are not suitable
- The radioactive waste management issues are there, the highly radioactive spent fuel has to be store for many years after use.
- It has high capital and maintenance cost.
- During the operation of nuclear power plants, radioactive waste is produced, which in turn can be used for the production of nuclear weapons.
- An accident may cause a major disaster releasing high amount of radiation resulting in thousands of casualties.

1.5 GAS TURBINE POWER PLANT [Oct. 17]

It is also one of the thermal power plant to convert heat energy into mechanical work. The use of gas turbine power plant was known in 1872. But due to difficulties in understanding the diffusion processes of air passing through a compressor and lack of high temperature materials, the technology was not practicable up to 1935.

In the last two decades, the rapid progress has been observed in the development and improvement of the gas turbine plants for electric power generation.

The gas turbine power plants are mainly classified into two groups as per the cycle of operation.

1. Open cycle gas turbine.
2. Closed cycle gas turbine

1. Open Cycle Gas Turbine Power Plant: A simple cycle consists of a compressor, combustion chamber and a gas turbine as shown in Fig. 1.10.

- The compressor takes in ambient air and raises its pressure adiabatically and supplies to combustion chamber.
- Heat is added to this air at constant pressure in combustion chamber by burning the fuel.

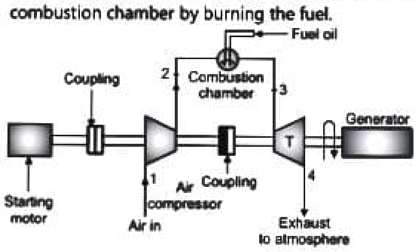


Fig. 1.10 : Open cycle gas turbine power plant

- Therefore the mixture of air and the products of combustion (produced by burning the fuel in combustion chamber) acts as a working fluid in open cycle gas turbine.
- The working fluid a at high temperature and pressure passes through turbine where it is expanded to the atmospheric pressure.
- The mechanical work is available at the turbine shaft. Part of the power generated is utilized to drive the compressor and other accessories.
- Rest is converted to electrical power by the generator.
- The gases coming out of the turbine are exhausted to atmosphere. Therefore, it is an open cycle.

Advantages of Open Cycle Gas Turbine:

- Almost all hydrocarbon fuels from high octane gasoline to heavy diesel fuel can be used.
- The weight of the unit per kW is small.
- Once the turbine speed is increased to rated speed by the starting motor, it starts and takes full load. i.e. warm up time is lesser.
- As the warm up time is very less, so it can be effectively utilized during peak load.
- It requires less space.
- The plant requires no cooling water, condenser and cooling towers, etc.

Disadvantages of Open Cycle Gas Turbine:

- Part load efficiency of this plant is very low as major part of the power generated is required to drive the compressor.
- It requires starting motor to drive the compressor initially.
- As fuel is burnt in the air in combustion chamber, the products of combustion are expanded into turbine. Therefore, erosion of blades occurs to the large extent.

2. Closed Cycle Gas Turbine Power Plant:

Fig. 1.11 shows the schematic of closed cycle gas turbine plant.

- In closed cycle gas turbine power plant, the working fluid (air) is compressed in the compressor.
- The pressurized air passes through the heat exchanger where heat is supplied to it.
- The high temperature and high pressure air expands in the turbine.
- The exhaust air from the turbine is cooled to its original temperature in the heat exchanger.
- This cold air is returned to the compressor. The working fluid is recirculated through the cycle.

The power cycle, on which it works, consists of two constant pressure and two constant adiabatic processes (Joule cycle) as shown in Fig. 1.12.

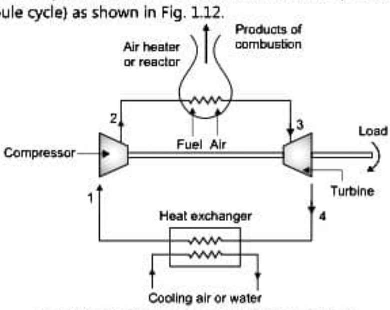


Fig. 1.11 : Closed cycle gas turbine power plant

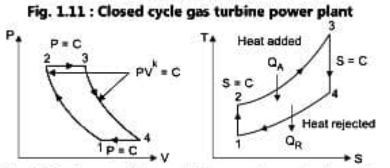


Fig. 1.12 : Open cycle gas turbine works on Joule cycle: consists of two adiabatic processes and two constant pressure processes

Advantages of Closed Cycle Gas Turbine:

- Higher thermal efficiency compared with open cycle gas turbine.
- The air which is expanded in the turbine is not contaminated by the dust particles and burnt flue gases. Therefore erosion of blades of turbine is not a severe problem.
- The need of air filtration in open cycle is now eliminated.
- As indirect heating air takes place in heat exchanger, a low quality fuel can be used (solid/liquid/gaseous fuel).
- No loss of working media.
- No corrosive gases are circulated in all the components of plant. Hence long life.
- Starting of turbine is simple.

