10

Major Electrical Equipment in Power Plants

10.1 Introduction

A power station is equipped with electrical equipment for power generation and supply of electrical power. The major electrical equipment in a power plant consists of the following :

(*i*) Generators (*ii*) Excitors
(*iii*) Transformers (*iv*) Reactors
(*v*) Circuit breakers (*vi*) Switch board
(*vii*) Control board equipment.

10.2 Generator

It is an important part of a power plant. All modern type of alternating current generators (alternators) essentially consist of a fixed stator and revolving rotor.

Stator mainly consists of following three parts :

(*i*) Stator frame
(*ii*) Stator core
(*iii*) Stator windings.

The stator frame is of circular in shape and is made of welded steel plates. The core is made of stampings of high permeability, low hysteresis and eddy current losses. The rotors are generally built in cylinderical form and diameter of rotor is limited to 100 to 110 cm. Large number of deep slots are machined in the rotor to accommodate the field windings which will carry field currents. There should be ample passage in the rotor through which cooling fluid can be circulated freely.

Generators coupled directly to the steam turbines are called turbo-generators and those directly coupled to water turbines are called water wheel generators.

The frequency at which generator operates is given by

$$f = \frac{pn}{120}$$

where f = frequency in cycles per second

n = speed in R.P.M.

p = number of poles of the generator.

The frequency is the standard one used in the particular country. In India it is 50 cycles per second. The number of poles is necessarily an even number.

The generators used with diesel engines are of salient pole type having large diameters and short lengths. The number of poles varies between 4 to 28 as the speed range of diesel engines driving the generator varies between 1500 to 214 R.P.M. A common range of capacities is from 25 to 5000 kVA, the power factor rating being 0.8 lagging. A 3 phase 50 cycles per second supply is to be obtained from generators and a common voltage rating is 440 V. Generator efficiency varies between 92 to 95%.

A common voltage rating for turbo-alternators is 11 kV. The turbo-alternators are generally rated at 0.8 power factor lagging most of turbo-alternators are 2 pole generators with a speed of 3000 R.P.M. Their efficiency may be taken between 98% and 99%.

The water wheel generators are built with salient (projecting) poles as they require large number of poles and run at comparatively low speeds. Therefore water wheel generator rotors are much greater in diameter than turbo-generator rotors. The water wheel generators usually run at 62.5 to 125 R.P.M.

In a power plant several generators are run in parallel with each other. The parallel operation of generators has the following advantages :

(*i*) There exists a high reliability of power supply to the consumers.

(*ii*) It becomes possible to achieve more stable frequency and voltage under conditions of varying load.

(*iii*) Better economy in running of power stations and their equipment is obtained.

10.3 Exciter

The generator needs an exciter to build up the necessary voltage on no load and then to keep it constant on load, when greater excitation will be required. The exciter is a D.C. generator shunt or compound. The capacity of the exciter depends on the speed, on the voltage rating of a.c. generator and on the voltage required to compensate for the drop due to load on generator.

The rating of exciter is 0.3 to 1% of the generator output. Exciters usually operate at a voltage between 115 volts and 400 volts.

10.4 Generator Constants

The following details of generator should be known to enable to determine their performance in the power system under different loading conditions :

(*a*) kVA rating
(*b*) number of phases
(*c*) frequency
(*d*) voltage
(*e*) power factor
(*f*) temperature rise limits
(*g*) star connections of the stator.

10.5 Generator Cooling Methods

Generator losses appearing as heat must be continuously removed in order to keep the temperature of various parts of the generator and winding insulation with in limits. If the heat is not removed properly then the generator gets overheated and insulation is damaged. Thus every generator requires continuous cooling during its operation.

The two methods commonly used for cooling of generator are as follows :

(*i*) Air Cooling
(*ii*) Hydrogen Cooling.

Air Cooling. Generators of smaller capacity (about 50 MW) are cooled by this method. In air cooling the air circulates through ducts in the stator and along the air gap and then passes through a set of water cooled coils. The air is passed over the surfaces of the water cooled coils for transfer of heat to the water.

Hydrogen Cooling. Hydrogen (H_2) is used for cooling generators of larger capacities. This method offers following advantages over air cooled generators :

(*i*) The windage losses of the rotor turning in hydrogen are only 10% of those in air.

(*ii*) The noise is considerably reduced due to lighter cooling medium and lower friction.

(*iii*) Life of insulation is increased because of absence of oxygen.

(*iv*) The higher thermal conductivity of hydrogen allows generators to develop about 25% more output than with air cooling for the same physical dimensions.

(v) The cooling surface required for H_2 cooling is considerably smaller than that needed for air cooling due to high heat transfer rates.

The main difficulty in hydrogen cooling is that it is required to ensure full safety against any possibility of explosion. This is due to the reason that when hydrogen is mixed with air in certain proportions the mixture becomes explosive. To avoid this following precautions are taken :

(a) It is necessary to use pure hydrogen. The generator enclosure must be gas tight so that air cannot penetrate into the generator.

(b) The pressure of hydrogen is kept at least 0.035 kg/cm^2 higher than outside atmospheric pressure to prevent the leakage of air into the system.

(c) Special labyrinth type oil gland seals on the bearings are used to help the hydrogen leakage to a safe minimum.

The efficiency of large turbo-generators can be taken as 98% with air cooling and 99% with hydrogen cooling.

10.5.1 Parallel running of alternators

The method of connecting an alternators in parallel with another alternator or with bus bars to which a number of alternators are connected is called synchronising. In order to achieve proper synchronising of the alternator of the following conditions should be fulfilled :

(i) The frequency of the two systems must be identical.

(ii) The phases of the incoming alternator must be identical with the phases of the bus bars.

(iii) The voltage of the incoming alternator must be the same or approximately same as that of the alternator with which it is to be run in parallel or with that of bus bar.

10.6 Power Transformers

They are used to convert alternating current of one voltage to alternating current of some other desired voltage. The power transformers used in power stations are either single phase transformers banks of three each or 3-phase transformers.

Three phase transformers can be used with advantages in place of banks of three single phase transformers. The connections most widely used in 3 phase transformers are as follows :

(i) Delta-star (ii) Star-delta
(iii) Delta-delta.

Star-star connections are not normally used.

The size of transformers depends on the size of generator units. The general practice is to use the unit system of operation *i.e.* one transformer for one generator. In such case the kVA capacity of the 3-phase transformer must then be the same as that of generator to which it is connected.

While selecting the type of transformer, the significant operating characteristic of the transformers as well as their initial cost should be considered. The losses in the transformer are also an important criterion for their selection. A 3-phase transformer is preferable compared with a bank of three single phase transformer as the core loss is about 20% less in 3-phase transformer.

Following factors should be considered in deciding the suitability of particular type of transformer for a particular application :

(*a*) Load factor (*b*) Losses
(*c*) Initial cost (*d*) Cost of losses
(*e*) Continuity of service (*f*) Methods of cooling
(*g*) Percentage impedance voltage
(*h*) Floor area (*i*) Weight
(*j*) Regulation of voltage.

Different methods of cooling the transformers are used. Two commonly used methods used are as self-oil cooled transformers or forced oil cooled transformer. Self-oil cooled transformers do not need any external equipment and are self-contained whereas forced oil cooled transformers require pumps etc.

Fig. 10.1 (*a*) shows a power transformer. The various parts are as follows :

1. Tank 2. Magnetic circuit (core)
3. Radiators 4. Windings
5. Transformer oil 6. Oil gauge
7. Relay 8. Vent pipe
9. Oil conservator 10. Terminal bush
11. Terminal bush
12. Temperature indicating thermometer
13. Tank supporting frame.

The tank of transformer is made of steel. The core and windings comprise an assembly which is placed with in the tank. The core serves as the magnetic circuit for the flux set up by the windings. The windings are made of copper wire. The transformer oil which is a special grade of mineral oil serves two functions as follows :

(*i*) it serves as medium for transfer of heat generated in the windings and core to the air surrounding the transformer.

(*ii*) to insulate the current carrying parts from each other and from the earthed tank.

Radiators increase the surface available for cooling the oil of transformer. The conservator ensures that the tank is always filled

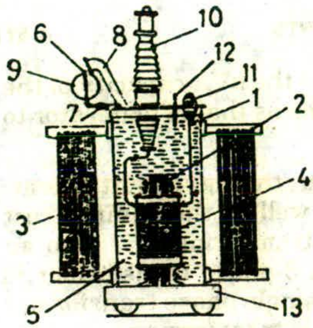


Fig. 10.1 (*a*)

with oil. The breather pipe permits the air to be taken in or expelled out as the level of oil in the conservator varies with change in temperature. Relay protects the transformer in the event of internal faults. The losses in the transformer are an important criterion for the selection of a transformer. A 3-phase transformer is preferable compared with a bank of three single phase transformers as the core loss is about 20% less in 3-phase transformers.

Further a 3-phase transformer has the following advantages as compared to three single phase transformers for ground surface power plant.

(*i*) Its cost is less (*ii*) Its weights less
(*iii*) It occupies less space (*iv*) It is more compact.

10.7 Reactors

Reactor help in protecting the electrical system. In large capacity installations short circuit current may attain very high values. This can be reduced considerably by the use of current limiting reactors and by their judicious placing.

A reactor should be so arranged that while there is no voltage drop across it under normal conditions of operation, it will prevent a large short circuit current being fed by the generators into the fault, thereby limiting the breaking currents of the circuit breakers.

10.8 Location of Reactors

The various ways by which reactors are located are as follows :

(*a*) **Reactors in generator circuits.** In this system the reactors are connected in the lines between the generators of the power plant and generator (G) bus bars. Fig. 10.1 shows this system. The disadvantage of this system is that if a short circuit occurs on one feeder the voltage at the common bus bars drop to a low value and the synchronous machines connected to the other feeders may fall out of step.

(*b*) **Reactor in series with feeders.** Fig. 10.2 show this arrangement. In this arrangement when a short circuit occurs on one of the feeders, most of the voltage drop occurs across its reactor and bus bar voltage does not drop to any considerable extent.

(*c*) **Bus bar reactors in ring system.** Fig. 10.3 shows this system. In this system under short circuit conditions the faulty feeder is mainly fed by one generator. The other generators feed the

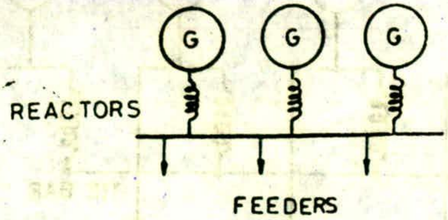


Fig. 10.1 (*b*)

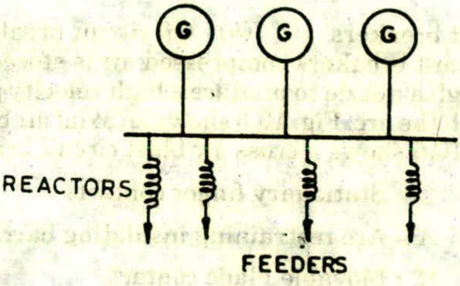


Fig. 10.2

faulty feeder only through the reactors which thus limit the fault current.

(*d*) **Bus bar reactors in Tie-bar system.** Fig. 10.4 shows this system. This system helps in reducing fault currents in the same way as the ring bus bar reactor system but in addition it has the advantage of limiting the currents.

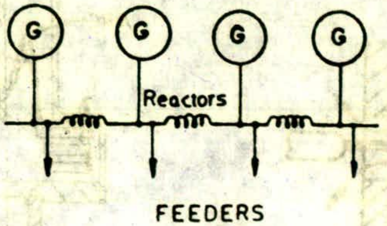


Fig. 10.3

10.9 Circuit-breakers

Their function is to break a circuit when various abnormal conditions arise and create a danger for the electrical equipment in an installation. There are two types of circuit breakers.

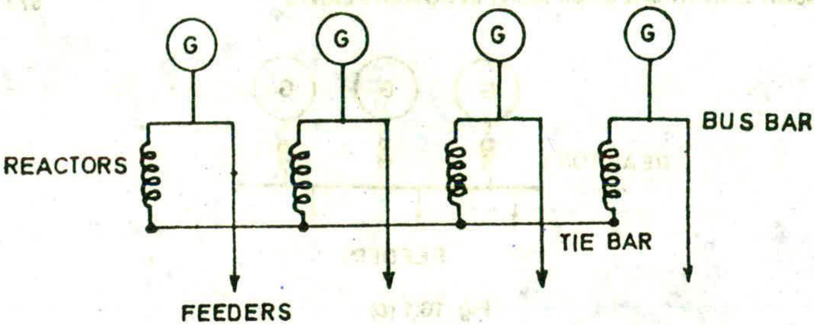


Fig. 10.4

(*a*) Air circuit breakers (*b*) Oil circuit breakers.

In air blast circuit breakers compressed air is stored in a tank and released through a nozzle to produce a high velocity jet and this is used to extinguish the arc. Fig. 10.5 shows an axial air blast circuit breakers and Fig. 10.6 shows a cross air blast circuit breaker.

C = Stationary finger contacts

A = Arc restraining insulating barrier

M = Movable blade contact.

Oil circuit breakers are quite commonly used. In these circuit-breakers oil plays an important role in the interrupting process. The rating range of these circuit breakers lies between 25 MVA at 2.5 kV to 5000 MVA to 230 kV. The use of oil in these circuit breakers offers following advantages.

(*a*) It has high dielectric strength.

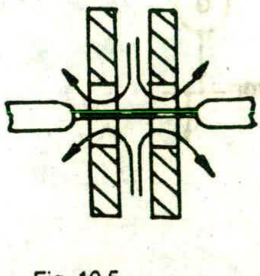


Fig. 10.5

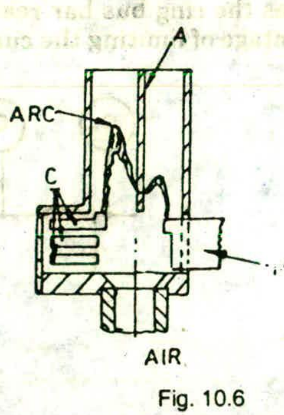


Fig. 10.6

(*b*) Surrounding oil in close proximity to the arc presents a large cooling surface.

(*c*) It acts as an insulator between live part and earth.

10.10 Earthing of a Power System

A power system is earthed at a suitable point. The various advantages of earthing are as follows :

(*a*) It provides lightning protection.
(*b*) It reduces operation and maintenance cost.
(*c*) It improves service reliability.
(*d*) Greater safety of power system is achieved.
(*e*) It provides greater safety to electrical equipment against over current.

The various methods commonly used for earthing a power system are as follows :

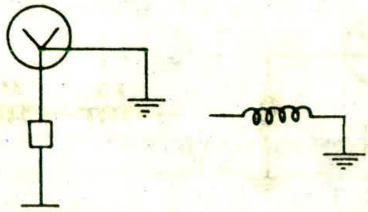


Fig. 10.7

1. *Solid earthing.* Fig. 10.7 shows this method of earthing. In this method neutral of a generator, power transformer or earthing transformer is connected direct to the station earth. This method of earthing does not make a zero impedance circuit.

2. *Resistance earthing.* Fig. 10.8 shows this method of earthing. In this method neutral is connected to the earth through one or more resistors. This method has the following advantages :

(*a*) It reduces the effect of burning and melting of faulted electrical equipment.

(*b*) It reduces electric shock hazard to personnel caused by stray earth fault current on the earth return path.

(*c*) It reduces mechanical stresses in circuits carrying fault currents.

3. *Reactance earthing.* Fig. 10.9 shows this method of earthing. In this method a reactor is connected between the machine neutral and earth. In order to minimise transient over voltages the earth fault current should not be less than 25% of the 3-phase fault current.

10.11 Layout of Electrical Equipment

The layout of electrical equipment of a power station consists of the following :

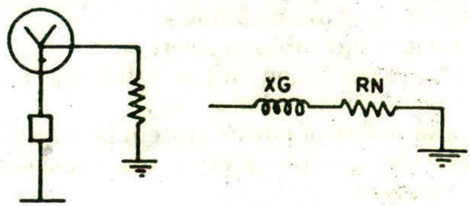


Fig. 10.8

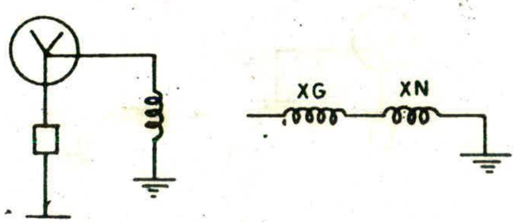


Fig. 10.9

(*a*) Arrangements of bus bars at the generator voltage.
(*b*) Arrangements of circuit breakers and switches.
(*c*) Location of transformers.
(*d*) Controlling switch board arrangement.

The various system used for la[illegible]t of electrical equipments are as follows :

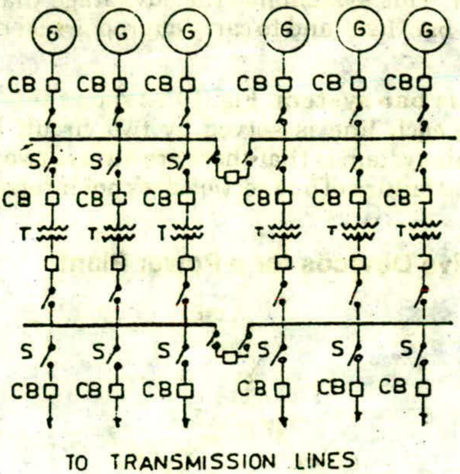
(*a*) **Single bus bar system.** Fig. 10.10 shows this system. In a power plant having a number of generators and a sin[illegible] bus bar arrangement, the bus bar is sectionalised by circuit breake[illegible]. It has the advantage that fault on one part of the bus bar or system does not completely shut down the whole station. However the use of such a large number of circuit breakers is out of date and now-a-days there is a tendency to use fewer.

(*b*) **Double bus bar system.** Fig. 10.11 shows this system. In this system both low voltage and high voltage bus bars are duplicated, any one of the bus bar sections can be used as desired. A bus

G = Generator

CB = Circuit breaker

S = Isolator or switch



LVB = low voltage bus bar

HVS = High voltage bus bar

T = Step up transformer.

Fig. 10.10

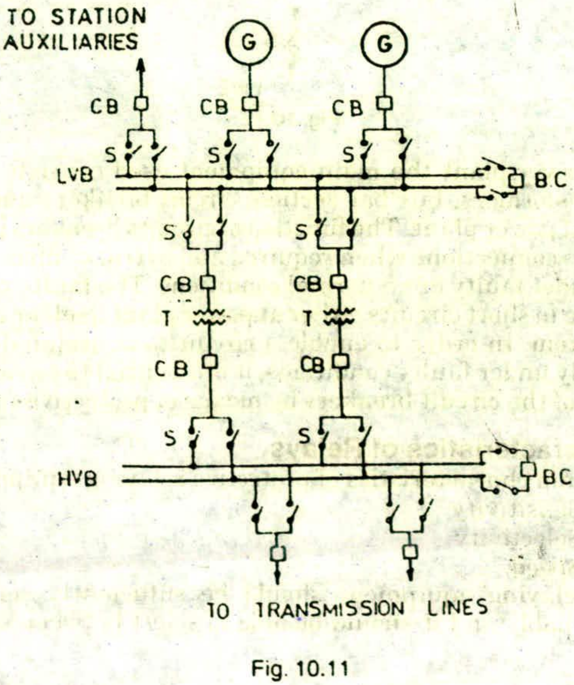


Fig. 10.11

bar coupling switch is provided to transfer operation from one bus bar to the other. This system has the advantage that it is possible to have one bus bar "live" and to carry out repairs on the other when required.

(*c*) **Ring bus bar system.** Fig. 10.12 shows this arrangement. In this system each line is served by two circuit breakers. The advantage of this system is that there are always two parallel paths to the circuit and failure of one section does not interrupt the service completely.

10.12 Protective Devices for a Power Plant

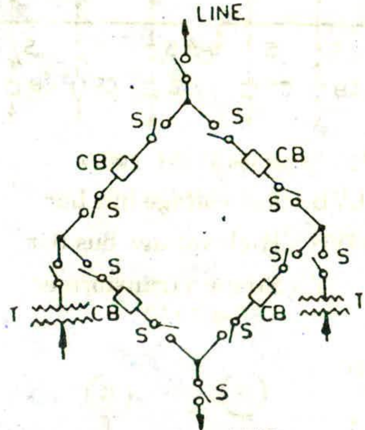


Fig. 10.12

In a power plant the main equipment used consists of generators, transformers, bus bar section, circuit breakers and circuits going out of power plant. The function of circuits breakers is to make the circuits connections when required and to trip or disconnect the circuits under faulty or *ab* normal conditions. The faulty conditions may be due to short circuits either at power plant itself or elsewhere in the system. In order to enable a circuit to be isolated from the system only under faulty conditions, it is essential to ensure correct operation of the circuit breakers by means of protective relays.

10.13 Characteristics of Relays

The main characteristics of protective relaying equipment are :

(*i*) Sensitivity

(*ii*) Selectivity

(*iii*) Speed.

The relaying equipment should be sufficiently sensitive to operate reliably and it should be able to select between conditions under which prompt operation is required and those under which no operation is required. A protective relay must operate at the required speed and must be reliable.