Disadvantages of Closed Cycle Gas Turbine :

- Due to heat exchangers (no direct contact), full heat of the fuel fired is not utilised.
- Large quantity of cooling medium is required.
- Space required is more as compared to open cycle.
- High internal pressures are involved. Therefore complicated design of all components and so high quality material is required.
- The response to load variation is poor as compared to open cycle.

1.6 HYDRO-ELECTRIC POWER PLANT

[Oct. 17, May 18]

- Rain falling upon the earth's surface has a potential energy relative to oceans due to its flow.
- Potential energy of rain falling on the earth's surface with respect to sea level is converted into mechanical energy by using suitable prime movers.

The power by a hydraulic turbine 'P' is given as (See Fig. 1.12)

$$P = \rho Q g \cdot h \text{ (watts)}$$

Where, Q = flow rate, (m^3/sec)

h = head, (m), Level difference between reservoir and tail race

ρ = density of water, (kg/m^3)

g = gravitational acceleration, (m^2/sec)

$$P \propto Q h$$

Therefore, to generate hydraulic power economically, ample quantity of water (Q at sufficient height (head) must be available.

1.6.1 Classification of Hydro-Electric Power Plants

(a) According to the Availability of Head :

1. Low head plants – head below 30 m
2. Medium head plants – head between 30 m to 180 m
3. High head plants – head 180 m and above.

(b) According to the Nature of Load :

1. Base load plant
2. Peak load plant.

(c) According to the Quantity of Water Available :

1. Run-off river plant without pondage.
2. Storage reservoir plant Pump storage plant.

Storage reservoir type hydroelectric power plant is explained as follows.

Storage Reservoir Plant :

- The storage type hydro-electric power plant is as shown in Fig. 1.13.

- Such plant has a large storage capacity of water, therefore water collected in rainy season is utilized during dry period of the year.
- The collection of water is done on yearly basis, therefore, the capacity of reservoir required is extremely large compared with the other types of hydroelectric power plant.

The elements of hydroelectric power plant are explained here;

- **Reservoir:** To store water during rainy season and supply the same during dry season.
- **Track Rash:** Its function is to prevent entry of debris into the penstock which may damage the wicket gates and turbine runner or choke up the nozzles of the impulse turbine.

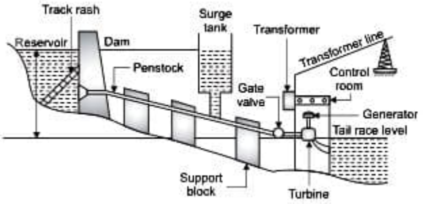


Fig. 1.13 : Storage type Hydro-electric power plant

- **Penstock:** It is a pipe from reservoir to the surge tank. The penstock has to bear heavy pressure from inside during decreased load conditions of generator and on outside surface during increased load condition of generator. Therefore, it is constructed in heavy reinforced concrete or M.S. plates.
- **Surge Tank:** There is sudden increase of pressure in the penstock due to sudden decrease in the rate of flow of water to the turbine when the gate admitting water to the turbine is suddenly closed.

This sudden rise of pressure in the penstock above normal pressure due to reduced load on the generator is known as "water hammer".

To avoid water hammering and vacuum forming tendencies, surge tank is introduced near the power house.

- **Power House:** It is a superstructure to protect the equipment's. If conventional topographic area is not available, one can prefer underground power house.
- **Prime Movers:** The main purpose of prime movers is to convert the K.E of water into mechanical energy to generate electric power for example, Pelton wheel, Kaplan turbine, Francis turbine, etc.
- **Draft Tube:** The draft tube is an essential part of reaction turbine. It has a diverging shape. It is so shaped to decelerate the flow with a minimum loss so that remaining kinetic energy of water coming out is recovered.

1.6.2 Advantages of Hydro-Electric Power Plant

- Operating cost is extremely low.
- No nuisance of smoke, exhaust gases, etc.
- Labour required to operate the plant is less.
- As these are located away from the developed areas, so the cost of land is not a problem.
- Easy start and stop facilities.
- These are able to respond to rapidly changing loads without loss of efficiency.
- No fuel is required. Therefore, there are no charges of fuel as well as the charges in connection with handling, storage and disposal of refuse.