The speed with which relays and circuit breakers operate have direct bearing on the following :

(*i*) Quality of power supplied to the consumer.
(*ii*) Stability of the system.
(*iii*) Amount of power supplied.

The relay has to operate in case of heavy over-loads, short circuits, reversals and such abnormal occurrences. The selection of relay is made on the basis of time grading of the system, the various relays being given appropriate time settings.

10.14 Types of Relays

Protective relays avoid damage to the equipment. The function of the relaying system is to recognise a short circuit and to initiate the operation of devices to isolate the defective element with the minimum of disturbance to the normal service of the power system.

The main principle used in the operation of relays is either electromagnetic attraction or electromagnetic induction. The various types of relays commonly used are as follows :

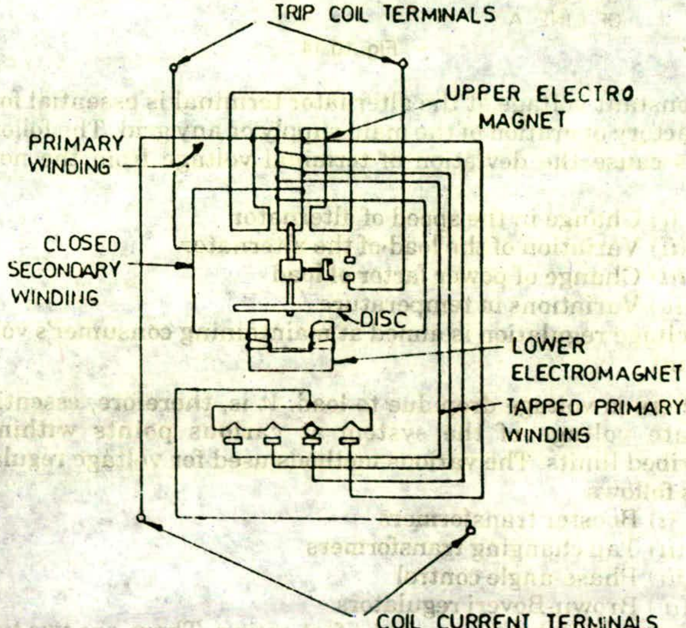


Fig. 10.13

(*i*) Electromagnetic attraction type relay
(*ii*) Induction type directional overcurrent relay
(*iii*) Induction type overcurrent relay
(*iv*) Differential relay
(*v*) Electromagnetic current balance relay.

Fig. 10.13 shows an induction type over current delay. Where as electromagnetic current balance relay is shown in Fig. 10.14.

10.15 Voltage Regulation of Transmission Lines

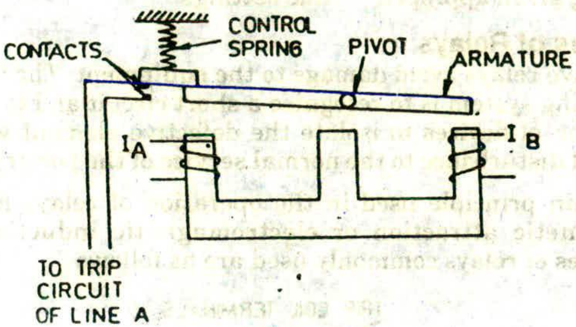


Fig. 10.14

Constant voltage at the alternator terminal is essential for the satisfactory operation of the main supply or any grid. The following factors cause the deviation of terminal voltage from the normal value.

(*i*) Change in the speed of alternator
(*ii*) Variation of the load of the alternator
(*iii*) Change of power factor of load
(*iv*) Variations in temperature.

Voltage regulation is aimed at maintaining consumer's voltage constant.

There is voltage drop due to load. It is, therefore, essential to regulate voltage of the system at various points within the prescribed limits. The various methods used for voltage regulation are as follows :

(*i*) Booster transformers
(*ii*) Tap changing transformers
(*iii*) Phase-angle control
(*iv*) Brown-Boveri regulators.

Voltage regulators should be fast acting. There are two type of voltage regulators.

(*a*) Electro mechanical regulators
(*b* Static voltage regulators.

Transformers with on load tap changers are widely used in electric power stations and power system sub-stations. Built in tap changers increase the cost of transformers.

Fundamentally there are two systems by which the electrical energy can be transmitted.

(*i*) High voltage D.C. system

(*ii*) High voltage A.C. system.

Various advantages of D.C. transmission are as follows :

(*i*) Only two conductors are used for transmission as compared to three conductors in A.C. system.

(*ii*) No stabilisers are required when power is to be transmitted over longer distances.

(*iii*) Inductance, capacitance, phase displacement and surge problems are eliminated in D.C. transmission.

(*iv*) In D.C. system the potential stress produced on the insulation is about 70% of A.C. effective voltage of same value.

The various advantages of A.C. transmission are as follows :

(*i*) It is possible to generate voltage as high as 33 kV as compared to 11 kV in D.C. system.

(*ii*) In A.C. system the alternating voltages can be efficiently stepped up by transformers which is not possible in D.C. system.

(*iii*) It is easier to maintain A.C. substation.

(*iv*) The transforming sub-stations are much efficient than the motor-generator sets used in D.C. system.

The various disadvantages of A.C. system are as follows :

(*i*) In A.C. system the amount of copper used is more.

(*ii*) The inductance and capacitance of the line effects the regulation of the line.

(*iii*) The speed of generator and alternators is not economical variation of these speeds must be controlled within very low limits.

(*iv*) Construction of transmission lines is not easy.

10.16 Transmission of Electric Power

The electric power may be transmitted by either underground cables or overhead lines.

Transmission by underground cables is quite suitable in densely populated areas. However underground transmission is about two times as much costly as over head system of transmission. Therefore, under normal circumstances an over head transmission system is preferred.

The main parts of the transmission system are as follows :

(*i*) Supports
(*a*) Poles (*b*) Towers
(*ii*) Conductors (*iii*) Insulators
(*iv*) Transformers (*v*) Protective devices
(*vi*) Control devices.

Poles or towers support the structures which support the conductors above the ground. Both poles and towers should ful fill the following requirements :

(*i*) High mechanical strength
(*ii*) High durability
(*iii*) Light weight
(*iv*) Low maintenance cost
(*v*) Low initial cost.

Poles may be made of materials like wood, steel, cement concrete etc. Usually RCC poles are used.

Fig. 10.15 shows RCC pole for single circuit and Fig. 10.15 (*a*) shows RC. C pole for double circuit.

Towers made of steel are mechanically sturdy and durable and are commonly used. Fig. 10.16 and Fig. 10.17 show steel towers. The steel towers are generally four legged, each leg anchored properly.

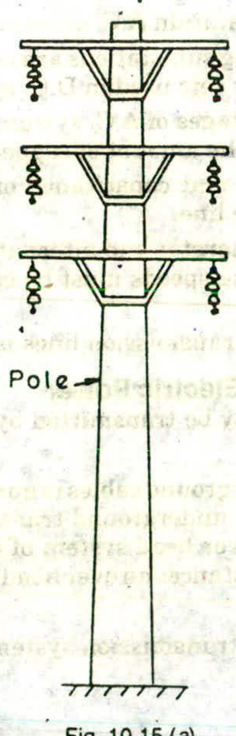


Fig. 10.15 (a)

Conductors are generally made of copper, aluminium, copper clad steel and steel cored aluminium conductors are used to carry electrical power from one end to the other for transmission and distribution. Conductors should ful-fill the following requirements.

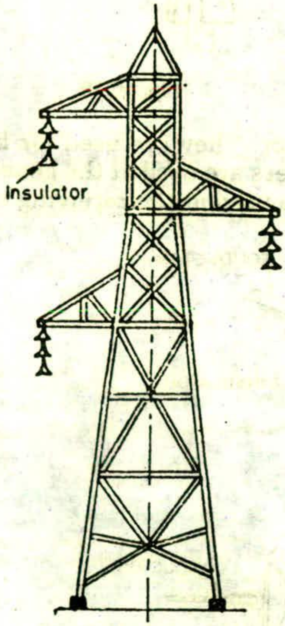


Fig. 10.16

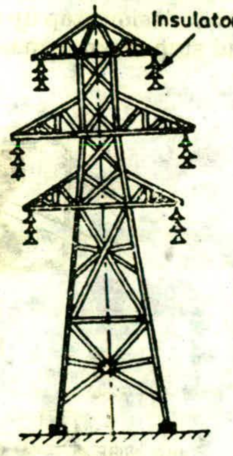


Fig. 10.17

(*i*) Good electrical conductivity
(*ii*) Low weight per unit volume
(*iii*) High tensile strength
(*iv*) Low cost
(*v*) High corrosion resistance.

Insulators are made of porcelain, glass or stealite. An insulator should have following properties :

(*i*) High mechanical strength
(*ii*) High insulation resistance
(*iii*) High dielectric strength.

Various types of insulator commonly used are as follows :

(*i*) Suspension type (*ii*) Pin type
(*iii*) Shackle type (*iv*) Strain type.

Fig. 10.18 shows a suspension type insulator.

Fig. 10.19 shows pin type insulator. In this insulator P is steel pin.

Shackle insulators are used for low voltage distribution lines. Fig. 10.19.1 shows shackle insulator mounted in a clamp.

Fig. 10.18

Fig. 10.19

Fig. 10.19.2 shows a strain insulator. They are used for high voltage transmission step up transformers are used at the generating end and step down transformers are used at the receiving end.

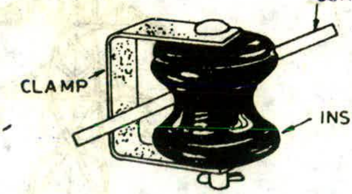


Fig. 10.19.1

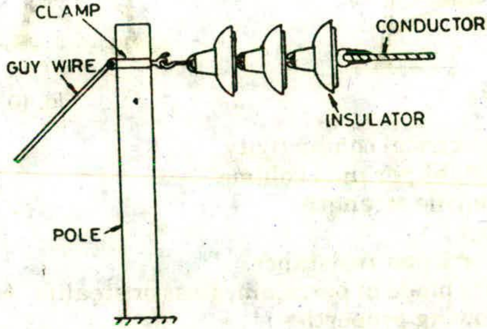


Fig. 10.19.2

Protective devices such as circuit breakers break the circuit when a fault occurs. Relays protect the circuit by energising the trip coils of the circuit breakers at the proper time.

The voltage of the transmission line is maintained constant or within limits by voltage control devices such as

(*i*) Synchronous compensators at the receiving end of the line
(*ii*) Regulators for the generators
(*iii*) Induction regulators
(*iv*) Tap changing transformers
(*v*) Line drop compensators.

The system control apparatus mainly consists of

(*i*) Quick-response excitation control apparatus for improving the stability of the system.
(*ii*) Governors and frequency control apparatus for controlling the load division between different stations in system.

10.16.1 Transmission Lines

Transmission lines are used to transmit power from the power station to load centre. The size of transmission lines, *i.e.* number of conductors and their cross-sectional area depends on the following factors :

(*i*) Amount of power to be transmitted.
(*ii*) Distance our which power is to be transmitted.

The various requirements of good and efficient electrical service of a power system are as follows :

(*i*) Constant voltage
(*ii*) Dependability
(*iii*) Balanced voltage
(*iv*) Minimum annual cost
(*v*) Constant frequency.

The voltage of transmission depends on the following factors :

(*i*) Power to be transmitted.
(*ii*) Distance over which power is to be transmitted.
(*iii*) Specific performance requirements regarding permissible regulation, losses etc.
(*iv*) Cost of transmission line equipment.

The standard voltages used for transmission in India are 11, 22, 33, 66, 110, 132, 166 and 230 kV.

Transmission lines are classified as follows :

(*i*) short (*ii*) medium (*iii*) long.

Transmission lines having a length less than 80 km are regarded as short transmission lines. Medium transmission lines have lengths between 80 and 240 km. Long lines have lengths more than 240 km. Performance of transmission line depends on length of line and power to be transmitted.

Percentage regulation. The percentage regulation of a transmission line is calculated as follows :

$$\varepsilon = \frac{V_s - V_r}{V_r} \times 100$$

where V_s = Sending end voltage

V_r = Receiving end voltage

ε = Regulation

Efficiency. Efficiency of transmission line is given by

$$\eta = \frac{P_r}{P_s}$$

where P_r = Receiving end power

P_s = Sending end power

η = Efficiency

Power loss. Power loss in a 3-phase transmission line is given by

$$\text{Power loss} = 3\, I^2 R$$

where I = current in line

R = Resistance of each phase.

The spacing of the transmission line between conductors is chosen considering the voltage between phases and the reactance and capacitance constants.

Capacitance (c). Capacitance of transmission line is defined as the ratio of charge to voltage

$$C = \frac{Q}{V}$$

where Q = charge

V = voltage

Capacitive reactance (X_C). It is given by

$$X_c = \frac{1}{2\pi f \,.\, C}$$

where f = frequency

Charging current (I_c). It is defined as the ratio of voltage to capacitive reactance

$$I_c = \frac{V}{X_c}$$

10.17 Systems of Electrical Energy Transmission

Fundamentally there are two systems by which the electrical energy is transmitted.

1. High voltage DC system. 2. High voltage AC system.

DC system

(*i*) DC two wire
(*ii*) DC two wire with mid point earthed
(*iii*) DC three wire.

AC System

(*a*) Single phase AC system
(*i*) Single phase two wire
(*ii*) Single phase two wire with mid-point earthed
(*iii*) Single phase three wire.
(*a*) Two phase AC system
(*i*) Two phase three wire
(*ii*) Two phase four wire
(*c*) Three phase AC system
(*i*) Three phase four wire.

However, three phase alternating currents system is mostly used. When transmission is being carried on over-head lines great care is taken to insulate the conductors from the cross arms and support towers.

The single phase system has its own limitations and therefore has been replaced by poly-phase system.

Poly-means many (two or more than two) and phase means windings or circuits each of them having a single alternating voltage of the same magnitude and frequency. Hence a polyphase system is essentially a combination or two or more than two voltages. These voltages have same magnitude and frequency but are displaced from one another by equal electrical angle called phase difference.

$$\theta = \frac{360 \text{ electrical degrees}}{N}$$

where θ = Phase difference

N = Number of phases

In two phase system there are two equal voltages of same magnitude and frequency having a phase difference of 90 degrees electrical.

In three phase system there are three voltages of same magnitude and frequency and having a phase difference of 120 degrees electrical.

The three phase system is most commonly used polyphase system and is exclusively used for generation, transmission and distribution of electric power.

10.18 A.C. Power Distribution

Electric power is generally generated and distributed in the form of alternating current. The advantage of using A.C. system is that voltage can be conveniently regulated by means of transformers.

A.C. power distribution system is of two types

(*i*) **Primary distribution system.**

According to this system the bulk consumers are generally supplied power at high voltage of 11 kV, although voltage may also be 6.6 kV or 3.3 kV. The voltage is stepped down to 400 V by step-down transformers. Three phase three wire system is preferred for distribution due to economic considerations.

Fig. 10.19 (*a*) shows a typical distribution system.

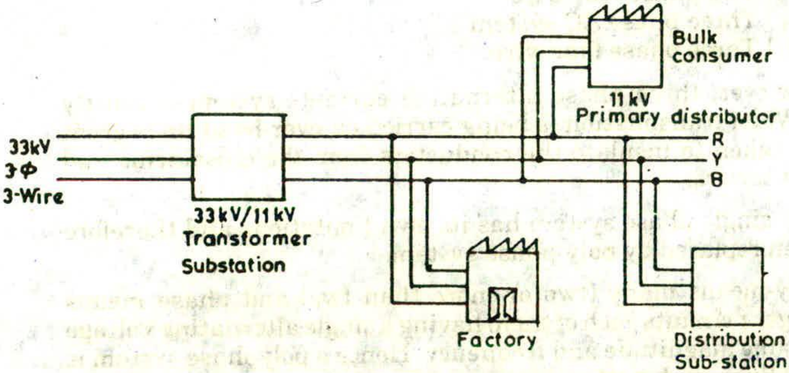


Fig. 10.19 (*a*)

(*ii*) **Secondary distribution system.** This system is used to supply power to small consumers at low voltage (400/230 V). Three phase—4 wire system is preferred the voltage is stepped down from 11 kV to 400 V by transformers installed at distribution sub-station. Fig. 10.19 (*b*) shows a secondary distribution system.

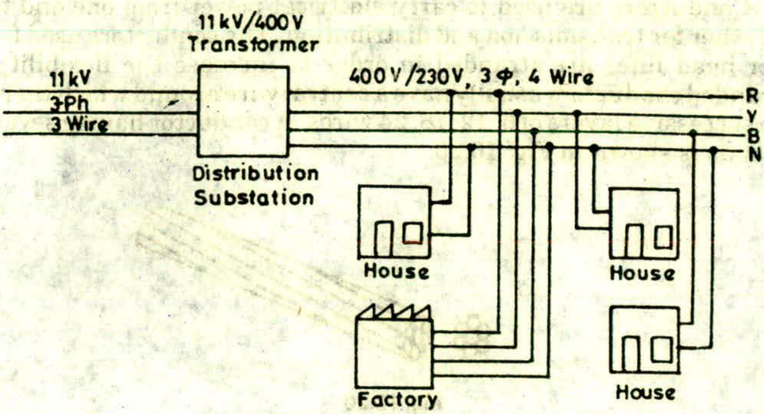


Fig. 10.19 (*b*)

10.19 Practical Working Voltage

Following voltages are generally adopted :

(*i*) For generation 6.6, 11 or 33 kV.

(*ii*) For main or primary transimission 66, 132, 220, 275, 330 and 400 kV.

(*iii*) For secondary transmission 11 or 33 kV.

(*iv*) For distribution 6.6, 11 or 33 kV.

It is not doubt economical to use higher voltages for transmission but there is a limit to which the voltage can be increased. Since an increase in transmission voltage introduces insulating problems as regards supporting of conductors and clearance between them.

10.20 Over-head and Under Ground Power Transmission Systems

Both over-head and underground systems are used for transmission of electrical power.

The over-head transmission system has the following advantages :

(*i*) It is cheaper to transmit power by over-head lines than underground cables.

(*ii*) Over-head lines can be easily repaired.

(*iii*) Insulation of over-head lines is easier.

The advantages of underground cable power transmission are as follows :

(*i*) It is easier to transmit power in densely populated areas.

(*ii*) Maintenance cost is low.

(*iii*) Underground cable is susceptible to less number of faults.

10.21 Conductors

Conductors are used to carry electrical power from one end to the other for transmission and distribution. The conductors used for over head lines are stranded in order to increase the flexibility. Stranded conductors usually have a central wire around which there are successive layers of 6, 12, 18, 24 wires. A conductor having seven strands is shown in Fig. 10.20.

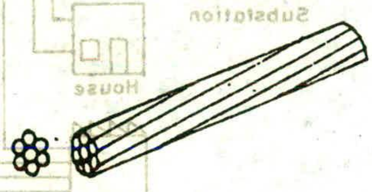


Fig. 10.20

Conductor materials. The conductor materials should possess the following properties :

(*i*) High conductivity *i.e.* low resistivity so that area of cross-section can be reduced.

(*ii*) High tensile strength.

(*iii*) High ductility so that the conductor can be easily drawn in shape of wires.

(*iv*) Low specific gravity so that low weight per unit volume is used.

(*v*) Low cost.

The most commonly used materials are as follows :

(*i*) Copper (*ii*) Aluminium

(*iii*) Steel cored aluminium (*iv*) Galvanised steel.

10.21.1 Disposition of Conductors

The disposition of conductors in transmission or distribution of electrical energy has much bearing on the performance of the line. The line may be either of single circuit or double circuit system. Single circuit and double circuit system can be compared as follows:

	Single Circuit Design		*Double Circuit Design*
1.	There is less danger at the time of repair	1.	Danger always exists from the other alive circuit.
2.	This design is subjected to less wind pressure and structure and therefore, it requires lighter towers and medium foundations.	2.	There is more wind pressure. This requires heavier structures and weight of tower is more.

3.	Larger spacing of conductors is required.	3.	Lesser spacing in conductors is used.
4.	Higher reactance as spacing between conductors is more.	4.	Low reactance as spacing between conductors is small.
5.	This design is not reliable so far as continuity of power supply is concerned.	5.	This design is quite reliable as regards continuity of power supply.

10.22 Electric Power System Stability

Whenever the speed of an alternator changes with respect to its synchronous speed it gives rise to variations in voltage and frequency. These variations are further transmitted to the lines and feeders connected to the alternators thereby setting up disturbances in the connected equipment.

Following measures help in providing stability to the electric power system :

(*i*) The stability can be improved by using lighting arrestors for protection of lines, by using quick acting circuit breakers and with relays having minimum time lag.

(*ii*) Voltage regulators connected on the line should be quick acting.

(*iii*) The governors attached to the turbines driving alternators should be as quick acting as possible so that the generator input to the load is quickly adjustable.

(*iv*) Stability is also improved mechanically by connecting the synchronous motors to heavy flywheels.

10.23 Control Room

The control room of a power plant should be properly located. Following points should be kept in mind while locating the control room :

(*i*) It should be near the switch house to reduce the lengths of connecting cables.

(*ii*) It should be well ventilated and lighted.

(*iii*) It should be located away from the sources of noise.

Following equipment is fitted in the control room :

(*i*) control equipment like
(*a*) voltage regulators
(*b*) frequency stabilisers
(*c*) load distributors.

(*ii*) protective devices like
(*a*) circuit breakers
(*b*) relays
(*c*) emergency trippers.

(*iii*) Indicating devices such as instruments for indicating the load, voltage, frequency, power factor and winding temperatures.

10.24 Layout of Power System

The generator, transmission and distribution of electric power is called power system.

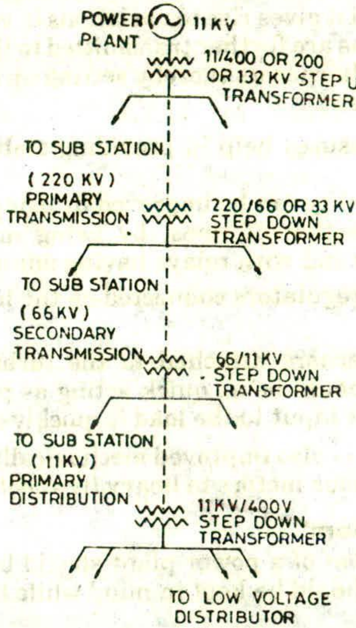


Fig. 10.21

Fig. 10.21 shows line diagram of power system. Generally a power system consists of the following stages :

(*i*) Power station

(*ii*) Primary transmission

(*iii*) Secondary transmission

(*iv*) Primary distribution

(*v*) Secondary distribution.

At the power plant the electric power is generated. The generation voltage may be 3.3, 11 or 33 kV. However 11 kV generation voltage is quite commonly adopted. Then the generation voltage of 11 kV is stepped up to 132, 220 or 400 kV at the power plant.

The power is then transmitted by primary and secondary transmission system using three phase three wire system. The electric power is finally supplied to the consumers by primary and secondary distribution system.

10.25 Factors Affecting Power Generation and Distribution

Electric power is generated by means of electric machines called generators when power generated is D.C. and Alternators when power generated is A.C. These machines are essentially convertors which convert mechanical energy into electrical energy *i.e.* these machines must be mechanically coupled to prime-movers.

Three phase system should be used for generation, transmission and distribution of electric power because of its superiority over single phase system.

Three phase three wire A.C. system is invariably employed for transmission of electric power because in this case power at high voltage can be generated and the voltage can be stepped up and stepped down easily and efficiently by using transformers.

To transmit the same amount of power over a fixed distance at a given voltage, 3-phase system requires about 3/4 of weight of conducting material of that required by single phase system.

Electric power generated at the power station is conveyed to the consumers through a network of transmission and distribution. The part of power system by which electric power is distributed among consumers is called distribution system. The electrical energy generated at the power plants is conveyed to the sub-stations from where the electric power is conveyed to the bulk consumers by high voltage distribution system whereas it is conveyed to the small consumers by low voltage distribution system.

The various factors which affect electric power generation and distribution are as follows :

(*i*) Type of phase system
(*a*) Single phase system
(*b*) Three phase system.

(*ii*) **Type of fuel used.** Hydro-electric power plant is best suited where water is available in large quantities and at sufficient head. Steam power should be installed near coal mines. However steam power plant or nuclear power plant can be used where neither coal nor water is easily available. For small loads diesel power plant or gas turbine power plant may be used.

(*iii*) **Transmission Voltage.** It is desirable to use highest possible voltage for transmission of electric power. Economic transmission voltage is one for which cost of transmission (cost of conductors, insulators, transformers, switch gear and other terminal apparatus like lightning arrestors etc.) is minimum.

(*iv*) Cost of transmission and distribution.

(*v*) **Type of transmission.** The electric power is generally transmitted and distributed by over head lines because of economy.

(*vi*) Type of substations :

(*a*) Indoor substations.

(*b*) **Out door substations.** Outdoor substations are preferred over indoor substations.

(*vii*) Type of load to be taken by the power station.

(*viii*) Capacity of power plant.

(*ix*) **Running cost of power plant.** The running cost of hydro power plant is less than steam or nuclear power plant.

PROBLEMS

10.1. What is the electrical equipment in a power plant.

10.2. Write short notes on the following :
(*a*) Generator (*b*) Excitor (*c*) Factors affecting power generation and distribution.

10.3. Describe the various generator cooling methods.

10.4. Write short notes on the following :
(*i*) Power transformer
(*ii*) Voltage regulation
(*iii*) Transmission of electrical power.

10.5. Discuss the factors to be considered while deciding the suitability of a transformer.

10.6. What is a circuit breaker ? What are the different types of circuit breakers that are employed in typical power stations ?

10.7. What is protective relay ? Describe any one relay system used to protect the equipment in a power plant.

10.8. Give a list of various electrical protective equipment used in a power station. (*A.M.I.E. 1979*)

10.9. Describe the various methods of controlling the voltage at the consumer terminal used in power supply system.

10.10. What are the different methods of earthing in power system ? Explain in details.

10.11. What is the function of a reactor ? Describe the various arrangements used for location of reactors.

10.12. Write short notes on the following :
(*a*) Over-head and underground power transmission systems
(*b*) System of electrical energy transmission
(*c*) Practical working voltage
(*d*) Disposition of conductors
(*e*) Characteristics of relays
(*f*) Parallel running of alternators

(*g*) Control room
(*h*) Poles and towers
(*i*) Types of insulators.

10.13. Discuss electric power system stability.

10.14. Sketch and describe a power transformer.

10.15. State the advantages and disadvantages of A.C. and D.C. systems of power transmission.

10.16. What are the properties of materials used for conductors. Name the materials used for conductors.

10.17. Describe A.C. power distribution systems.

10.18. Sketch and describe layout of power system.

11

Non-Conventional Sources of Energy

11.0 Introduction

In our country power is needed in plenty to sustain our industrial growth and agricultural production. Existing sources of energy such as coal, oil, water and uranium may not be sufficient to meet the increasing energy demands. This requires that scientists and engineers should undertake research work which would help in exploring the possibilities of harnessing energy from several non-conventional sources of energy. The various non-conventional sources of energy are as follows :

(*i*) Solar energy
(*ii*) Wind energy
(*iii*) Bio-gas and bio-mass
(*iv*) MHD generator
(*v*) Geo thermal
(*vi*) Tidal power
(*vii*) Fuel cells
(*viii*) Thermo-electric generation
(*ix*) Thermionic converter.

It is recognised that an early, smooth and successful transition from fossil fuel (coal, oil, water) to new and renewable sources of energy depends on a strong, integrated and purposeful R and D programme. In our country the Commission for Additional Sources of energy is responsible for the development of new and renewable sources of energy. The technology to obtain power from renewable sources should be so developed that power generated is cheaper. The power plants working on renewable sources of energy should have low capital cost, there should be no pollution of atmosphere and running cost should be less.

The Energy Ministry proposes to give a bigger thrust to the exploitation of new and renewable (non-conventional) sources of energy to meet a variety of energy needs in urban and far flung rural areas in a decentralised manner.

The main advantages of non-conventional sources of energy are as follows :

(*i*) They are widely available.

(*ii*) They are non-polluting.

(*iii*) They are well suited for decentralised use a distinct advantage in a large country like India. Owing to technological developments and improvements in systems designs it has been observed that renewable sources of energy can now be shown to be more attractive in many situations and locations. For example calculations of the economics of bio-gas plants show that the pay back period is two and half years in terms of value of fuel saved and manure produced. According to energy experts the non-conventional sources of energy can be used with advantage for power generation as well as other applications in a large number of locations and situations in the country. It is hoped that these alternative energy sources will be able to meet considerable part of energy demand in coming future. Solar energy, however is not free from problems. It is now available at night and when local weather conditions obscure the sun. Moreover solar energy is diffused in nature and is at a low potential. Consequently if solar energy is to be economically competitive it must be converted into a usable form of energy with maximum effectiveness to reduce capital cost of solar power plants.

11.1 Solar Energy

Among the various non-conventional sources of energy the solar energy seems to hold out the greatest promise for the mankind. It is free, in exhaustible, non-polluting and devoid of political control. Rapid depletion of fossil fuels and combined crisis of pollution and of steep rise in oil prices have brought about an upsurge of interest in solar energy.

Solar radiations can be converted directly or indirectly in the form of energy such as heat and electricity. Solar power would eliminate most of the serious environmental problems associated with fossil fuel and nuclear power. Energy is released by the sun as electromagnetic waves of which 99% have wavelengths between 0.2 to 4.0 μ where, μ is micrometer. Solar energy reaching the top of earth's atmosphere consists of about 8% ultra violet radiation (short wave length less than 0.39 μ), 46% visible light (0.39) to (0.78 μ) and 46% infrared radiation (long wave length more than 0.78 μ).

Solar radiation that has not been absorbed or scattered and reaches the ground directly from the sun is called Direct Radiation. It is the radiation which produces a shadow when interrupted by an opaque object. The radiations received after scattering is called Diffuse Radiation. Diffuse radiation comes to earth from all parts of the sky. The total solar radiation received at any point on the earth's surface is the sum of direct and diffuse radiation.

Fig. 11.1 (*a*) shows solar energy storage.

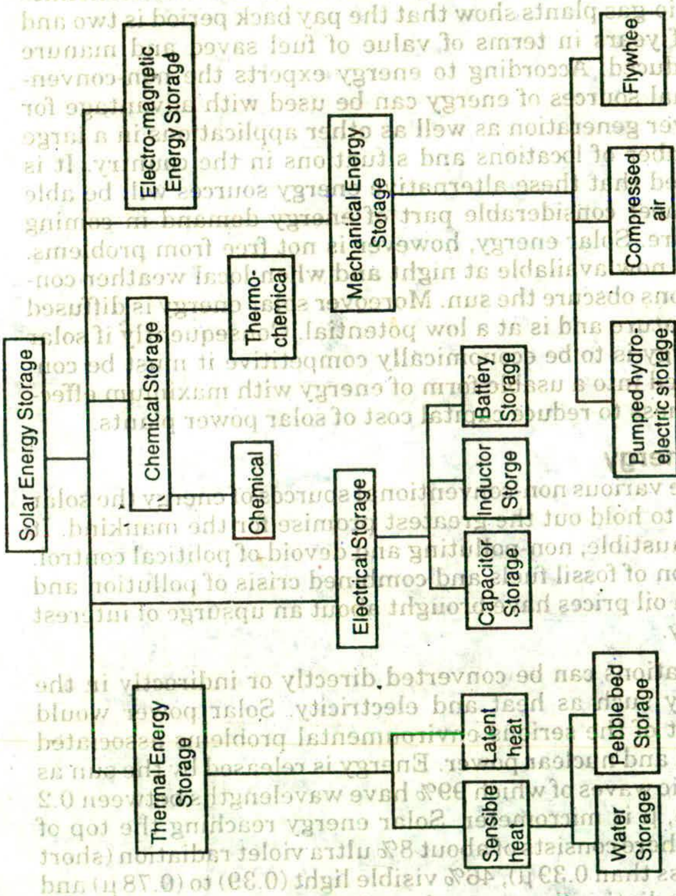


Fig. 11.1 (a)

The thrust of the research efforts in our country in the solar energy has been directed both towards solar thermal applications and direct conversion of solar electricity. Utilisation of solar energy is of great importance to our country as it lies in tropical climate region where sun light is abundant for a major part of the year. The target for power generation from non-conventional energy sources have been upgraded to 200 MW from 600 MW for eighth plan. The most promising and fast moving solar technology today is that of solar cells, flat metallic blue chips made of highly pure silicon that can convert sun light into electricity. These photo-voltaic cells are being used in rural areas and isolated locations for a variety of applications such as (*i*) water pumping for irrigation and drinking water supply.

(*ii*) Community and street lighting.

(*iii*) Power supply for micro wave repeater station.

(*iv*) Communication equipment, radio and television receivers.

(*v*) Solar water heaters.

(*vi*) Solar refrigeration.

11.2 Solar Radiation Measurement

Following two type of instruments are used for solar radiation measurement :

(*i*) *Pyrheliometer.* It collimates the radiation to determine the beam intensity as a function of incident angle.

(*ii*) *Pyronometer.* It measures the total hemi-spherical solar radiation. The pyranometer is quite popular.

11.3 Solar Constant

It is the rate at which solar energy arrives at the top of atmosphere. This is the amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun. The rate of arrival of solar radiations vary throughout the year. According to National Aeronautics and Space Administration (NASA) the solar constant is expressed in following three ways.

(*i*) 1.353 kilowatts per square metre or 1353 watts per square metre.

(*ii*) 429.2 Btu per square foot per hour.

(*iii*) 1164 kcal per sq. m. per hour.

11.4 Solar Energy Collectors

Solar energy can be exploited in various ways as follows :

(*i*) By direct conversion to a fuel by photosynthesis.

(*ii*) By direct conversion to electricity by photo voltaic.

(*iii*) By conversion to electricity *via* thermo-electric power system. However thermo-electric system is most commonly used to as other two systems are still far away from acceptable limits.

Following thermo-electric systems are presently used for power generation.

(*i*) Low temperature cycles using flat plate collectors.

(*ii*) Concentrator collector for medium and high temperature cycles.

(*iii*) Power concept for power generation.

11.5 Flat Plate Collectors

A flat plate collector is shown in Fig. 11.1. Flat plate collectors are made in rectangular panels from about 1.7 to 2.9 sq. m in area and are relatively simple to construct and erect. Flat plates can collect and absorb both direct and scattered solar radiation they are thus partially effective even on cloudy days where there is no direct radiation.

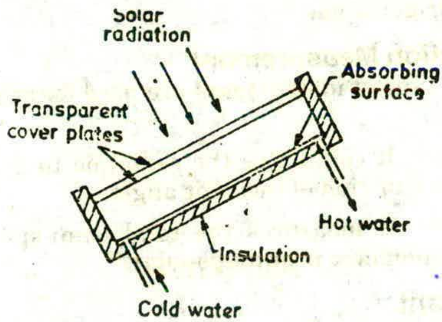


Fig. 11.1

The solar rays pass through transparent covers and fall on absorbing surface. The absorbing surface which is usually made of copper, aluminium, or steel coated with a heat resistant black (carbon) point intercepts and absorbs the solar radiation energy. Radiation energy is converted into heat and water flowing through the tubes gets heated. It is not possible to generate steam with plate collectors so this system can not be used directly to run the prime mover. So some other organic fluid such as Freon-14, 150 butane etc. which evaporate at low temperature and high pressure by absorbing heat from heated water. The vapours formed can be used to run the prime mover (turbine or engine) to generate power.

Insulation is used to prevent loss of heat from the absorber and heat transporting fluid. The insulating materials commonly used are fibreglass or styrofoam.

Flat plate collectors are also called non-concentrating type. Collectors are classified as low temperature collectors because they can generate temperature less than 90° and have a collection efficiency of about 30 to 50%.

11.6 Concentrating Collectors

Concentrating or focusing collectors are of two types :

(*i*) Line focusing collectors

(*ii*) Point focusing collectors.

Focusing collectors collect solar energy with high intensity of solar radiations on the energy absorbing surface. Such collectors generally use optical system in the form of reflectors or refractors and can heat the fluids up to about 500°C. An important difference between collectors of non-focusing and focusing types is that the latter concentrate only direct radiation coming from a specific direction.

11.7 Line Focusing Collectors

Fig. 11.2 shows a parabolic trough collector. In this collector the solar radiations coming from a particular direction are collected over the area of the reflecting surface and is concentrated at the focus (F) of parabola. Mostly cylindrical parabolic concentrators are used in which absorber is placed along focus axis. Fig. 11.3 shows a typical cylindrical parabolic collector. It consists of parabolic cylinder reflector to concentrate sun light on to a collecting pipe. The reflector is steered during day time to keep sun light focused on the collector. This type of concentrator produces much higher temperature than flat plate collectors. The dimensions of parabolic trough collector or parabolic cylindrical collector can vary over a wide range, the length of a reflector unit may be above 3 to 5 m and width about 1.5 to 2.4 m. Ten or more such units may be connected end to end in a row, several rows being connected in parallel. Parabolic trough reflectors may be made from polished aluminium, silvered glass or a thin film of highly aluminised plastic on a firm base.

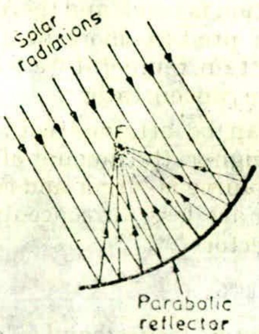


Fig. 11.2

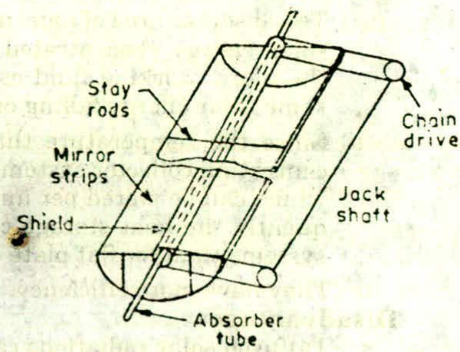


Fig. 11.3

11.8 Point Focusing Collector

Fig. 11.4 shows a paraboloidal dish collector which bring solar radiation to a focus at a point. In this collector a dish 6.6 metre in diameter made from about 200 curved mirror segments forming a paraboloidal surface is used. The absorber located at the focus is a cavity made of a zirconium-copper alloy with a black chrome selective coating. The heat transport fluid flows into and out of absorber cavity through pipes bonded to the interior. The dish can be turned left and right and up and down so that sun rays can be focused properly.

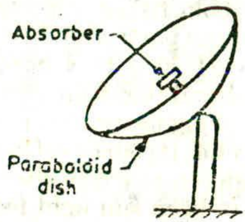


Fig 11.4.

11.9 Advantages and Disadvantages of Concentrating Collectors

Concentrating collectors have the following advantages over flat collectors :

(i) Reflecting surfaces are structurally simpler and need less material.

(ii) Cost of collecting system per unit area is low.

(iii) The absorber area of concentration is small and therefore, solar energy concentrated can produce more heat and therefore, working fluid can attain temperature for the same solar energy falling on the concentrator.

(iv) Since the temperature that can be attained with concentrating collector system is higher, the amount of heat which can be stored per unit volume is larger and consequently the heat storage costs are less for concentrator systems than for flat plate collectors.

(v) They have more efficiency.

Disadvantages

(i) Diffused solar radiations can not be focused and is lost.

(ii) Initial cost is high.

(iii) Costly orienting system for reflector to track the sun is required.

11.10 Solar Thermal Power Generation

Solar thermal power generation uses power cycles which are broadly classified as :

(*i*) Low temperature cycle.
(*ii*) Medium temperature cycle.
(*iii*) High temperature cycle.

Low temperature cycles usually can be used up to 100°C and use flat plate collectors whereas medium temperature cycles are used for temperatures between 150 to 300°C and high temperature cycles are used for temperatures above 300°C. Two principal forms of energy into which solar radiations can be converted for practical applications are as follows :

(*i*) Heat
(*ii*) Electricity.

Heat is obtained when solar radiation is absorbed by a black surface. The heat then may be used in two ways :

(*a*) Direct thermal applications such as water heating, drying, cooking, distillation etc.

(*b*) In-direct conversion of solar energy into electricity using photo voltaic cells, thermo electric thermionic and photo chemicals. Photo voltaic effect is quite popular.

The mechanical power production is called solar thermal power production system. So far as conversion of solar energy into electrical energy is concerned it may be done either by solar thermal power production route or solar radiations can be directly converted into electrical power.

11.11 Low Temperature Thermal Power Generation

Fig. 11.5 shows a low temperature thermal election power generation scheme using solar pond. Hot water from pond enters an evaporator where the organic working fluid is vaporised. Then the vaporised organic fluid at high pressure enters a turbine and thereby expanding through the turbine wheel to produce power.

The vapour now passes through a condenser where it is condensed to a liquid. This liquid is pumped back to the evaporator where cycle is repeated.

Another type of low temperature solar power plant is shown in Fig. 11.6. This system uses an array of flat plate collectors to heat water to about 70°C and then in heat exchanger the heat of water is used to boil butane. The butane at high pressure is made to pass through a turbine. This scheme is quite commonly used for lift irrigation purposes.

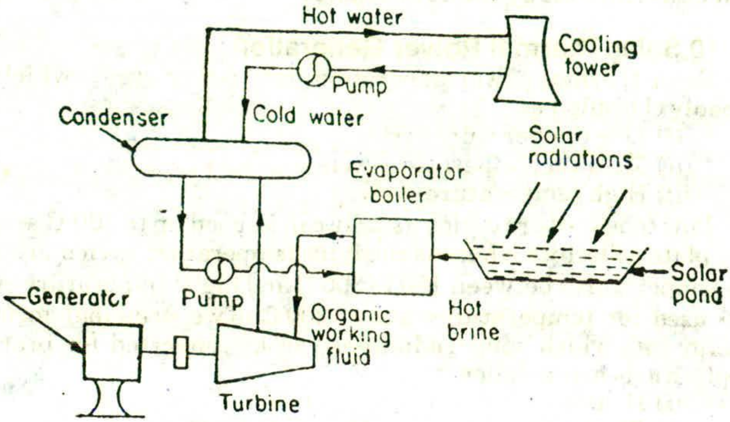


Fig. 11.5

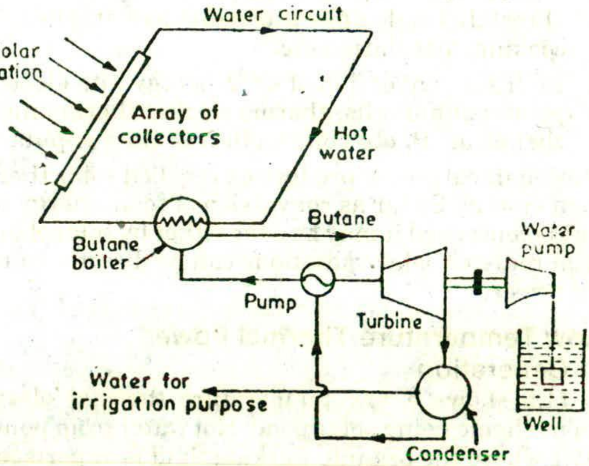


Fig. 11.6

High Temperature Systems

Two basic arrangements for converting solar radiation into electrical energy systems are as follows.