1.6.3 Disadvantages of Hydro-Electric Power Plant

- Initial cost of the plant including the cost of the dam is too high.
- Power generation from such plant is dependent on the quantity of water which in turns depend on the natural phenomenon of rain. Thus, the availability of power is not very reliable.
- These are usually away from the consumers. Therefore, transmission of power from power station to the load centres involves use of long transmission lines and consequent investment and loss of power in transmission are unfavorable factors.
- The suitable sites required for this plant are rarely available.

1.7 THERMOELECTRIC GENERATORS (TEG)

Fig. 1.14 shows the schematic of thermoelectric generators

- The term thermoelectric is combination of two words thermo and electric and as its name indicates thermal means heat energy and electric means electrical energy.
- Thermoelectric power generators are the devices which used to convert temperature difference between two junctions into electrical energy.
- A thermoelectric generator (TEG) is a device that converts heat directly into electricity or transform electrical energy into thermal power for heating or cooling through a phenomenon called the Seebeck effect (a form of thermoelectric effect).
- These devices are based on thermoelectric effects Involving interactions between the flow of heat and of electricity through solid bodies.
- Thermoelectric generators function like heat engines but have no moving parts and less bulky.

Thermoelectric generators could be used in power plants in order to convert waste heat into additional electrical power and in automobiles as automotive thermoelectric generators to increase fuel efficiency.

- A working of thermoelectric generator is based on Seebeck effect. According to which, when the two junctions of dissimilar metal are kept at different temperature emf develops in the material.
- Hence it is also referred as Seebeck Power Generation.
- A thermo-electrical generator basically consists of heat source, which is kept at high temperature and a heat sink, which is maintained at a temperature less than the heat source.
- The temperature difference between heat source and heat sink causes direct current to flow through the load. This energy conversion is called as direct power conversion as there is no intermediate energy conversion like in case of most of the conversion.
- The power generated due to Seebeck power generation is single phase DC and given by I^2RL or VIL where RL is the load resistance. /The output voltage and output power are increased either by increasing the temperature difference between the hot and cold ends or by connecting several thermoelectric power generators in series.
- The current will continue to flow as long as heat is supplied to the hot junction and removed from the cold junction.
- This current produced by thermoelectric or Seebeck power generation is DC in nature and can be converted into AC by using invertors and its voltage level can be further step up by using transformers.

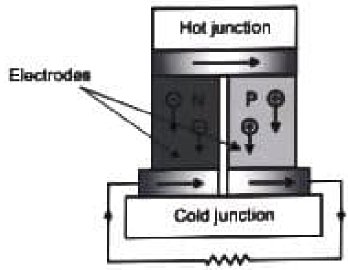


Fig. 1.14 : Schematic of thermoelectric power generation unit

- Consider a thermoelectric power generator having heat source at one end and heat sink at other end.
- The heat source is kept at high temperature as compare to heat sink. Let the temperature difference between two junctions is ΔT.
- The sides of generating device are insulated so, the heat flows along the length only.
- The applied heat to the hot junction causes the electrons in the n type block and the holes in the p type block to flow away from the heat junction and thereby producing a electrical potential difference.
- The circuit is completed by connecting a load resistance, RL. The current will start flowing through this load resistance, RL.
- The voltage of this generator is given by $V = \alpha \, \Delta T$ where α is Setback coefficient and ΔT is the temperature difference between hot and cold junction.
- ΔT can be increased by increasing the temperature difference between heat source and heat sink.

The thermoelectric power generation offers one method of producing electric power directly from the heat of combustion, where the fuel is relatively cheap.

This power generator can be used as a standby or even base load plants.

The thermal efficiency of this plant is of the order of 3%., so this power generation is not so attractive for special power generation.

1.8 THERMIONIC POWER GENERATOR (TPG)

- Thermionic power generator (TPG) is another form of direct conversion of heat energy to electrical energy.
- Thermionic emission is the basis for the working of this system.
- The thermionic emission is the emission of electrons from metal surface due to heat.
- A thermionic energy converter or thermionic power generator is a device consisting of two electrodes placed near one another in a vacuum.
- One electrode is normally called the cathode, or emitter, and the other is called the anode, or plate.
- Ordinarily, electrons in the cathode are prevented from escaping from the surface by a potential-energy barrier.
- When an electron starts to move away from the surface, it induces a corresponding positive charge in the material, which tends to pull it back into the surface.
- To escape, the electron must somehow acquire enough energy to overcome this energy barrier.
- At ordinary temperatures, almost none of the electrons can acquire enough energy to escape. However, when the cathode is very hot, the electron energies are greatly increased by thermal motion.
- At sufficiently high temperatures, a considerable number of electrons are able to escape.
- The liberation of electrons from a hot surface is called thermionic emission.