11.12 Tower Concept Type Solar Power Plant

This type of power plant uses an array of plane mirrors or heliostats which are individually controlled to reflect radiation from the sun into a boiler mounted on a tall (about 500 m high) tower. The steam is generated in the boiler. The steam may attain a temperature up to 2000°K. The steam so produced is used to drive a turbine coupled to a generator. Fig. 11.7 shows a tower concept type solar power plant.

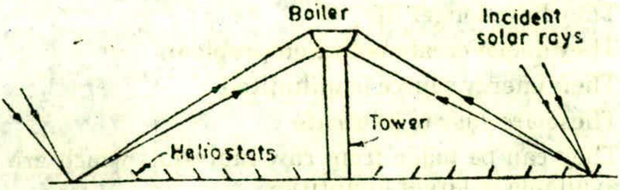


Fig. 11.7

Another type of solar power plant based on similar principle is shown in Fig. 11.8. It uses an array of heliostats guided mirrors to focus sun light into a cavity type boiler near the ground to produce high temperature high pressure steam which is used to drive a steam turbine. The solar rays striking the mirrored faces of heliostats modules are reflected and concentrated in the cavity of boiler.

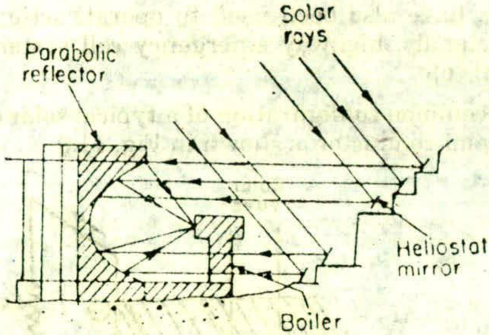


Fig. 11.8

11.13 Photovoltaic (PV) Cells or Solar Cells

These cells directly convert solar energy to D.C. power. These cells are made of semiconductors that generate electricity when they absorb light. Solar cells made of single crystal silicon are commonly used as its theoretical efficiency is about 24%. But commercially available cells have an efficiency of about 10 to 12%. Gallium arsenide is the another solar cell material. Cells of this material may achieve an efficiency of 20 to 25%. Solar cells made of gallium arsenide can retain efficiency at much higher temperature than cells made of silicon.

The silicon cell consists of a single crystal of silicon into which a doping material is diffused to form a semi-conductor. The best known application of photovoltaic cells for electrical power generation has been space craft for which silicon solar cell is the most highly developed type.

Various advantages of solar cells are as follows :

(*i*) They need little maintenance

(*ii*) They have longer life

(*iii*) They do not create pollution problem

(*iv*) Their energy source is unlimited

(*v*) These are easy to fabricate

(*vi*) They can be made from raw materials which are easily available in larger quantities.

The disadvantages of solar cells are as follows :

(*i*) Compared with other sources of energy solar cells produce electric power at very high cost.

(*ii*) Solar cell output is not constant and it varies with the time of day and weather.

(*iii*) They can be used to generate small amount of electric power.

Solar cells have also been used to operate irrigation pumps, navigational signals, highway emergency cell systems, rail road crossing signals etc.

The most common configuration of a typical solar cell to form a *p-n* junction semi-conductor is shown in Fig. 11.9.

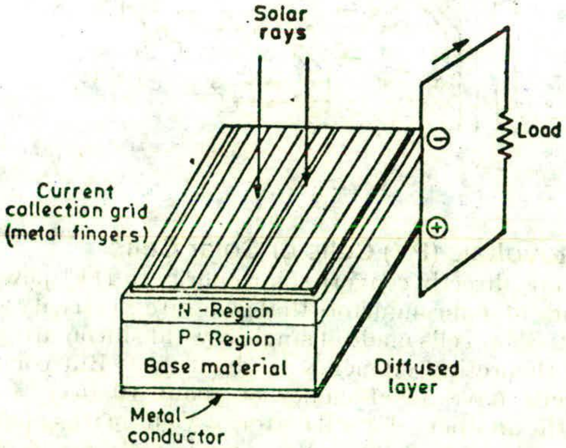


Fig. 11.9

11.1.4 Solar Pumping

The various parts of solar pumping system are as follows :

(*i*) Solar collectors such as

(*a*) Flat plate collectors
(*b*) Stationary concentrators.
(*ii*) Heat exchanger or Boiler
(*iii*) Heat engine such as
(*a*) Brayton cycle as turbine
(*b*) Stirling hot gas engine
(*c*) Rankine engine
(*iv*) Condenser
(*v*) Pump such as
(*a*) Centrifugal pump
(*b*) Reciprocating pump
(*c*) Rotary pump.

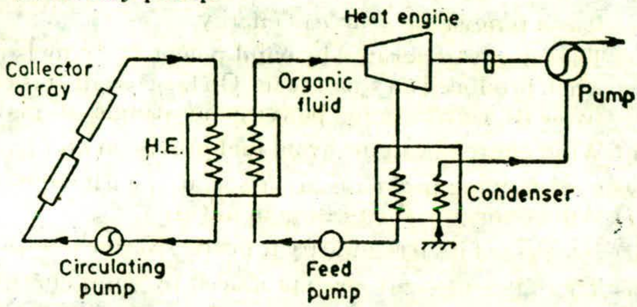


Fig. 11.10

The power generated by solar energy is used for water pumping useful for irrigation purpose. Fig. 11.10 shows a typical solar energy power water pumping system. The primary components of the system are an array of flat plate collectors and Rankine engine with an organic fluid as the working substance. In this systems a heat transfer fluid flows through the collector arrays. The fluid get heated due to solar energy. The fluid (water) is then made to flow through a heat exchanger (boiler) where it transfers its heat to other fluid in the boiler. This other fluid then gets evaporated and expands in the engine before reaching the condenser. Some of the working fluids used in cycle are tolune (CP-25), monochloro benzene (MCB), and trifluoro ethanol. The major obstacle to the increased use of solar irrigations system is its relatively high capital cost. H.E. in figure indicates heat exchanger.

11.15 Wind Energy

Energy of wind can be used for the generation of electrical energy. The potential of wind energy as a source of power is large. Wind energy which is an indirect source of energy can be utilised to run wind mill which in turn drives a generator to produce electricity. Wind energy is one of America's greatest natural resources. According to NASA study the U.S. has enough harvestable wind to generate 1.28 trillion kWh of electrical energy per year. Wind mills have been used for several centuries in countries like Denmark, Netherland China, Europe, Persia etc. In India high wind speeds are obtainable in coastal areas of Sourashtra. Western Rajasthan and some parts of Central India. In these areas there could be a possibility of using medium and large sized wind mills for generation of electricity.

Some of the characteristics of wind energy are as follows :

(*i*) Wind power systems are non-polluting.

(*ii*) It is a renewable source of energy.

(*iii*) The energy generated by wind-power systems is cheaper when produced on small scale. On large scale it is competitive with conventional power generating systems.

(*iv*) Wind energy systems avoid fuel provision and transport.

However following problems are associated with wind energy :

(*i*) Wind energy is fluctuating in nature

(*ii*) Because of its irregularity it needs storage devices

(*iii*) There is sufficient noise produced by wind energy power generating systems.

In our country a number of wind mill systems for water pumping and for production of small amount of electrical power have been set up. Some of the developments installed are as follows :

(*i*) Madurai wind mill at Madurai (T.N.)

(*ii*) Sholapur wind mill at Sholapur

(*iii*) Ca... wind mill at Jodhpur (Rajasthan)

(*iv*) MP-1 sail wind mill at NAL Bangalore

(*v*) Wind mills are Central Salt and Marine Chemicals, Research Institute, Bhavnagar (Gujarat).

At present about 43 MW aggregate wind power capacity has been established in our country. It is proposed to establish additional 100 MW capacity in the Eighth five year plan. Emphasis would be to set up indigenously produced wind Electric Generator (WEG). As a conservative assessment wind power potential in the country is about 20000 MW.

11.16 Wind Mills

Wind energy is used to run wind mill which in turn drives a generator to produce electricity. A wind mill converts the kinetic energy of moving air into mechanical motion that can be either used directly to run the machine or to turn the generator to produce electricity. Various types of wind mills are as follows :

(*i*) Horizontal axis wind mills

(*a*) Multi blade type wind mill

(*b*) Sail type wind mill

(c) Propellor type wind mill.

(ii) Vertical axis wind mills

(a) Savionius type wind mill

(b) Darrieus type wind mill.

Vertical axis wind mills are of simple design as compared to the horizontal axis. Horizontal axis wind mills may be single bladed, double bladed or multi bladed.

Wind energy conversion devices are commonly known as wind turbines because they convert the energy of the wind stream into energy of rotation : the component which rotates is called rotor. The terms turbine and rotor are however often regarded as being synonymous. An electric generator is coupled to the turbine to produce electric power. The combination of the wind turbine and generator is sometime called as an Aero Generator.

The fraction of free flow wind power than can be extracted by a rotor is called the power coefficient.

K = Power coefficient

$= P_1/P_2$

where P_1 = Power of wind rotor

P_2 = Power available in the wind.

The maximum theoretical power coefficient is 0.593.

The mass of air is calculated as follows :

Q = Amount of air passing in unit time

$= A \times V$

where A = Area through which air passes

V = Velocity of air

M = Mass of air traversing through area A swept by the rotating blades of wind mill type generator.

$$M = \rho \, . \, A \, . \, V$$

where ρ = Density of air

K.E. = Kinetic energy of moving air

$$= \frac{1}{2} M.V^2$$

$$= \frac{1}{2} \rho A.V.V^2 = \frac{1}{2} \rho A.V^3$$

P_2 = Available wind power

= Kinetic energy

$$= \frac{1}{2} \rho.A.V^3$$

The physical conditions in a wind turbine are such that only a fraction of available wind power can be converted into useful work. The power available in the wind increases rapidly with the speed and hence Wind Energy Conversion (WEC) machines should be located preferably in areas where winds are strong and persistent.

Wind turbine generators have been built having capacity ranging from a kilowatt or so to a few thousand kilowatts. Wind power has been successfully used for cooling of homes, space heating, for operating irrigation ; navigational signals and for offshore drilling operations.

Fig. 11.11 shows the various parts of a wind-electric generating power plant. They are

(*i*) Wind turbine or rotor
(*ii*) Wind mill head
(*iii*) Generator
(*iv*) Supporting structure.

The wind mill head supports the rotor housing the rotor bearings. The moving air makes the blades to rotate and the electricity is produced at the generator. Part *A* indicates transmission; Speed increaser. Drive shaft and bearing brake clutch and coupling.

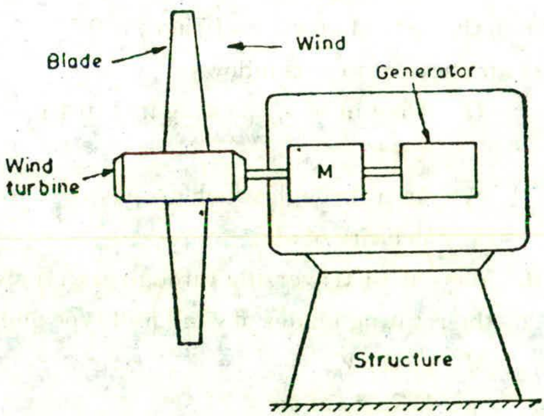


Fig. 11.11

Fig. 11.12 shows schematic arrangement of a horizontal axis type wind mill and Fig. 11.13 shows vertical axis type wind mill.

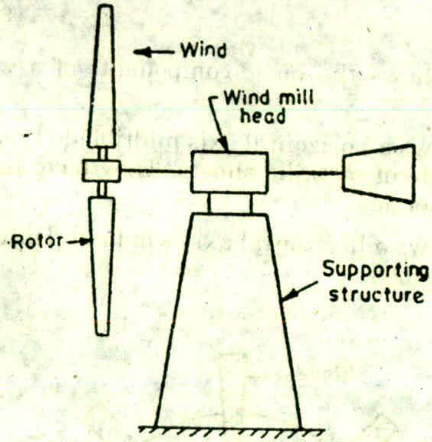


Fig. 11.12

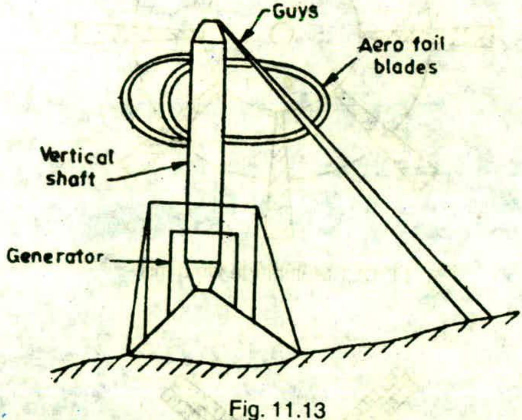


Fig. 11.13

11.16.1 Basic Components of a Wind Energy Conversion System (WECS)

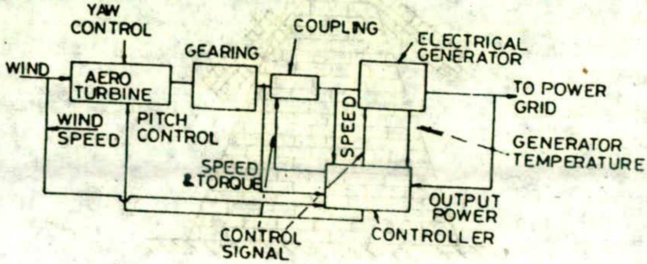


Fig. 11.13 (*a*)

Fig. 11.13 (a) shows the basic components of a wind energy conversion system.

Fig. 11.13.1 shows a horizontal axis multiblade type wind mill. The blades are made of metallic sheets. They have high starting torque and are economical.

Fig. 11.13.2 shows a horizontal axis wind mill Dutch type. The blades are made of wood.

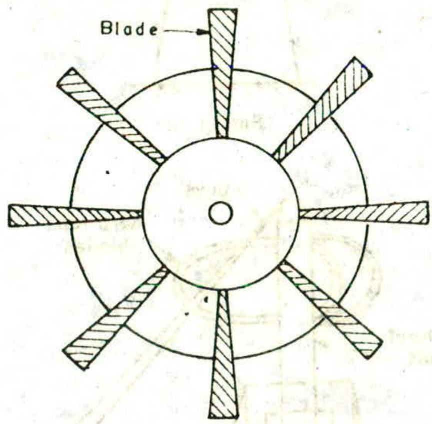


Fig. 11.13.1 Multiblade wind mill.

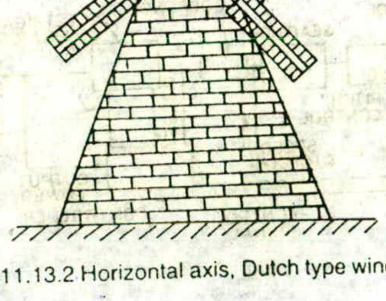


Fig. 11.13.2 Horizontal axis, Dutch type wind mill.

Aeroturbines convert the wind energy to rotary mechanical energy. A mechanical interface consisting of a step up gear and a coupling transmits the rotary mechanical energy to an electrical generator. The output of generator is connected either to load or power grid. The purpose of controller is to sense wind speed, wind direction, shafts speeds and torques, output power and generator temperature.

11.17 Site Selection for Wind Mill Units

Following factors should be considered while locating Wind Energy Conversion Systems (WECS).

(*i*) Wind energy conversion machines should be installed at sites where winds are strong and persistent. The most suitable sites for wind turbines would be found where the annual average wind speeds are known to be moderately high. It is desirable to have average wind speed of about 3.5 – 4.5 m/sec which is the lower limit at which WECS generators start turning. An ideal site will be one where a smooth steady wind flows all the time.

(*ii*) It is desirable to instal WECS at higher altitudes because the winds tend to have higher velocities at higher altitudes.

(*iii*) The ground conditions at the site should be such that the foundations for WECS are secured. The land cost should be low.

(*iv*) Icing problem, salt spray or blowing dust should not be present at the site as they affect aeroturbing blades.

(*v*) The site selected should be near to the users of generated electric energy.

(*vi*) The site should be near to the road or railway facilities.

The best site for wind energy systems are found off shore and the sea coast and at mountains.

11.17.1 Performance of Wind Machines

The wind electric plants should make use of wind energy in the best possible method. The overall efficiency of an aero-generator is calculated as follows :

$$\eta_0 = \eta_A \cdot \eta_g \cdot \eta_c \, \eta_{Gen}$$

where η_0 = overall conversion efficiency of an aero-generator.

η_g = Efficiency of gearing

η_c = Efficiency of coupling

η_{Gen} = Efficiency of generator

η_A = Efficiency of aeroturbine

$$= \frac{\text{Useful shaft power output}}{\text{Wind power input}} = C_P$$

where C_P = coefficient of performance

The coefficient of performance of an aero-turbine is 0.593 for horizontal axis wind machines.

Wind speed plays an important role in the power output. The efficiency of wind generator depends on design of wind rotor and rotation speed expressed as $\frac{V_T}{V}$.

where V_T = Blade tip speed.

V = wind speed.

The value of V_T is given by

$V_T = \pi DN$ m/sec

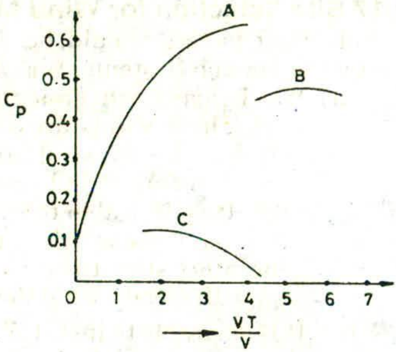


Fig. 11.13 (*b*)

where D = Diameter of rotor (metres)

N = Rotation frequency or rotation per second.

Fig. 11.13 (*b*) indicates the variation of coefficient of mance (C_P) and the ratio $\frac{V_T}{V}$ for some of the wind machine

The curve A shows ideal efficiency for propeller type wind n The curve B shows the variation of coefficient of performance i high speed two blade wind mill and curve C is for Dutch four arm type wind mill.

11.18 Biomass

As a result of energy shortages in the years to come, interest in the alternative fuel sources has increased considerably. Biomass is one of the such sources being considered. Biomass as a source of energy has several advantages over dwindling fossil resources :

(*i*) It is renewable
(*ii*) It is environmentally clean
(*iii*) It is easily adaptable.

Biomass is produced in nature through photosynthesis achieved by solar energy conversion.

Solar energy → Photosynthesis → Biomass → Energy generation.

Energy from Biomass is obtained in following three ways :

(*i*) Biomass in its traditional solid mass (wood and agricultural residue).

The biomass is burnt-directly to obtain the energy.

(*ii*) Biomass in non-tradition form (converted into liquid fuels).

In this case the biomass is converted into ethanol and methanol to be used as liquid fuels in engines.

(*iii*) To ferment the biomass anaerobically to obtain a gaseous fuel called bio-gas.

Biomass resources are as follows :

(*i*) Concentrated wastes like

(*a*) industrial wastes

(*b*) municipal solid

(*c*) manure at large lots.

(*ii*) Dispersed waste residue like crop residue, disposed manure.

(*iii*) Harvested bio-mass, standing bio-mass.

11.19 Biomass Gasification

Biomass gasification is used to produce a gas for burning purposes. Gasification is a process which converts a solid or liquid into a gaseous fuel without leaving a carbonaceous residue. Gasification is carried in a gasifier which is an equipment that can gasify a variety of biomass like wood waste, agricultural wastes. Biomass gets dried, heated pyrolysed, partially oxidised and reduced. The gas produced in the gasifier is a clean burning fuel. A gasifier can be easily operated, is reliable and its maintenance cost is low.

11.20 Tidal Power

Tide is periodic rise and fall of water level of the sea. In about 24 hours there are two high tides and two low tides. These are called as semi-diurnal tides. The rise and fall of wall level follows a sinusoidal curve as shown in Fig. 11.14 with point M indicating the high tide point and point N indicating the low tide point. The difference between high and low water levels is called the range of the tide.

Tides occur due to the attraction of sea water by the moon. These tides can be used to produce electrical power which is called tidal power. World's first tidal power plant was commissioned at Rance in France. This plant is of 240 MW capacity.

Following are the important points for the selection of location of tidal power plant :

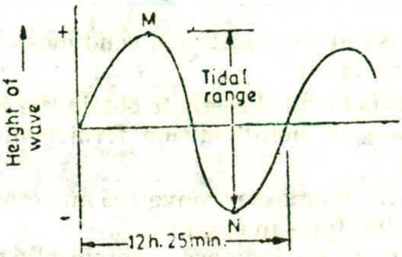


Fig. 11.14

(*i*) The tidal range at the desired location should be adequate throughout the year.

(*ii*) The site selected for tidal power plant should be free from the wave attack of sea.

(*iii*) There should be no appreciable change in tidal pattern at the proposed site.

(*iv*) The site at which tidal power plant is to be located should not have excessive sediment load.

11.20.1 Tidal Power Plants

The large scale up and down movement of sea water represents an unlimited source of energy. If some part of this vast energy can be converted into electrical energy it would be of an important source of power.

The three main components of a tidal power plant are as follows:

(*i*) The dyke to form basic or basin

(*ii*) Sluice ways from the basin to the sea and *vice versa*

(*iii*) The power house.

The turbines, electric generators and other auxiliary equipments are the main equipments of power house.

11.21 Classification

Tidal power plants are classified on the basis of number of basin used for the power generation. They are further subdivided as one way or two way system as per the cycle of operation for power generation. Various types of tidal power plants are as follows :

(*i*) Single basin system

(*a*) One way system (*b*) Two way system

(*c*) Two way with pump storage.

(*ii*) Double basin system

(*a*) Simple double basin system

(*b*) Double basin with pumping

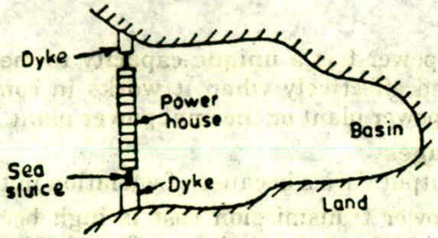


Fig. 11.15

Fig. 11.15 shows a single basin one way tidal power plant. In this plant a basin is allowed to get filled during the flood tide and during the ebb tide, the water flowing from the basin to the sea through the turbine and generates power. The power is available for a short duration during ebb tide.

In single basin two way tidal power plant the power is generated both during flood tide as well as ebb tide. The direction of flow through the turbines during the ebb and flood tides alternates but machine acts as a turbine for either direction of flow.

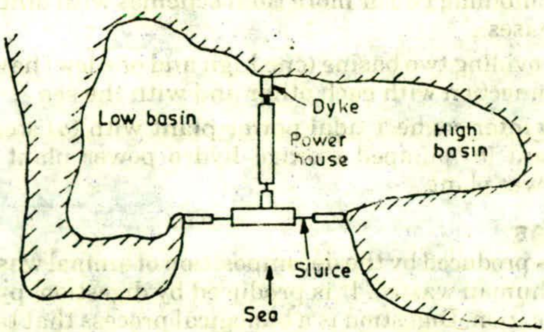


Fig. 11.16

Fig. 11.16 shows a double basin one way tidal power plant. In this plant one basin is intermittently filled by flood tide and other is intermittently drained by ebb tide. For some more details of tidal power see Chapter 1.

11.22 Advantages and Disadvantages of Tidal Power

Advantages

Various advantages are as follows :

(*i*) It is free from pollution.

(*ii*) It is inexhaustible and does not depend on rain.

(*iii*) Tidal power plants do not require large area of valuable land because they are located on sea shore.

(iv) Tidal power has a unique capacity to meet peak power demand effectively when it works in combination with hydropower plant or thermal power plant.

Disadvantages

(i) The output varies because of variation in tidal range.

(ii) The power transmission cost is high because the tidal power plants are located away from load centres.

(iii) Sedimentation and silteration of basins are the problems associated with tidal power plants.

(iv) Because of variable tidal range the turbines have to work on a wide range of variable head.

(v) Capital cost of the plant is high.

11.22.1 Regulation of Tidal Power Supply

The tidal power plants generate unregulation power from tides. Some of the methods which help to generate regular power from tidal power plants are as follows :

(i) Combining two or more tidal schemes with different tidal phases.

(ii) Providing two basins (one high and one low) having inter-connection with each other and with the sea.

(iii) To inter-connect tidal power plant with (a) steam power plant (b) pumped storage hydro power plant (c) hydro power plant.

11.23 Biogas

Biogas is produced by the decomposition of animal wastes, plant wastes and human wastes. It is produced by digestion, pyrolysis or hydro-gasification. Digestion is a biological process that takes place in the absence of oxygen and in the presence of an aerobic organisms at ambient pressures and temperature of 35–70°C. The container used for digestion process is called digester. There are two significant temperature zones in an aerobic digestion. It is observed that two types of micro-organisms mesophilic and thermophilic are responsible for digestion at the two temperature ranges. The optimum mesophilic temperature is around 35°C while optimum thermophilic temperature is about 55°C. The gas temperature falling very steeply when the temperature goes below 20°C. It is easier to maintain the temperature of the digester at the mesophilic range rather than at the thermophilic range. See some more details in Chapter 9.

11.24 Classification of Bio-gas Plants

Various types of bio-gas plants as follows :

(i) Continuous and batch type

(ii) The dome and drum type

(*iii*) Different variations in the drum type.

Continuous types. The continuous process may be completed in a single stage or separated into two stages. Fig. 11.17 shows a single stage continuous process type digester. In the digester the entire process of conversion of complex organic compounds into biogas is completed in a single chamber. This chamber is regularly fed with raw materials while the spent residue keeps moving out.

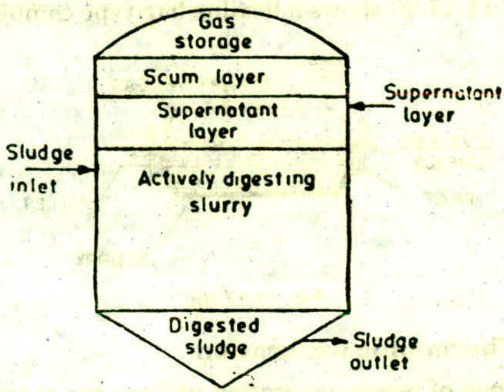


Fig. 11.17

Fixed dome digester. Fig. 11.17 (*a*) shows circular fixed dome digester plant. The fixed dome is made of masonry structure. The digestion takes place in the masonry well. The gas generated is taken out from the top. Are movable man hole cover sealed with clay is provided.

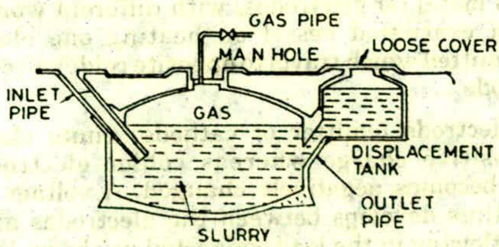


Fig. 11.17 (*a*)

11.24.1 Factors affecting bio-digestion or generation of gas.

The generation of gas in bio-gas plants depends upon the following factors :

(*i*) pH or hydrogen ion concentration. A pH value between 6.5 and 8 is best for fermentation and gas formation.

(*ii*) Temperature

(iii) Loading rate
(iv) Seeding
(v) Solid contents of the feed material
(vi) Type of feed stocks
(vii) Nutrients
(viii) Pressure
(ix) Stirring and mixing of the contents of the digester
(x) Acid forming and methane forming bacteria.

Flexible bag digester. This digester is made of plastic material and can be easily installed. However the life of this digester is small. Fig. 11.17 (b) shows a flexible bag type combined digester.

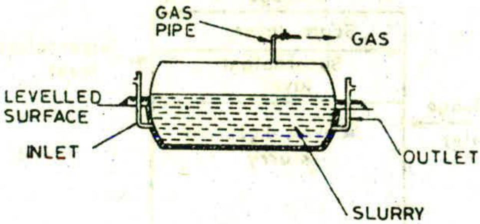


Fig. 11.17 (b)

11.24.2 Thermionic Generation

This method of power generation utilises the thermionic emission effect which means emission of electrons from heated metal surface. The energy required to extract an electron from the metal is called work function of the metal and depends on the nature of metal and its surface condition.

11.24.3 Thermionic Converter

The thermionic converter utilises thermionic emission effect. It consists of two metal (or electrodes) with different work functions sealed into an evacuated vessel on heating one electrode, the electrons are emitted which travel to opposite colder electrode called collector or anode.

The hot electrode (emitter or cathode) emits electrons and acquires a positive charge whereas colder electrode collects electrons and becomes negatively changed. A voltage (or electro motive force) thus develops between the electrodes and a direct current starts flowing in the load connected as shown in Fig. 11.17 (c).

The electrode with the large work function is maintained at higher temperature than one with the smaller work function.

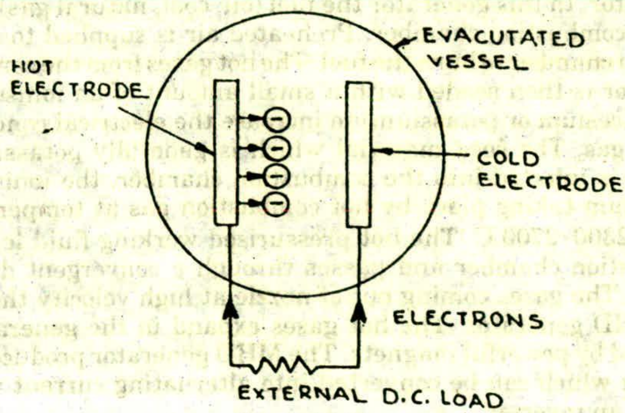


Fig. 11.17 (*c*)

The thermionic converter will continue to generate electric power as long as heat is supplied to the emitter and a temperature difference is maintained between it and the collector.

By thermionic converter the currents that can be produced are extremely small except in special case of metals at high temperatures. To achieve a substantial electron emission rate and hence a significant current out put as well as a high efficiency the emitter temperature in a thermionic converter containing cesium should be at least 1000°C. The efficiency is then about 10 percent. Higher efficiency can be obtained by operating at still higher temperatures.

Electric power (P) is given by

$$P = E.I.$$

where E = voltage

I = current.

11.25 Types of MHD Generators

An MHD generator is a device for converting heat energy directly into electrical energy without a conventional electric generator. The major advantage of MHD generator (converter) is that it can take better advantage of high temperatures attained in the combustion of a fossil fuel.

MHD generator are of two types :

(*i*) Open cycle generators

(*ii*) Closed cycle generators.

In open cycle the working fluid after generating electrical energy is discharged to the atmosphere through a stack. In closed cycle the working fluid is continuously recirculated.

11.25.1 Open cycle generator

Fig. 11.18 shows schematic arrangement of open cycle MHD generator. In this generator the fuel (oil, coal, natural gas) is burnt in the combustion chamber. Preheated air is supplied to the combustion chamber to burn the fuel. The hot gases from the combustion chamber is then seeded with a small amount of an ionised alkali metal (cesium or potassium) to increase the electrical conductivity of the gas. The seed material which is generally potassium carbonate is injected into the combustion chamber, the ionisation of potassium taking place by hot combustion gas at temperature of about 2300–2700°C. The hot pressurised working fluid leaves the combustion chamber and passes through a convergent divergent nozzle. The gases coming out of nozzle at high velocity then enter the MHD generator. The hot gases expand in the generator surrounded by powerful magnets. The MHD generator produces direct current which can be converted into alternating current with the help of an inverter.

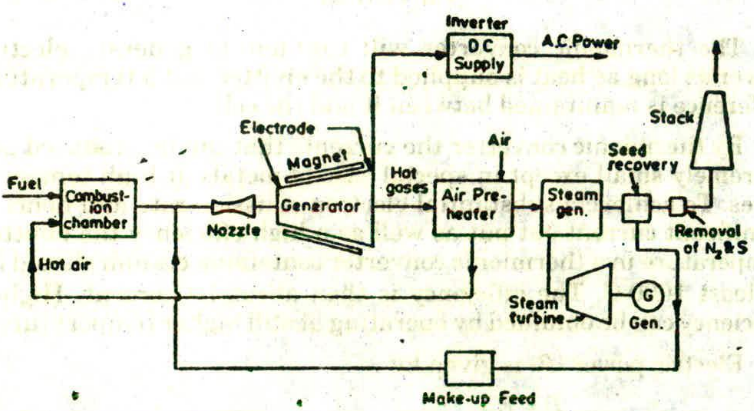


Fig. 11.18

11.25.2 Closed cycle systems

There are two types of closed cycle MHD generator systems :

(*i*) seeded invert gas system

(*ii*) liquid metal system.

Fig. 11.19 shows a liquid metal system. In this system a liquid metal is used as working fluid. The liquid potassium coming out of breaker reactor at high temperature is possessed through a nozzle to increase its velocity before passing to MHD generator. The liquid potassium coming out of MHD generator is passed through a heat exchanger (boiler) to use its remaining heat to system to run a turbine and then pumped back to the reactor. There are lot of operational and constructional difficulties in this system. MHD-

GEN indicates MHD Generator, Inv. means invertor and S.T. indicates steam turbine.

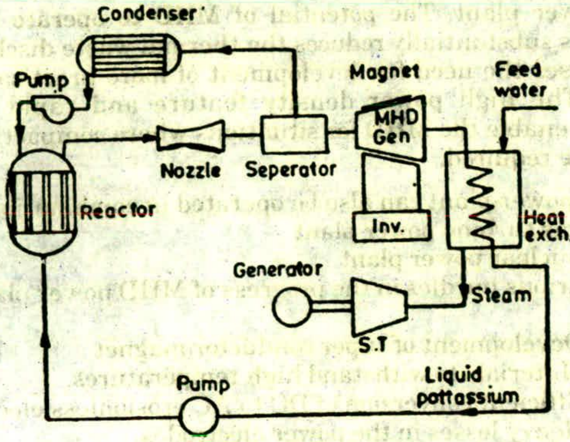


Fig. 11.19

11.25.3 Advantages of MHD System

The various advantages of MHD Steam power plant are as follows :

(*i*) The size of the plant is considerably smaller than conventional fossil fuel plants.

(*ii*) It can be started and put on line within few seconds.

(*iii*) It has high thermal efficiency (50-55%).

(*iv*) It proves instantaneous stand by power. It can be used most economically as peak load plant.

(*v*) Closed cycle produces power free from pollution. Some more details are given about MHD system in Chapter 9.

11.25.4 Combination of MHD power plant and steam power plant

- There is substantial improvement of thermal efficiency when MHD power plant and steam power plant operate together.

The cost of a combined MHD and conventional power plant may be too high and is not economical at low power generation. But at higher capacities, the cost will not be more than 20% that of a conventional coal-fired thermal power plant. The open cycle coal-fired MHD system, when combined with a conventional steam power plant, can develop efficiencies upto 50%. Closed cycle MHD may have the potential to approach the efficiency of open cycle.

It is economical to generate electric power by a combined MHD steam power plant. The potential of MHD to operate at higher efficiencies substantially reduces the thermal waste discharge and thus stresses the need for development of more practicable MHD devices. The high power density feature and rapid start up capability enable the MHD for situations where compact electrical sources are required.

MHD power-plant can also be operated in combination with

(*i*) gas turbine power plant

or (*ii*) nuclear power plant

The various hurdles in the progress of MHD power plant are as follows :

(*i*) Development of super conductor magnet.

(*ii*) Materials to withstand high temperatures.

(*iii*) Efficient conversion of DC to AC erosionless electrodes.

(*iv*) Heavy losses in the power electrodes.

11.26 Fuel Cell

Fuel cell details are discussed in Chapter 9.

11.27 Thermo-Electric Power

This method of producing electrical energy uses see-beck effect according to which an e.m.f. is produced when in a loop of two dissimilar metals the junctions are kept at different temperatures The efficieney of thermo-electric generator depends upon the temperatures of hot and cold junctions.

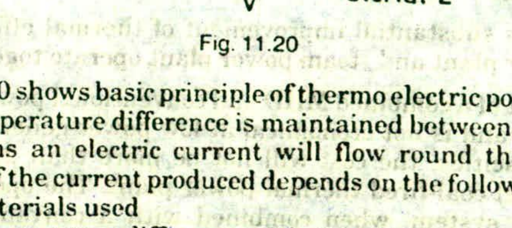


Fig. 11.20

Fig. 11.20 shows basic principle of thermo electric power generation. If a temperature difference is maintained between the hot and cold junctions an electric current will flow round the loop. The magnitude of the current produced depends on the following factors:

(*i*) Materials used

(*ii*) Temperature difference of the junctions.

If the circuit is broken an open circuit voltage (V) appears across the terminals of the break as shown.

Thermo e.m.f. V produced by the device is given by

$$V = \alpha_s \times \Delta T$$

where α_s = Seebeck coefficient

ΔT = Temperature difference

$= T_2 - T_1$

where T_2 = temperature of cold junction

T_2 = Temperature of hot junction.

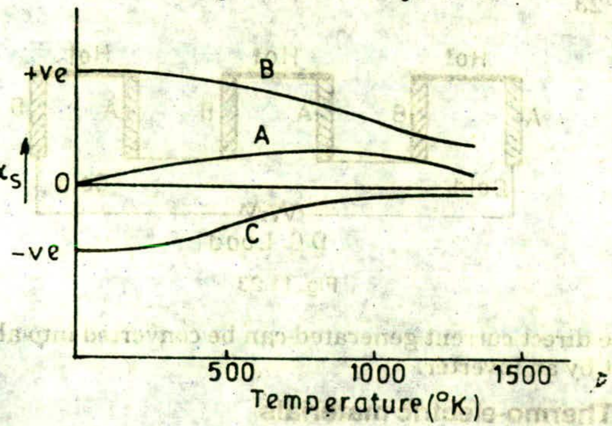


Fig. 11.21

Fig. 11.21 shows variation of seebeck coefficient with temperature for the following materials.

(*a*) Metal

(*b*) *P*-type semi conductors

(*c*) *N*-Type semi conductors

The coefficients is positive for *P*-type semi conductors and negative for N-type semi-conductors.

11.28 Thermo-electric Power Generator

Fig. 11.22 shows a simple arrangement for utilising the thermo couple arrangement for power generator.

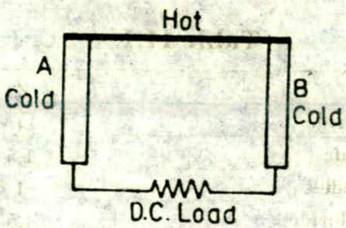


Fig. 11.22

The materials A and B are joined at the hot end. An electric voltage (or electromotive force) is then generated between the cold ends. A direct current will flow in a circuit or load. Connected between the ends. For a given thermo couple the voltage and electric power output are increased by increasing the temperature difference between the hot and cold ends.

To increase voltage and power several thermo-couples are connected in series in a thermoelectric power generator as shown in Fig. 11.23.

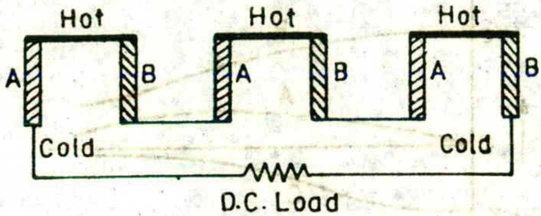


Fig. 11.23

The direct current generated can be converted into alternating current by an inverter.

11.29 Thermo-electric materials

The commonly used materials in thermoelectric power generator are as follows :

(*i*) Lead telluride (*ii*) Bismuth telluride
(*iii*) Bismuth sulfide (*iv*) Zinc antimonide
(*v*) Cesium sulfide.

An index used in rating thermo-electric materials is called figure of merit.

The figure of merit (z) depends on properties of materials. A high value of figure of merit is obtained by using materials of

(*i*) large seebeck coefficient
(*ii*) small thermal conductivity
(*iii*) small electrical resistivity.

Table 11.1 indicates figure of merit for some of thermo electric materials.

Table 11.1

Materials	$Z\,(k^{-1})$
Bismuth telluride	4×10^{-3}
Lead telluride	1.5×10^{-3}
Cesium sulfide	1×10^{-3}
Germanium telluride	1.5×10^{-3}
Zinc Antimonide	1.5×10^{-3}

Example 11.1. *At a tidal site the observed difference between the high and low water tide is 9 m. The basin area is 0.6 sq. km. which can generate power for 3 hours in each cycle. The average available head is 8.5 m. and over all efficiency of generation is 75% calculate the yearly power out put. Specific weight of sea water is 1025 kg/m^3 and there are 705 full tidal cycles in a year.*

Solution.

A = Area of basin

$= 0.6 \text{ sq. km.} = 0.6 \times 10^6 \text{ m}^2$

h = Difference in water tide = 9 m

$v = \text{volume} = A \times h$

$= 0.6 \times 10^6 \times 9 = 5.4 \times 10^6 \text{ m}^3$

T = Time = 3 hours

Q = Average discharge

$$Q = \frac{V}{T}$$

$$= \frac{5.4 \times 10^6}{3 \times 3600} = 500 \text{ m}^3/\text{S}$$

ω = specific weight of water = 1025 kg/m^3

$$P = \text{Power} = \frac{\omega Q H}{75} \times \eta$$

where H = Average available head = 8.5 m

η = Efficiency = 0.75

$$P = \frac{1025 \times 500 \times 8.5}{75} \times 0.75$$

$= 4.3 \times 10^4$ H.P.

E = Energy per cycle

$= P \times 0.736 \times T$

$= 4.3 \times 10^4 \times 0.736 \times 3 = 9.3 \times 10^4$ kWh.