Principle of Working

Thermionic power generator is based on the principles of Thermionic effect in which the electrons are emitted from a hot metal surface and this electrons are responsible for the production of electricity. Fig. 1.15 shows the principle of working of thermionic power generation.

Construction

- The TPG consist of cathode material such as tungsten impregnated with a barium metal, which is negatively charged and acts as an emitter.
- There is positively charged electrode called as collector consist of material barium and strontium. It is collecting the ejected electrons. The emitter and collector are kept in a vacuum quartz tube.
- The electrons within a metal can be treated as "electron gas" in which individual outer most electrons are capable of moving freely under the influence of a field.
- This movement of electrons is responsible for the function of electric circuits.

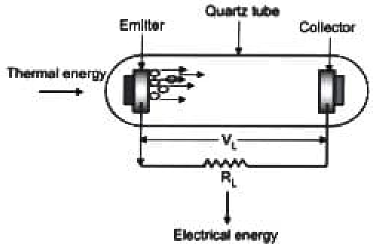


Fig. 1.15 : Principle of working of Thermionic power generation

- At the surface of a metal, a potential barrier exists which prevents the electrons from escaping unless certain conditions are met. This concept can be explained as follows. Fig. 1.16 depicts the emission process of electrons from emitter.

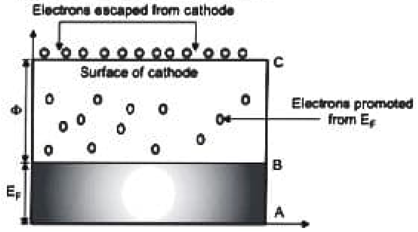


Fig. 1.16 : Emission process of electrons from emitter

- It is known from the free electron theory, at 0K, all the energy levels up to E_F (fermi energy) are completely filled and all the energy level above the EF are completely empty.

- The energy level from the surface of metallic cathode to the level of E_F (BC in figure) is the potential energy barrier called work function (ϕ).
- If any electron wants to escape from the surface of the metallic cathode, they should cross this potential barrier.
- At 0 K, all the electrons are bound within fermi energy level and cannot escape from the surface of cathode (emitter).
- When the thermal energy is supplied on the emitter side, some of the electrons are triggered above the fermi level.
- These activated triggered electrons can cross the potential energy barrier and escape from the surface of cathode and responsible for the current production.
- As long as the temperature increased, the number of electrons escapes from the surface of emitter increases.
- Collector collects the emitted electrons and there is an external circuit through which the current flows.
- The thermionic emission current density is determined by the 'work function' of the material, which is basically the magnitude of the potential energy barrier. Good emitters should have low work functions.

1.9 ENVIORNMENTAL ASPECTS FOR SELECTING THE SITES AND LOCATION FOR POWER PLANTS

The principle factors to be considered for the site selection of the power plants

- Availability of raw material for the plant and transportation facility.
- Availability of water and fuel
- Skilled man power availability
- Land acquisition cost
- Degradation of local air quality
- Land use impacts
- Transmission grid accessibility
- Electricity consumption point

1. **Availability of Raw Material and Transport Facility :** Steam power plants requires large amount of fuel per year. So the coal fields should be nearer to the power plant location. If it is away from the power plant then it may create problems due to transportation failure. Therefore it is needed to store at least 15 days coal storage. This will result in increased space requirement, increase investment and more staff requirement.

   In other case the plant can be located near to the Railway stations to reduce the cost of road transportation. For transportation of the fuel and heavy equipments required for the plant, the plant should be located where the adequate transport facilities are available.

2. **Availability of Water and Fuel :** Large amount of water is needed for steam power plant. Also water is required for condensing the steam coming out from the turbine, if water cooled condensers are used. Therefore it becomes essential to locate the plant near to the place where required quantity of water is available throughout the year.

   Fuel availability influences choices positively; its marginal utility is diminishing with supply. The location of the power plants should be nearer to the fuel fields for cutting down the cost.

3. **Skilled Man Power Availability :** A power plant requires labor for construction and operation. Local communities can benefit from these employment opportunities. Generally, sites that can make use of local labor are more desirable. These sites would have a larger skilled work force within a short distance from the plant site.