N = Number of tidal cycle per year = 705

Total out put per year

$= E \times N = 9.3 \times 10^4 \times 705$

$= 6.4 \times 10^7$ kWh.

Example 11.2. *For a thermo-electric power generator following para meters are given*

Temperature of sink = 280°K

Temperature of hot reservoir of source = 620°K

Figure of merit for the material = $1.8 \times 10^{-3}\ ^{\circ}k^{-1}$

Calculate

(*a*) *Efficiency of thermo-electric power generator*

(*b*) *Carnot efficiency of generator.*

Solution.

$$T_H = \text{Temperature of hot source} = 620^{\circ}\text{K}$$

$$T_C = \text{Temperature of sink} = 280^{\circ}\text{K}$$

$$Z = \text{Figure of merit}$$

Figure of merit depends on the properties of thermo-electric materials used. The high value of figure of merit can be obtained as follows

(*i*) by using materials of large seebeck coefficient

(*ii*) small thermal conductivity

(*iii*) small electrical resistivity

$$Z = 1.8 \times 10^{-3}\ ^{\circ}k^{-1}$$

$$\eta = \text{Efficiency of thermo electric generator}$$

$$= \left[\frac{T_H - T_C}{T_H}\right]\left[\frac{M-1}{M + \frac{T_H}{T_C}}\right]$$

where

$$M = \left[1 + \frac{Z}{2}(T_H + T_C)\right]^{\frac{1}{2}}$$

$$= \left[1 + \frac{1.8 \times 10^{-3}}{2}(620 + 280)\right]^{\frac{1}{2}} = 1.32$$

$$\eta = \left[\frac{T_H - T_C}{T_H}\right]\left[\frac{M-1}{M + \frac{T_H}{T_C}}\right]$$

$$= \left[\frac{620 - 280}{620}\right]\left[\frac{1.32 - 1}{1.32 + \frac{620}{280}}\right]$$

$$= 0.12 = 12\%$$

η_c = carnot cycle (reversible) efficiency

$$= \frac{T_H - T_C}{T_H} \times 100 = \frac{620 - 280}{620} \times 100$$

$$= 52\%.$$

11.30 Methods for Maintaining Biogas Production

The techniques usually suggested for maintaining the biogas production are briefly summarized as follows :

1. *Insulating the gas plant.* To reduce heat losses from the digester, the external surface of the digester is adequately insulated using different materials like mineral wool, aluminium cladding, fibre glass, straw etc.

2. *Composting.* In this process the heat released in aerobic composting of agriculture residues around the annular ring in the upper part of the digester could be utilized to raise the digester operating temperatures. It is observed that a temperature rise of 8–10°C above ambient temperature even during the coldest season, takes place as a result of heat released from composting manure and straw. Under optimum conditions of moisture, composting is complete in 3-4 weeks and the released heat varies with time markedly. Small quantity of water in the straw around the digester is added later when the drop in temperature occurs and therefore the temperature of the composting material and digester contents can be kept relatively at constant temperature.

Geothermal Sources

Geothermal energy is the energy which lies. According to various theories the earth has a molten core. The fact that volcanic action takes place in many places on the surface of the earth supports these theories. The steam and hot water comes naturally to the surface of the earth in some locations of the earth.

Various geothermal energy re-sources are as follows :

1. Hydro thermal systems
   (*a*) Vapour dominated or dry steam fields
   (*b*) Liquid dominated system or wet steam fields
   (*c*) Hot water fields

Hydrothermal systems are those in which water is heated by contact with the hot-rock, as explained earlier.

In **Vapor-dominated systems,** the water is vaporized into steam that reaches the surface in a relatively dry condition at about 200°C and rarely above 7 kg/cm^2 (8 bar). This steam is the most suitable for use in turbo electric power plants.

In **Liquid-dominated systems,** the hot water circulating and trapped underground is at a temperature range of 175 to 315°C. When tapped by wells drilled in the right places and to the right depths, the water flows naturally to the surface or is pumped up to it.

2. **Geopressured Systems.** These resources occur in large, deep sedimentary basins. The reservoirs contain moderately high temperature water (or brine) under very high pressure. They are of special interest because substantial amounts of methane CH_4 (natural gas) are dissolved in the pressurized water (or brine) and are released when the pressure is reduced. Geopressured water is tapped in much deeper underground acquifers (it is a water-bearing stratum of permeable rock, gravel or sand), at depths between about 2400 to 9000 M.

3. **Petro-thermal or Hot dry rocks (HDR).** This represents by for the largest resource of geothermal energy of any type, as it accounts for large per cent of the geothermal resource. Much of the HDR occurs at moderate depths.

4. **Magma resources.** These resources consist of partially or completely molten rock, with temperatures in excess of 650°C, which may be encountered at moderate depths, especially in recently active volcanic regions. These resources have a large geotherr energy content, but they are restricted to a relatively few loc

5. Volcanoes.

PROBLEMS

11.1. What are non-conventional sources of energy ?

11.2. Write short notes on the following :
  (*a*) solar energy
  (*b*) solar radiation measurement
  (*c*) solar constant.

11.3. Describe various types of solar collectors.

11.4. State the advantages and disadvantages of current rating type solar collectors.

11.5. Describe solar thermal power generation.

11.6. Write short notes on the following :
  (*a*) Low temperature solar thermal power generation
  (*b*) Tower concept type solar power plant
  (*c*) PV cells
  (*d*) Solar pumping.

11.7. What is wind energy ? State the characteristics of wind energy.

11.8. (*a*) What is a wind mill ? What are various types of wind mills ?
  (*b*) Describe a horizontal axis and vertical axis wind mill.

11.9. State the factors to be considered while selecting the site for wind mill.

11.10. Write short notes on the following :
(*a*) Bio mass
(*b*) Bio gas
(*c*) Fuel cell
(*d*) Power coefficient of wind mill.

11.11. (*a*) Describe MHD generator principle.
(*b*) Describe an open cycle and a closed cycle MHD power generator.

11.12. What is tidal power ? What is tidal range ? State advantages and disadvantages of tidal power.

11.13. (*a*) Name the main components of a tidal power plant.
(*b*) State the points to be considered while selecting a site for tidal power plant.

11.14. How do you classify tidal power plants. Describe
(*a*) single basin one way
(*b*) double basin one way tidal power plant.

11.15. How do you classify bio-gas plants ? Describe a continuous type bio gas plant and fixed dome type plant.

11.16. Describe various parts of a wind electric generating plant.

11.17. State the advantages of MHD power generation system.

11.18. Write short note on the following :
(*i*) Thermo-electric power
(*ii*) Thermo-electric power generator
(*iii*) Materials for thermal electric power generator
(*iv*) Figure of merit.
(*v*) Basic components of a wind energy conversion system.

11.19. Write short notes on the following :
(*i*) Performance of wind machines
(*ii*) Overall efficiency of aero-generator
(*iii*) Efficiency of aero-turbine
(*iv*) Methods of regulation of tidal power.

11.20. Write short notes on the following
(*i*) Methods for maintaining bio-gas production.
(*ii*) Geothermal energy resources.

12

Environment Pollution and its Control

12.1 Introduction

The electric power demand is continuously increasing. The electric utilities and faced with simultaneous demand for increased power as well as problem of harmful impurities which are ejected into the environment surrounding the utilities. The power engineering specialists should develop and implement the effective means in the field of environmental protection from harmful effluents of power plants. The effects of power plant pollutants on the environment are mainly on the air and water and to a lesser extent on the land.

Most of the pollution in the cities can be avoided if power plants are located outside the city boundary. The pollution from the nuclear power plants is radio-active waste in the form of gases, liquids and solids whose radio-active property may retain number of years. The dumping and leakage of these wastes are major problems in nuclear power plants.

Combustion generated pollution is by far the largest man-made contributor to atmospheric pollution. The principal pollutants emitted by fossil fuel fired boilers in large power plants are products of incomplete combustion such as combustible particulate matter CO, NOx, SOx and fly ash and particulates formed due to the use of fuel additives.

The methods of control of pollutants include :

(*i*) low excess air combustion (excess air 2%).
(*ii*) staged combustion with heat removal between stages.
(*iii*) flue gas re-circulation.
(*iv*) gasification of coal and residual fuel oil.
(*v*) fluidised bed combustion.

(*vi*) improved atomisation and aeration of the fuel spray in case of gas turbine combustors.

12.2 Stean. Power Plant Pollutants

The thermal power plants burning conventional fuels (coal, oil, gas) contribute to air pollution in a large measure. The influence of thermal power plants on the surroundings is determined by their ejection of flue gases, heat and contaminated waste waters. Though thermal power plants are not among the worst contaminants of water basins in terms of scope and composition of their liquid wastes, their discharge into water basins can cause great harm if proper means are not taken for water protection.

The main pollutants from thermal power plants are follows :

(*i*) CO	(*ii*) CO_2
(*iii*) SO_2	(*iv*) Nitrogen oxides such as :
(*a*) Nitrogen dioxide (NO_2)	(*b*) Nitric oxide (NO)
(*v*) Dust	(*vi*) Fly ash

With incomplete combustion of fuel in furnaces, carbon monoxide (CO), hydro carbons CH_4, C_2H_4 etc. are produced. The CO is injurious to human health as it combines with haemoglobin in the red blood corpuscles and thus interfere with their normal function of supplying oxygen to the blood tissues.

The thermal power plants contribute substantially to CO_2 emissions. CO_2 has very harmful effect on atmospheric climate which could turn fertile land into deserts. Therefore the implications and control of CO_2 need priority study. Sulphur dioxide (SO_2) is the main pollutant from steam power plant. The primary source of SO_2 in the atmosphere is the combustion of bituminous coal and residual oil fuel. Vegetables are most sensitive to the content of SO_2 gas in the atmosphere. The toxic effect of SO_2 gas is associated with deterioration of the surfaces of leaves or needles due to destruction of their chlorophyll. Nitrogen dioxide (NO_2) and nitric oxide (NO) are often referred collectively as nitrogen oxides.

Nitrogen oxides are toxic and produce a sharp irritating effect. People living in NO_2 contaminated areas suffer from reduced respiratory function and have a higher incidence of respiratory diseases.

Acid rains is another menace caused by the thermal power plants. Three main constituents of flue gases which mainly affect acidity of rains are SO_2 and nitrogen oxides. In the atmosphere SO_2 is fairly readily converted into sulphuric acid (H_2SO_4) whereas the nitrogen oxides get converted into nitric acid (HNO_3). During rainy season the acid formed in the atmosphere falls on the ground in the form of rain called acid rain. The effect of this rain is to increase the acidity of lake, well water and water of flowing rivers

In general SO_2 contributes about 60% of the acidity whereas nitrogen oxides contribute 35% carbon dioxide (CO_2) also cause the rain to be acidic but to a very small extent.

Maximum permissible limit of nitrogen oxide is 0.05 to 0.1 ppm.

The further detrimental effect of acid rains is the reduction of ground fertility and crops yield smoke, dust and fly ash carried by flue gases also produce injurious effects on human health. The quantity of ash. (Q) carried off by flue gases per kg of fuel burnt and taking into account unburnt carbon is found by the following formula

$$Q = K \cdot \frac{W}{100}\left[1 + \frac{P}{100 - P}\right]$$

where K = Fraction of solid particles carried off from furnace with flue gases.

W = Ash content of working mass of fuel in %

P = Content of combustible in fly ash in %.

The ash is also a problem as it also emits heat to the atmosphere as well as small particles of ash are carried by the air. Large quantity of heat discharged to the atmosphere also is a cause of pollution. Toxic substances contained in flue gases discharged from stacks of thermal power plants can produce harmful effects on the whole complex of living nature or the bio-sphere. The bio-sphere comprises the atmosphere layer near the earth's surface and upper layers of soil and water basins.

Depending on the type of fuel and capacity of boiler the ash collection from thermal power plants can be effected by the following devices.

(*i*) Ash collectors (*ii*) Fly ash scrubbers
(*iii*) Electro static precipitators.

Fly ash, cinders, various gases and smoke discharged from the stack become atmospheric contaminants. Gases diffuse in all directions. The path followed by the flue gases depends upon the thermal and dynamic properties of gases and wind flow past the stack.

The various variables affecting the area over which flue gases constituents will settle out are as follows :

(*i*) Stack height
(*ii*) Stack exit gas velocity
(*iii*) Wind velocity
(*iv*) Gas temperature
(*v*) Particle size
(*vi*) Surrounding topography.

The combustible content of stack dust is important in pollution. Coarser particles settle closer to the plant. Flue gases dust quantity and quality depend on the type of fuel and burning equipment.

The toxic substances like CO, CO_2, SO_2, SO_3, NO_2, ash, hydro carbons etc. contained in the waste gases may be harmful for vegetation, animals, water basins and people even in very low concentrations above the specified safe limits. It is therefore desirable to remove these toxic substances from flue gases as far as possible.

The control of the atmosphere at steam power plant is mainly aimed at minimising the discharge of toxic substances into the atmosphere.

Environmental issues in power sector are of major importance in our country due to the significance of electric power on the economic development process. Seventy percent of power generation in our country is coal based. The environmental impact of power production in general and coal based power production in particular are serious in terms of human health.

Coal based power generation affects air, land and water resources. Emission of particulate matter, sulphur dioxide and oxides of nitrogen causes air pollution. Accumulation of ash at power stations pre-empts land and endangers both ground and surface water. The associated increase in coal production to meet the additional demand can degrade more land, deplete water resources and cause water pollution.

12.3 Control of Pollutants

The control of the atmosphere at thermal power plants is mainly aimed at minimising the discharge of toxic substances into the atmosphere. The task of preserving the purity of atmosphere and water basins is of national significance. Thermal power plants consume about more than 1/3 of all the fuel produced and thus can significantly affect the local environment and the whole biosphere. Large condensation plants are among the greatest sources of heavy ejections of contaminants into the atmosphere. The effects of particulate matter in the atmosphere surrounding steam power plant are many and varies. Adverse effects on health, climate and water basin are quite serious. Adverse health effects are associated with SO_2 concentrations. Acid fall out in the form of acid rain is one of the more serious environmental hazards of increased concentrations of sulphur and nitrogen oxides in the atmosphere.

As regards thermal power plants the state of environment around them depends on the following :

(*i*) kind of fuel used

(*ii*) organisation of fuel combustion
(*iii*) operation of dust collecting and gas cleaning plants
(*iv*) devices used for ejection of flue gases into the atmosphere
(*v*) the influence of thermal power plants on the surroundings is also determined by their ejection of flue gases, heat and contaminated waste waters.

During high temperature combustion of gaseous or liquid fuel the pollution of the atmosphere by solid particles, CO and SO_2 can be kept minimum by suitable organisation of the following :

(*i*) combustion process
(*ii*) burning gas with excess air
(*iii*) choice of proper length and diameter of furnace chamber
(*iv*) correct stabilisation of flame.

It is necessary to minimise the emission of SO_2 into the atmosphere from thermal power plants as its contribution to pollution is maximum.

Large amounts of air pollutants are produced with coal combustion than any other fuel. Therefore research is continued on converting coal to cleaner and more convenient gaseous and liquid fuels.

The permissible maximum concentrations of SO_2 at ground level are 0.05 to 0.08 ppm for 24 hours, 0.12–0.2 ppm for 1 hour and 0.1–0.5 ppm for five minutes. The maximum permissible limit of nitrogen oxide is 0.05 to 0.1 ppm.

12.4 Control of Particulate Matter

Steam power plants generally use the following mechanical arrestors for the removal of solid particles :

(*a*) Fabric filters (*b*) Electrostatic precipitators.

It is economically feasible to obtain a high degree of pollution control over particles which are larger than 2 to 3 microns. About 95% of fly ash under 2 microns in diameter are difficult and costly to be removed. The particulate removal is the major problem (so far as cost is concerned) in power plants using pulverised fuel. Irrespective of all steps taken to remove the particulates from gases before going to stack, about 1% is always discharged to the atmosphere. The particulates effects can be reduced by using the following :

(*a*) coal cleaning
(*b*) using improved electrostatic precipitator design
(*c*) to control the dust within allowable limit. It can be done by increasing the height of chimney so that the dispersion will be on the larger area thus reducing concentration.

Electrostatic precipitators are used to remove the dust particles from flue gases. Details of electrostatic precipitator are given in Chapter 3. A combination of mechanical and electrostatic precipitators can remove more than 99.5% of the particulate matter from the effluent gases. Fly ash scrubbers are used to remove fly ash. A fly ash scrubber is explained in Chapter 3.

Cinder catcher and cyclone dust collector are explained in Chapter 3.

Furnaces burning coal in suspension (pulverised coal burners and spreader stokers) throw dust in the form of fly ash and collectors should be installed in the breeching to remove ash particles.

Smoky atmosphere is less healthful than smoke free atmosphere. Smoke has deadly effect on the vegetation principally because of sulphur products it carries. Smoke Corrodes metals and darkens paints. Fuels should be burnt completely to reduce quantity of dust particles in the flue gases.

12.5 Control of SO_2

Solid fuels contain sulphur in the following three forms.

(*i*) as inclusions of pyrite (FeS_2)

(*ii*) sulphur in molecules of organic mass of fuel

(*iii*) sulphate sulphur (in sulphur salts of calcium and alkali metals).

SO_2 is one of the principal toxic component which may pollute the atmosphere substantially.

Following methods are used to reduce the quantity of sulphur dioxide (SO_2) produced during combustion of fuel

(*a*) **Desulphurisation of fuels.** Decreasing the sulphur content in fuel is called desulphurisation process. This process can remove a substantial amount of sulphur from fuel.

Following three methods are used to remove sulphur from coal :

(*i*) Chemical treatment (*ii*) Froth flotation

(*iii*) Magnetic separation.

These processes leave the coal unchanged in form. In chemical treatment coal is leached with an aqueous solution of ferric sulphate at a temperature in the range of 90–130°C. In froth flotation process the coal is suspended in water through which air is bubbled. The air bubbles tend to attach themselves to the coal particles rather than to the mineral matter. The mineral waste falls to the bottom and is discharged.

In magnetic separation the finely crushed coal is passed through a strong magnetic field which removes pyrite (FeS_2) from coal. Coal itself is non-magnetic.

The sulphur from liquid petroleum fuels is generally removed by reaction with hydrogen gas in the presence of a catalyst at a moderately high temperature and pressure. Sulphur is converted into hydrogen sulphide which is then removed.

(*b*) **To use low sulphur fuels.** To use low sulphur content fuels is the commercially proved means to control SO_2 emission into atmosphere.

(*c*) **Use of tall stakes.** To prevent air pollution with SO_2 tall chimneys are used to disperse flue gases over larger area.

(*d*) **Cleaning of flue gases.** Commonly the three methods used to remove SO_2 from the flue gases are as follows :

1. Wet scrubbing
2. Solid absorbent
3. Catalytic oxidation.

It is observed that to remove SO_2 from flue gases is more economical as compared to removing sulphur from coal. Methods used to prevent air pollution with SO_2 are different for gaseous, liquid and solid fuels. It is advisable to remove H_2S from natural gas before burning it.

The sulphur content of liquid fuels can be reduced by following ways subjecting the fuel to a high temperature either with the use of oxidants (gasification) or without them (pyrolysis).

The process of gasification is effected at a high temperature (900–1300 C) with a limited admission of oxygen.

Pyrolysis of fuel is carried out at 700 – 1000 C without an oxidant. Pyrolysis is effected by contacting atomised oil directly with a heat carrier which may be in either a stationary or moving state. The combustible gas thus produced is purified from sulphur compounds and other harmful impurities and used as pure power fuel. Pyrolysis of fuel oil, crude petroleum and heavy petroleum residues can also be made by using liquid heat carriers as fused salts, slags etc.

12.5.1 Wet Scrubber

Wet scrubber also called wet flue gas desulphurisation system uses lime stone in the form of an aqueous slurry. This slurry when brought into contact with the flue gas absorbs SO_2 in it. Fig. 12.1 shows schematically the wet lime stone scrubbing process. In this scrubber SO_2 of exhaust gases is absorbed and reacts chemically with water and lime stone to form products that are transferred from scrubber to tank. In reaction tank chemical reactions take place resulting in disposable precipitates. Make up slurry is added to the tank and scrubbing liquid is sent back to the scrubber. The thickner receives a mixture of 5 to 15% suspended solids in water which are concentrated by sedimentation and removed to a pond or land fill.

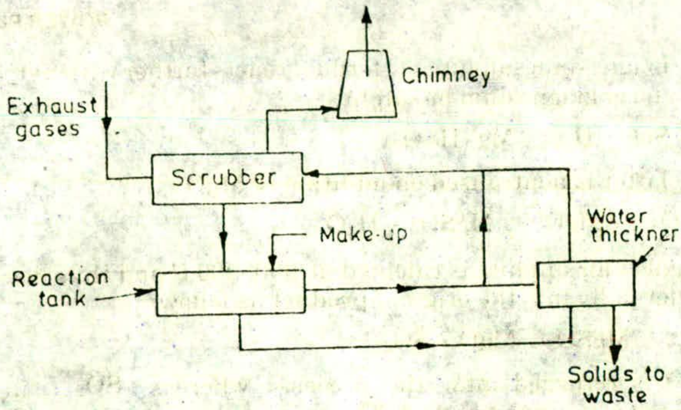


Fig. 12.1

In the scrubber following reactions take place.

$$Ca(OH)_2 + SO_2 = CaSO_3 + H_2O$$

$$CaCO_3 + SO_2 = CaSO_3 + CO_2$$

The calcium sulphite ($CaSO_3$)· SO produced gets partially oxidised to calcium sulphate. In most of the cases products of neutralisation are not utilised but go to waste. Lime stone scrubbers are capable of removing up to 90% of SO_2 from the gases entering the scrubber which may have 0.2 to 0.3% SO_2.

Various advantages of wet scrubber are as follows :

(*i*) High efficiency
(*ii*) Low flue gas energy requirement
(*iii*) Good reliability.

The disadvantages are as follows :

(*i*) High capital and operating cost
(*ii*) Costly disposal problem for the waste material which is a water logged sludge.

12.5.2 Catalytic oxidation

It is used to produce sulphuric acid from dilute SO_2 in the flue gas. The sulphuric acid is separated from flue gases.

12.5.3 Magnesium oxide scrubbing

In this process magnesium sulphate and sulphite salts are regenerated, producing a concentrated stream of SO_2 and magnesium oxide (MgO) for reuse in the scrubbing loop.

$$MgO + SO_2 = MgSO_3$$

The magnesium sulphite SO formed reacts further with SO_2 and water to form magnesium bi-sulphite

$$MgSO_3 + SO_2 + H_2O = Mg(HSO_3)_2$$

The latter is neutralised on addition of MgO.

$$Mg(HSO_3)_2 + MgO = 2\ MgSO_3 + H_2O$$

Magnesiunrsulphite is calcined at 800–900°C and thus decomposed thermally into the original product as follows :

$$MgSO_3 = MgO + SO_2$$

MgO is returned into the process whereas SO_2 can be reprocessed into sulphuric acid. The principal disadvantage of this process is that it involves numerous procedures with solid substances. It causes abrasion wear of equipment and formation of much dust. Further much heat is needed for the drying of crystals and removal of hydrate moisture.

12.6 Control of NO_2

Nitrogen oxides possess high biological activity. Nitrogen oxides are poorly soluble in liquids and for that reason can penetrate deep into lungs and can cause harmful diseases.

People living in NO_2 contaminated areas may suffer from following :

(i) reduced respiratory function
(ii) higher incidence of respiratory diseases
(iii) exhibit certain changes in the peripheric blood

Lower concentration of NO_2 though being apparently harmless for plants can inhibit their growth.

The combustion of fossil fuels in air is accompanied by the formation of nitric oxide (NO) which is partly oxidised to nitrogen dioxide (NO_2). The resulting mixture of variable composition is represented by the symbol NO_x where x has a value between 1 and 2. Nitrogen oxides (NO and NO_2) are present in flue gases produced by burning coal, oil and gas, in exhaust gases from internal combustion engines and gas turbines.

NO_x is formed in high temperature zones of combustion chamber from N_2 and O_2 of air. It is observed that usual' ..p to about 1000C the formation of NO from air is negligible but above 1000 C the amount increases with increasing temperature.

The various methods commonly used to reduce the emission of NO_x from steam power plants and gas turbine power plants are as follows :

(*i*) Reduction in temperature in combustion zone. By adjusting the combustion conditions to minimise the formation of nitric oxide. The obvious requirements are low combustion temperatures and use of low nitrogen fuels if possible.

Although higher temperature during combustion of fuels produce less amount of CO but higher temperatures also lead to the formation of nitric oxide (NO). Therefore the combustion temperature should be so adjusted that minimum amount of NO and CO are formed.

(*ii*) Reduction of residence time in combustion zone.

This is the most promising method because reducing the time of residence of combustion products in high temperature zone not only reduces the formation of NO_x but also produces minimum amount of CO_2, SO_2 and hydrocarbons.

(*iii*) Increase in the equivalence ratio in the combustion zone.

By carrying out combustion using equivalence ratio of 1.6 to 1.8 the amount of NO_x produced can be reduced.

12.7 Control of Waste Waters from Steam Power Plant

The waste waters discharged from steam power plant pollute the water basin if the waste waters are not properly handled. The waste water discharge into the basins may be in the following forms.

(*i*) Single
(*ii*) Periodic
(*iii*) Continuous with constant flow rate
(*iv*) Continuous with variable flow rate
(*v*) Occasional.

The most favourable mode of waste water discharged is that at which the maximum permissible (safe) concentration (MPC) of impurities in the basin is not exceeded.

Steam Power Plants are the sources of following types of waste waters :

(*i*) Cooling waters which mainly cause thermal contamination.
(*ii*) Waste waters of water treatment plants.
(*iii*) Waters from hydraulic ash disposal systems.
(*iv*) Used water after hydraulic cleaning of fuel conveying system.
(*v*) Rain water collected on the territory of power plant.

Cooling waters of steam power plant carry an enormous amount of heat into water basins waste waters of water treatment plants contain various neutral salts acids and alkalis which may affect water basin by changing pH value of water and by varying the salt concentration in water. The waste waters of hydraulic ash disposal systems should be discharged into water basin only when they contain no coarse particle substances.

Since waste waters usually contain a number of pollutants therefore waste waters should be purified before being discharged into water basins. Use of contaminated waste waters may harm agriculture, fishing industry etc.

Purification of waste waters is carried by number of methods. Some of the methods are as follows :

(*a*) Methods for direct separation of impurities
(*i*) Filtering
(*ii*) Centrifuging
(*iii*) Flotation
(*iv*) Settling and clarifying
(*v*) Micro straining through fine nets
(*vi*) Coagulation
(*b*) Bio-chemical methods.
(*c*) Methods of impurity separation with a change in the phase state of water or impurity.
(*d*) Methods based on transformation of impurities.

Steam power plants should use stacks of proper design. These stacks should be able to disperse harmful substances of flue gases in the atmosphere so as to reduce their concentrations to the specified safe limits. Taller stacks are preferred stacks having heights 100 m to 300 m and even more may be used. In a steam power plant use of poor quality fuels which are characterised by higher concentrations of ash and sulphur should be avoided.

Pollution of biosphere by gaseous contaminants can be avoided by the following :

(*i*) By using fuel of proper quality
(*ii*) By cleaning fuel
(*iii*) By cleaning flue gases
(*iv*) By using stack of sufficient height for proper dispersion of effluents.

The global concern for the environment protection and pollution control has made it mandatory for most combustion plants to continuously monitor flue gases for pollutants like CO, NO, SO_2, and also measure O_2, temperature, smoke density or dust concentration.

Analyser used for CO, NO and SO_2 and for the reference variable O_2 may be micro processor-controlled which feature automatic status monitoring.

12.8 Pollutants from Nuclear Power Plants their Effects and Control

A nuclear reactor produces α and β particles, neutrons and γ quanta which can disturb the normal functioning of living organisms. The radioactive isotopes which form in nuclear reactors have a high toxicity and their effect on living organisms may be accumulative. For this reason the problem of disposal transport and storage of solid and liquid radioactive wastes are extremely important.

At atomic power plant there are three main sources of radio active contamination of air :

(i) Fission of nuclei of solid or gaseous nuclear fuels.

(ii) Due to the effect of neutron fluxes on the heat carrier in the primary cooling system and on the ambient air.

(iii) The third source of air contamination is damage of shells of fuel elements. Potential sources of radioactivity at atomic power plants are also various auxiliary structures and elements such as cooling ponds, reactor below off system, tanks for collecting radioactive leakage etc. They may liberate radioactive inert gases etc.

One of the major problems at nuclear power plants is the disposal of waste products which are highly radioactive. They emit large quantities of γ rays.

The solids, liquid and gaseous radioactive wastes are produced at different stages of nuclear fuel cycle. These radioactive wastes should be disposed off in such a way that there is no hazard to human and plant life special care is taken to prevent leakage of liquids containing radioactive substances into the ground in the area ground the power plant. Liquid wastes are usually filled in stainless steel tanks mounted in concrete cells with bottoms. These tanks are buried in the ground till their decay of radioactivity. Solid wastes are buried in the ground. The waste gases are mixed with in active air discharged from ventilation systems and after passing through the filters are released through high stacks. The radioactive gases may also be collected and stored in a tank burried in the ground and disposed of to the atmosphere when radioactivity level is sufficiently low. The waste gases should be passed through a clean up plant to remove radioactive iodine which constitutes the major gaseous hazard. Cleaning of gases from radioactive iodine is made by using adsorbing filters with activated carbon as adsorbent.

Waste waters of atomic power plant are contaminated with radioactive impurities. These impurities must be separated before discharging waste waters into water basins. The radioactivity of waste waters can be lowered by several times of magnitude by treating them in evaporators. The level of radioactivity on the territory surround the atomic power plant should be checked periodically. This level should be kept below the permissible level.

12.9 Noise Pollution and Noise Control

Heavy noise environment has extremely unplease effect on people exposed to it. Continuous exposure reduce hearing ability. The main sources of noise in a power plant are turbo-alternators, fans, power transformers etc. Complete sound proofing and complete casing of turbo-alternators can reduce noise level.

12.10 Standardisations for Environmental Pollution

Standardisations in the field of atmospheric protection are the rating for exhaust emissions in air depending on the composition and concentration of emissions. The quantities of contaminants discharged with effluents should not exceed the permissible limits. The standardisation varies from country to country as well as from place to place. Standardisation depends on the following factors :

(*i*) Type of fuel used
(*ii*) Surrounding air velocity
(*iii*) Temperature
(*iv*) Humidity
(*v*) Population density
(*vi*) Atmospheric dispersion characteristics.

The rules and regulations regarding the emission of pollutants to the atmosphere should be properly followed. The standards specify the general requirements for the protection of atmosphere.

Water basins, land and living organisms. The standards define the maximum permissible emission (MPE) for each of the atmospheric pollutant.

Table 12.1 indicates typical values of Maximum Permissible concentration (MPC) of some of harmful substances in air of populated areas.

Table 12.1

Pollutant	*MPC* (mg/m^3)	
	Average daily	*Highest Single*
Soot (Fly Ash)	0.05	0.15
Non toxic dust	0.15	0.5
CO	1.00	3.00
Nitrogen dioxide	0.085	0.085
Sulphur Anhydride	0.05	0.5
Hydrogen sulphide	0.008	0.008

12.11 Thermal Pollution

Thermal power plants like fossil, nuclear, solar plant reject low temperature heat to the environment. All the heat energy used in human activities eventually becomes a heat input into environment almost all of which enters the atmosphere and can affect climate.

It is observed that in thermal power plants heat added and heat rejected are functions of plant efficiency.

$$\eta = \text{Efficiency}$$
$$= \frac{W}{H_A} = \frac{W}{W + H_R}$$
$$= \frac{1}{1 + \frac{H_R}{W}}$$

where W = Working output

H_A = Heat added = $W + H_R$

HR = Heat rejected

$$1 + \frac{H_R}{W} = \frac{1}{\eta}$$

$$\frac{H_R}{W} = \frac{1}{\eta} - 1$$

This shows that an increase in efficiency will reduce the amount of heat rejected.

12.12 Cleaning of Ventilation Air at Atomic Power Stations

The air in various rooms of atomic power stations may contain radioactive aerosols and gases, including iodine, which may have evolved with heat-carrier leakages or formed due to neutron activation of air. The flow rate of ventilation air at a 1000-MW station may be of an order of hundreds of thousands cubic metres per hour. It is not needed to purify such a large volume of air from radioactive noble gases, since their concentration in the ventilation air is not dangerous for the environment. On the other hand, these gases must be cleaned from aerosols.

The methods for air cleaning from aerosols are much like the common methods of air purification from inactive dust.

At present, filtration is the principal method for cleaning the air from radioactive aerosols. This is usually done by using filters based on special fine-fibrous materials.

The resistance of the filter fabric at various air speeds can be found by the formula

$$\Delta p = p\frac{V}{0.01}, \ \text{Pa}$$

where V is the nominal air speed, m/s, and p is the standard resistance of the fabric, Pa.

12.13 Fuel economy in furnaces of boilers

Fuel economy in furnaces leads to economic operation of the furnaces. In a furnace the largest losses are contained in the waste flue gases and radiation from furnace walls.

The heat carried away by flue gases can be reduced by

(*i*) providing sufficient air for combustion
(*ii*) adequate mixing of fuel and air
(*iii*) preventing air infiltration
(*iv*) providing heat exchangers in the path of flue gases leaving the boiler.

Recovery of waste heat escaping through the boiler chimney by use of superheater, economiser and combustion air preheater reduces the fuel consumption in boiler. Heat lost in boiler chimney flue gases at various temperature for various excess air levels have been shown in Fig. 12.12.

(*v*) **Preheating of Solid Stocks for Heat Recovery**

This technique is also used for recovery of heat from flue gases going out of the system examples are Multi-chambered Ring Furnaces used in brick, refractory/ceramic industries, carbon electrode industry, Rotary kilns in cement industry. In all these appliance the charges are preheated by the counter current contact of the flue gases which are consequently cooled during this process before it is

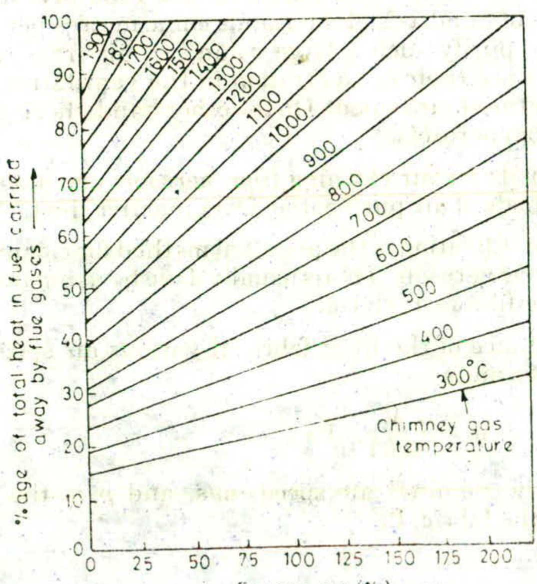


Fig. 12.2

exhausted through the chimney. The combustion air is preheated by extracting heat from the hot products coming out of furnaces.

(*vi*) Using accurate amount of air

Accurate and automatic proportioning of fuel and air improves fuel economy, furnace efficiency and process control. The use of oxygen analyser on the products of combustion leads to improved fuel economy and efficiency.

One of the most important factors influencing the efficient use of the fuels is their stock loss *i.e.* that proportion of the fuel energy release which is carried out of the operating furnace as the sensible heat of the flue gases. The important factors governing this parameter are normally the temperature of the flue gases leaving the furnace and their oxygen content (which is related to the production of air used for combustion above strict stoichiometric

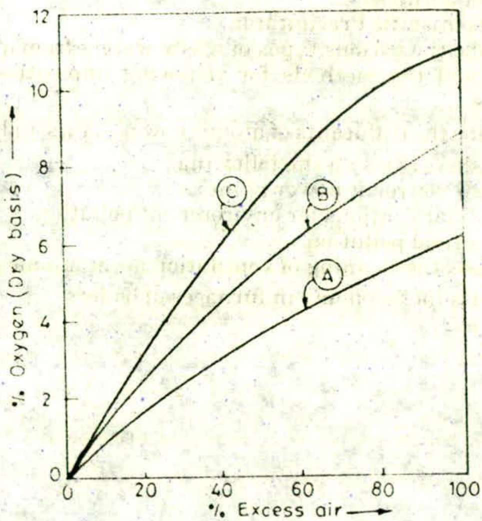


Fig 12.3 Relationship of % oxygen in waste gases and % excess air.

requirements *i.e.* % excess air). The general relationship between the % oxygen content and % excess air for both low C.V. fuel (*e.g.* blast furnace gas) and rich fuel (*e.g.* coke oven gas, heavy fuel oil etc.) is shown in Fig 12.3. The factors that the furnace using fluidised bed combustion of coal has more efficiency as compared to furnaces using pulverised coal. In the figure curve A is for blast furnace gas, the curve B for converter gas and curve C is for heavy fuel oil and coke oven gas.

Thus through the above means of heat recovery systems, the overall thermal efficiencies of boiler furnaces may be brought to a level of 85-90% or even more.

PROBLEMS

12.1. What is environmental control of power plant.

12.2. Discuss the various pollutants from steam power plant.

12.3. What are the effects of SO_2 and NO_x on human life and vegetation ?

12.4. Write short notes on the following :
(*i*) Acid rain
(*ii*) Control of particulate matter from steam power plant.

12.5. Describe the methods used to control the following from a steam power plant.
(*i*) SO_2 (*ii*) NO_x

12.6. Write short notes on the following :
(*i*) Cinder catcher
(*ii*) Cyclone dust collector
(*iii*) Wet Scrubber
(*iv*) Electrostatic Precipitator.

12.7. Describe the various types of waste waters from a steam power plant and the methods for removing impurities from waste waters.

12.8. Describe the pollutants of atomic power plants and their control.

12.9. Write short notes on the following :
(*i*) Noise control at power plants
(*ii*) Standardisations for environment pollution.
(*iii*) Thermal pollution.

12.10. Discuss the cleaning of ventilation air at atomic power plants.

12.11. Discuss fuel economy in furnaces of boilers.

Direct Energy Conversion Systems

13.1 Introduction

The direct energy conversion systems convert naturally available energy into electricity there being no intermediate conversion into mechanical energy.

The various direct energy conversion systems are as follows.

1. Thermo electric conversion system
2. Thermionic conversion system
3. Electrostatic mechanical generators
4. Photo voltaic power system
5. Electro gas dynamic generator (EGD)
6. MHD system
7. Nuclear batteries
8. Fuel cells

13.2 Thermo-electric Conversion System

The direct conversion of heat energy into electric energy (*i.e.* without a conventional electric generator) is based on seebeck Thermo electric effect Fig. 13.1 shows two dissimilar materials joined together in the form of a loop so that there are two junctions. If a temperature difference is maintained between hot and cold junctions an electric current will flow round the loop. The magnitude of the current will depend upon

(*i*) temperature difference

and (*ii*) materials used

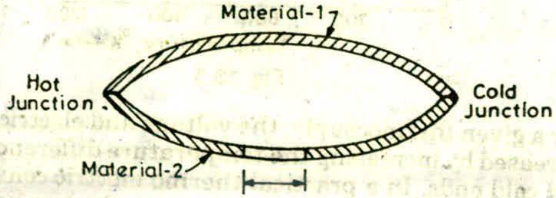


Fig. 13.1

Let T_2 = Temperature of hot junction

T_1 = Temperature of cold junction

V = e.m.f.

$= \alpha \Delta T$

where α see beck coefficient

ΔT = Temperature difference

$= T_2 - T_1$

Fig. 13.2 shows D.C. load connected in simple thermo couple arrangement.

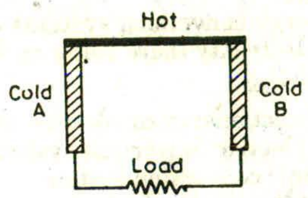


Fig. 13.2

Fig. 13.3 shows variation of see beck coefficient (α) with temperature for

(a) p-type semi conductor

(b) metal

(c) n-type semi-conductor

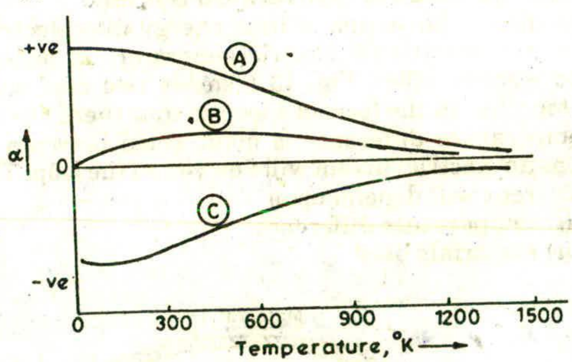


Fig. 13.3

For a given thermocouple, the voltage and electric power output are increased by increasing the temperature difference between the hot and cold ends. In a practical thermo electric converter, several couples are connected in series to increase both voltage and power as shown in Fig. 13.4.

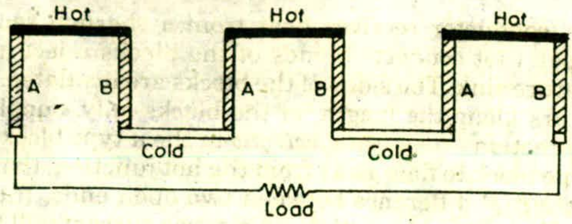


Fig. 13.4

A thermoelectric converter is a form of *heat engine*. Heat is taken up at an upper temperature (*i.e.* the hot junction) and part is converted into electrical energy ; the remainder is discharged (or removed) at a lower temperature (*i.e.* the cold ends). As with other heat engines, the thermal efficiency of a given thermocouple for conversion of heat into work (electrical energy) is increased by increasing the upper temperature and/or decreasing the lower temperature.

Thermoelectric generators have been built with power out put ranging from a few watts to kilowatts.

The source of heat for a thermo electric power generator may be

(*i*) a small oil or a gas burner

(*ii*) a radio 150 tope

or (*iii*) direct solar radiation.

13.3 Performance Analysis of Thermo-electric Power Generator

Fig. 13.5 shows a schematic arrangement of Thermoelectric convertor. It consists of two blocks A and B of semi conductor materials connected together by a conductor.