4. **Land Acquisition Cost :** Each site will have unique land acquisition requirements and effects. Generally, sites that have lower land acquisition costs and require shorter acquisition times are more desirable.

5. **Degradation of Local Air Quality :** Operating power plants that burn coal, oil, or natural gas emits air pollutants into the atmosphere requiring the plant be fitted with pollution control equipment to reduce emissions. Many of these Power plant air pollutants have been identified and are regulated by Central Pollution Control Board (CPCB). Public exposure to air

emissions (air pollution) is regulated for major air pollutants, including sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), ozone (O_3), particulate matter ($PM_{2.5}$ or PM_{10}), and lead (Pb).

6. **Land Use Impacts :** Industrial forests are a valuable commodity. Site evaluation should address the forest resources of the site and nearby lands, and the effects of plant construction and operation on these resources. Generally, more desirable sites have fewer impacts on these resources. Typically, active or vacant industrial lands may be more compatible and urban residential lands may be less compatible with power plants. Generally, sites that are more compatible with present and planned land uses are more desirable.

7. **Transmission Grid Accessibility :** An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

8. **Electricity Consumption Point :** A power plant must be located near the load to which it is supplying the power. However a plant a plant cannot be located near all loads. As such C.G of the load is determined with reference to two arbitrarily axis.

Environmental Aspects

Local regulations and law will control the effect of power station on the local environment. The important considerations are:

- Exhaust emissions of SOx, NOx and particulate matter.
- Height of chimney.
- Noise level at the site boundary.
- Treatment of boiler and water treatment plat effluent.

EXERCISE

1. Write short a note on steam power plant.
2. Explain the function of economizer and air preheater in steam power plant.
3. What are the advantages and disadvantages of steam power plant?
4. Explain with neat sketch the elements of Nuclear power plant.
5. Explain the components of nuclear reactor and their functions.
6. What are the different types of Nuclear reactors and explain any one nuclear reactor.
7. What are the advantages and disadvantages of nuclear power plants?
8. Explain open cycle gas turbine power plant with neat sketch
9. Explain closed cycle gas turbine power plant with neat sketch
10. What are the advantages and disadvantages of open cycle gas turbine power plant?
11. What are the advantages and disadvantages of closed cycle gas turbine power plant?
12. Compare open cycle gas turbine power plant with closed cycle gas turbine power plant.
13. Give classification of hydroelectric power plants.
14. Explain the components of a typical hydroelectric power plant with a neat sketch.
15. What are the advantages and disadvantages hydroelectric power plant?
16. Write short note on thermoelectric generator.
17. Write short note on thermionic power generator.
18. Discus the environmental aspects for selecting the sites and location for power plants.

UNIVERSITY QUESTIONS

October 2017

1. Identify the power plants for the following places. **[4]**

   (i) Bakreshwar in West Bengal –Thermal Power Plant

   (ii) Idukki in Kerala –Hydroelectric Power Plant

   (iii) Kavaratti in Lakshwdeep – Ocean Thermal Power Plant

   (iv) Paras in Maharastra – Thermal Power Plant

2. Explain the working principle of Gas turbine power plant with a neat sketch. **[4]**

December 2017

1. Explain the working of a Hydro Electric Power plant with a neat diagram? Write at least four advantages and disadvantages each of the Hydro Electric Power. **[6]**

2. What are the fossil fuels used for generation of conventional power? Write the correct type of energy produced by the following power plants. **[6]**

   (i) Kalkappam in Tamil Nadu,

   (ii) Reliance Power in Pokharan in Rajashthan,

   (iii) Almatti in Karnataka, and

   (iv) Koradi in Maharashtra

May 2018

1. How is energy released from Uranium atoms? Explain with a neat sketch how the nuclear power plant generates electricity. Label all the major parts of the plant and their functions. **[6]**

2. What are the fossil fuels used for generation of conventional power? List the auxiliary equipment's of Diesel engine power plants and state any five advantages of diesel engine power plants **[6]**

3. What are the Mini and Micro Hydro power plants. Compare the Hydroelectric plants with the diesel power plant in respect of sit requirement, initial cost fuel transportation, reliability, operating cost, simplicity and cleanliness. **[6]**

June 2019

1. Classify gas turbine power plants. Explain the various elements of gas turbine power plant. **[6]**

2. Why most of the thermal power plants are set near coal mines or oil reservoirs? Explain the cooling water circuit in a thermal power plant. **[6]**

3. Compare the Hydroelectric plants with the diesel power plant in respect of site requirement, initial cost, fuel transportation, reliability, operating cost, simplicity and cleanliness. **[6]**

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