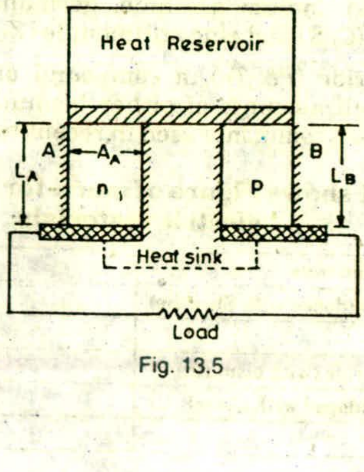


Fig. 13.5

The conductor receives heat from a thermal source and the lower open (not connected) ends of the blocks reject heat to a low temperature sink. The sides of the blocks are insulated. Hence, heat flow occurs along the length of the blocks only, supplying heat to the hot junction causes the *electrons* in the *n* type block and *holes* in the *p*-type block to flow away from the hot junction, thereby producing a potential difference between two open ends. If the circuit is completed at the cold junction, an electric current will flow through the load.

Let R_L = External Load Resistance

ΔT = Temperature difference between hot and cold functions

P = Power fed into external load

$$= \left[\frac{\alpha_{AB}\,\Delta T}{(R + R_L)}\right]^2 \times R_L$$

where α_{AB} = seebeck coefficient

R = Resistance of thermo couple

The factor $\frac{\alpha_{AB}^2}{R}$ is called figure of merit.

13.4 Thermo electric Materials

Semi conductors due to their much higher values of seeback coefficient (α) are preferred as compared to metals. The commonly used materials for thermo electric elements are as follows.

Lead telluride (Pb Te) in *n* and *p*-type forms, bismuth telluride ($B_{i2}T_{e3}$), bismuth sulfide ($B_{i2}S_3$), antimony telluride (Sb_2T_{e3}), tin telluride (*SnTe*), indium arsenide, germanium telluride (*GeTe*), cesium sulfide (*CeS*) and zinc antimonide (Z_n S_b).

Lead telluride (*Pb Te*), a compound of lead and tellurium, containing small amounts of either bismuth (*n*-type); or sodium (*p*-type), has been commonly used in recent times for thermoelectric converters.

Table 13.1 shows Figure of merit for some of thermo-electric materials.

Materials	$Z(°K^{-1})$
Bismuth telluride (doped with Sb or Se)	4×10^{-8}
Lead telluride	1.5×10^{-3}
Germanium telluride (with bismuth)	1.5×10^{-3}
Zinc antimonide (doped with silver)	1.5×10^{-3}
Cesium sulfide	1.0×10^{-3}

13.5 Analysis of Thermionic Generator

A thermionic generator works on the principle of thermionic emission which implies emission of electrons from the metal when it is heated.

A thermionic generator consists of two metals or electrodes with different work functions seated into an evacuated vessel. The anode (cold electrode or collector) has low work function and cathode (hot electrode or emitter) has high work function.

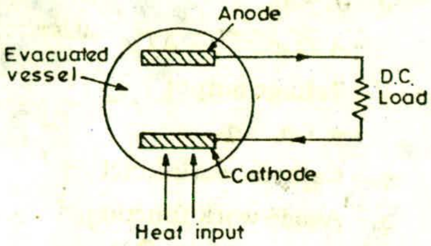


Fig. 13.6

Anode is generally made of barium and strontium oxide whereas cathode is made of tungsten impregnated with a barium compound. The fuel used in thermionic generator may be fossil fuel, nuclear fuel or solar energy. The emitter (cathode) temperature in thermionic converter containing cesium should be at least 1000°C.

The emitted current density as given by Fermi Dirac is

$$J = \frac{4\pi m e k^2}{h^3} T^2 e^{-\phi/KT}$$

$$= A T^2 e^{-\phi/KT} \text{ amp/cm}^2$$

Where A is constant and has the value equal to 120×10^4 Amp/m^2 as described in the previous section.

$$A = \frac{4\pi m e}{h^3} k^2$$

h = Planck's constant

e = Charge

ϕ = work function in e_v

T = Temperature (°K)

K = Boltzmann constant $J/$K

m = mass of an electron (kg)

Now, J_c = Current leaving cathode

$$J_c = A\,T_c^2\, e^{-(\phi_c + e\,V_b)/KT_c}$$

$$= A\,T_c^2\, e^{-eV_c/KT_c}$$

Ja = electron current leaving the anode

$$J_a = AT^2\, e^{-eV_a/KT_a}$$

J = net current density flow

$$J = J_c - J_a$$

$$= A\,T_c^2\, e^{eV_c/KT_c} - AT_a^2 e^{-eV_a/KT_c}$$

V = Voltage output

$$= \phi_c - \phi_a - \phi_p$$

where ϕ_c = Cathode work function

ϕ_a = Anode work function

ϕ_p = Plasma potential drop.

P = Power produced = $J.V$ (work output)

H = Heat Supplied to the cathode (cathode heat flux)

$$= \frac{Qc}{Ac}$$

$$= J\left(\phi_c + \frac{2kT_c}{r}\right) + \epsilon\ .\ \sigma\,(T_c^4 - T_s^4)$$

where T_c = Temperature of cathode

T_s = Temperature of surroundings

ϵ = Emissivity

σ = Stefan Boltzmann Constant

$= 5.668 \times 10^{-12}$ Joule/sec cm^2 k^4

η = Efficiency of generator = $\frac{P}{H}$

where $P = JV$

$$H = \frac{Qc}{Ac}$$

13.6 Electro-gas dynamic generator (EGD)

It uses the potential energy of a high pressure gas to carry electrons from a low potential electrode to a high potential electrode, thus doing work against an electric field.

Fig. 13.7 shows gas duct in EGD convertor. The carona electrode at the entrance of the duct generates electrons. This ionised gas particles are carried in the duct with the neutral atoms and the ionised particles are neutralised by the collector electrode at the end of the insulated duct. The working fluid may be either combustion gases produced by burning fuel at high temperature or it may be pressurised reactor gas coolant. Number of such channels are connected in series or in parallel. The output of EGD is nearly 10 to 30 W per channel. This system is as good as MHD system of producing electricity.

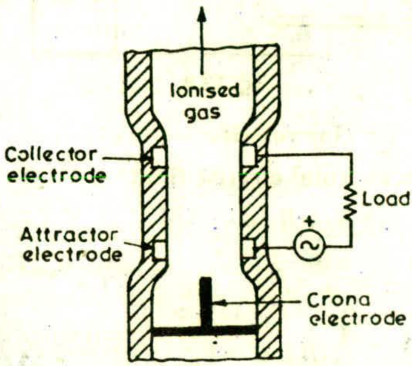


Fig. 13.7

13.7 Power output of MHD generator

The MHD power generation is a method of generating electric power which utilizes a high temperature conducting plasma moving through an intense magnetic field.

Fig. 13.8 shows

(*i*) direction of magnetic field

(*ii*) Ionised gas velocity

and (*iii*) force

in MHD system (Faraday generator).

The motion of the gas is in x direction, magnetic field B is in y direction and force on the particle is in z direction.

R_L = load resistance

I = current flowing across load resistance

V = voltage across the load

E_z = Electric intensity between the plates

$$= -\frac{V}{d}$$

where d = Distance between the plates.

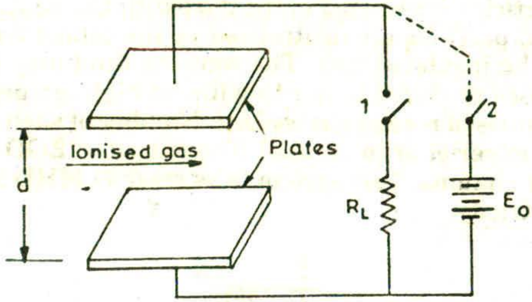


Fig. 13.8

u = Gas velocity

$$E'_z = \text{Total electric field}$$

$$= E_z + B \cdot u$$

$$= \frac{-v}{d} + Bu$$

$$= \frac{1}{d}(B.u.d. - v)$$

The electromagnetic field Ez and B acting on the moving gas produce the same force on the ions as the electromagnetic fields Ez and B produce on a gas with zero average velocity.

Thus the open circuit voltage (E_o) is given by

$$E_o = B.u.d.$$

Let Rg = Internal resistance of the generator

$$= \frac{d}{\sigma \cdot A}$$

where σ = Conductivity of the gas

A = Plate area

Fig. 13.9 shows electric circuit of M.H.D. generator

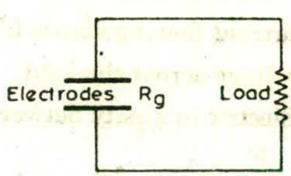


Fig. 13.9

R_L = Load resistance

when, $R_g = R_L$ the power obtained is maximum power (P_{max}).

$$P_{max} = E_o I$$
$$= I \cdot R_g \cdot I$$
$$= I^2 R_g$$
$$= \left(\frac{E_o}{R_L + R_g}\right)^2 R_g$$
$$= \frac{E_o^2}{4R_g} \quad \text{as } R_L = R_g$$
$$= \frac{B^2u^2d^2}{4R_g} \quad \text{as } E_0 = B.u.d.$$

Putting the value of R_g as $R_g = \frac{d}{\sigma A}$

we get, $$P_{max} = \frac{B^2u^2d^2}{4d}\,\sigma A$$
$$= \frac{1}{4}\,\sigma u^2 B^2\, dA$$

Maximum Power per unit volume

$$= \frac{1}{4}\,\sigma u^2 B^2$$

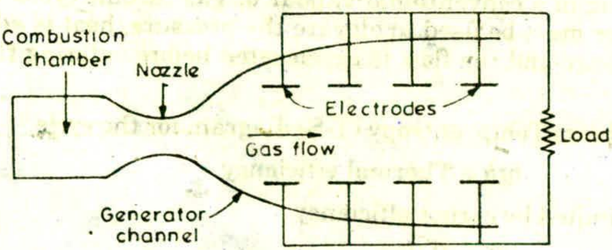


Fig. 13.10 shows a simple MHD generator.

An ionized gas is employed as the conducting fluid. Ionization is produced either by *thermal means i.e.* by an elevated temperature or by *seeding* with substance like cesium or potassium vapours which ionize at relatively low temperatures. The atoms of the seed element split off electrons. The presence of the negatively charged electrons makes the carrier gas an electrical conductor.

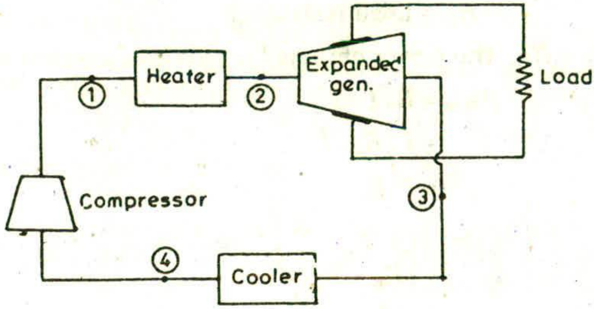


Fig. 13.11 shows over all power cycle for MHD generator.

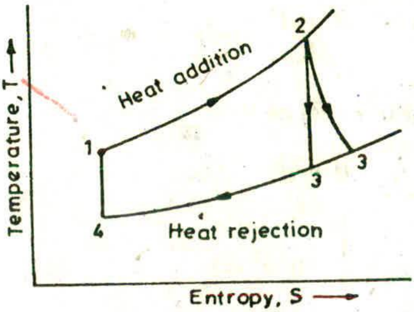


Fig. 13.12 shows Temp. entropy diagram for the cycle.

In the overall power cycle, the MHD converter takes the place of a turbine in a conventional vapour or gas turbine cycle. Still, a compressor must be used to elevate the pressure, heat is added at high pressure and the flow is accelerated before entering the converter.

Fig. shows Temp. entropy (T-S) diagram for the cycle.

ηth = Thermal efficiency

It is limited by carnot efficiency

Now $P_1 = P_2$

Pressure, $P_3 = P_4$

$$\eta_{th} = \frac{\text{work output}}{\text{heat input}} = \frac{(h_{20} - h_{30}) - (h_{10} - h_{40})}{(h_{20} - h_{10})}$$

Where the indicated enthalpies are *stagnation* values which take into account the K.E. of the flow. The stagnation enthalpy is defined as

$$h_0 = h + \frac{V^2}{2g_c}$$

where V is the flow velocity. In practical MHD converters, high velocity ionized gases are usually employed for the conversion process, so that the K.E. of the flow represents a substantial portion of the total energy.

Example 13.1 An M.H.D. generator has the following specifications

Average gas velocity	$= 10^3$ m/s
Plate area	$= 0.26$ m^2
Distance between plates	$= 0.50$ m
Flux density	$= 2$ Wb/m^2
Gaseous conductivity	$= 10$ Mho/m.

Determine : maximum power out put

Solution. $E_o = B\,u\,d$ where E_o = open circuit voltage

B = flux density

u = Average gas velocity

d = distance between plates

$$E_o = 2 \times 1000 \times 0.50 = 1000 \text{ volts}$$

R_g = Generator resistance

$$R_g = \frac{d}{\sigma A} \text{ where } A = \text{plate area} = 0.26 \text{ m}^2$$

$$= \frac{0.50}{10 \times 0.26} = 0.19 \text{ ohm}$$

$$\text{Maximum power} = \frac{E_o^2}{4R_g}$$

$$= \frac{(1000)^2}{4 \times 0.19} = 1252 \times 10^3 \; W.$$

13.8 Materials for MHD generator

In MHD generators the temperature of plasma in nearly 2700°C which is quite high. Therefore refracting materials are commonly used in several parts of the generator like electrodes, channel or duct wall.

Important factors to be considered for the selection of materials are as follows :

(i) Density
(ii) Melting point
(iii) Thermal shock resistance
(iv) Electrical conductivity

(v) Corrosion resistance
(vi) Erosion resistance
(vii) Oxidation reduction resistance

13.9 Electrode materials

The materials used should be with higher electrical conductivity so that they contribute towards better charge transfer across the electrodes/plasma interface. Most of the initial channel wall designs involved water cooled metallic electrodes due to the oxidising condition. But the cold surface creats cold boundary layer which generally promote high thermal losses, low conductivity and leads to considerable voltage drop in this region. The alkali seed condensation and cold slag condensation degrade the properties of electrode.

The commonly used materials for electrodes are as follows.

(i) **Zirconia Based Materials.** Zirconia is a good refractory oxide (Melting point 2800°C). However, pure zirconia can not be used as it undergoes phase transitions at different temperatures. During these phase transitions, non-linear thermal expansion takes place. Therefore elimination of the disruptive phase transition is necessary. This can be achieved by the addition of CaO (calcium oxide), Y_2O_3 (yitrium oxide), MgO, which results in the formation of cubic phase that is stable over a wide range of temperature and composition 15 to 27% CaO and 7 to 52% Y_2O_3 are required for stabilization of ZrO_2.

(ii) **Chromite Based Materials.** Lanthanum Chromite $LaCrO_3$ is one of the materials which has been found suitable. Incorporation of substantial amount of MgO improves its thermochemical properties without significantly changing its thermomechanical properties and electrical properties as compared to SrO doped chromite (5-20 M/O). It is a good electronic conductor with little variation in conductivity with temperature. Materials of an optimum composition LC 20 M (20% MgO doped $LaCrO_3$) is found to be highly promising for use in MHD.

(iii) **Aluminate Based Materials.** Spinel ($MgAl_2O_4$) is a high resistivity insulator and hence used for inter-electrode insulation on addition of Fe_3O_4 it becomes conducting electrodes material. As its melting point is 1860°C, it cannot be used safely above 1750°C. It is suitable for coal MHD generators.

(iv) **Nickel Oxide Based Materials**

Lithium doped NiO is a good electronic conductor but does not posses high enough melting point. Hence the most suitable materials are CeO_2 and $ZrO_2 - CeO_2$ solid solution.

13.10 Materials for channel

Ceramics are quite commonly used for channel or duct as ceramics offer superior chemical stability towards oxidation and corrosion. This will therefore resist corrosion and erosion caused by high velocity plasma.

13.11 Batteries

Batteries can play an important role in energy resources conservation.

A battery is defined as a combination of individual cells. A cell is the elemental combination of materials and electrolyte constituting the basic electro-chemical energy storer.

13.12 Division of batteries

There are two division of batteries.

(*i*) Primary batteries

(*ii*) Secondary batteries

Primary Batteries non chargeable, *e.g.* "drycell" flash light batteries. In primary batteries the chemical reactions are nonreversible.

Secondary Batteries rechargeable, *e.g.* a lead acid battery. There are many types of secondary batteries. The chemical reactions are reversible in secondary batteries.

Secondary batteries are of chief interest for solar electrics (Solar and wind energy, electrical storage), and therefore secondary batteries or storage batteries are important.

In a storage battery, individual cells are connected in various ways to provide the desired power output. Since storage batteries are generally portable, they are common mobile sources of energy. A major use, for example, is the starting-lighting Ignition (SLI) system of automobiles. Among the many other applications are those in the operation of mine locomotives, forklift trucks, golf carts, road vehicles, and submarines and other underwater craft.

13.13 Battery Principle

A generalized cell consists of two electrodes called the anode and cathode immersed in a suitable electrolyte. When an electrical load is connected between the electrodes charge separation occurs at the interface between one electrode and the electrolyte, freeing both an electron and ion. The electron flows through the external load and ion through the electrolyte, recombining at the other electrode.

The polarity and magnitude of the cell terminal voltage is, in general, a function of the electrode materials, electrolyte, cell temperature, etc.

In the charged cell, electrical energy is stored as chemical energy which can be recovered as electrical energy when the cell is discharged.

The storage capacity of a battery depends on the discharge rate (or discharge time). Increase in the discharge rate (or decrease in discharge time) for a given battery results in a decrease in the amount of electrical energy that can be delivered. This effect is very marked in the lead-acid battery commonly used in automobiles.

13.14 Types of batteries

Various types of batteries are as follows :

(*i*) *Conventional Batteries,* such as lead acid, Nickel cadmium ; Nickel-iron, Nickel-zinc. Silver Zinc, Silver Cadmium, and Zinc-Bromine.

(*ii*) *Metal-Gas Batteries,* such as Iron-Air, Zinc-Air, Zinc-Oxygen, Zinc-chlorine, Nickel hydrogen, Cadmium-oxygen, Cadmium-air, Aluminium-air, Lithium-Sulfur Dioxide, Sodium-air and Magnesium-air.

(*iii*) *Alkali-metal-High temperature Batteries,* such as Sodium-sulfur, Sodium-Chlorine, Lithium-Sulfur, Lithium-Iron Sulfide, Lithium-Chlorine, Lithium-Copper, Lithium-Nickel halide.

13.15 Battery Equivalent Circuit Models

There are two such models

(*i*) **First order model.** In this model leakage effects are negligible, and it is the one which is most widely used, Fig. 13.13 shows this model.

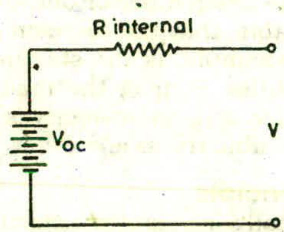


Fig. 13.13

VOC = open circuit voltage

(*ii*) **Second order model.** In this model leakage is the cause of "run down" and short shelf life on secondary batteries.

Fig. 13.14 shows this model.

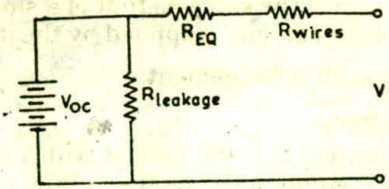


Fig. 13.14

13.16 Types of Battery Arrangements

There are generally two types of arrangements

(*i*) **Series arrangement.** In this arrangement cells are connected in series with the positive electrode of each cell connected to the negative electrode of the adjacent cell. The total electromotive force (emf) or voltage of the battery is then the sum of the separate voltages. In most automobile batteries, for example, six cells each with an emf of close to 2 volts are connected in series to provide a 12-volt output. The total current (in amperes) drawn from the series of cells, is however, the same as that drawn from each cell.

Fig. 13.15 shows cells connected in series.

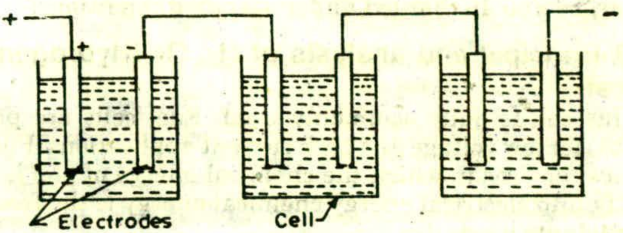


Fig. 13.15

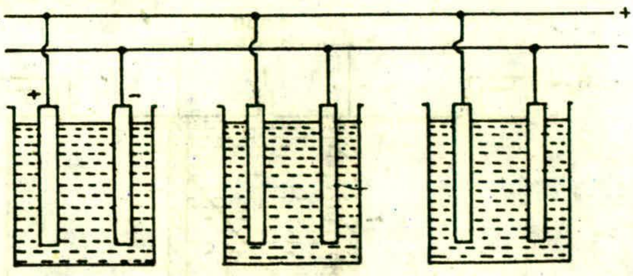


Fig. 13.16

(*ii*) **Parallel arrangement.** In this arrangement cells are connected in parallel. All the positive electrodes of the individual cells are connected together and so also are all the negative electrodes.

The battery voltage is now the same as that of a single cell, but the current is the sum of the currents supplied by the individual cells.

Fig. 13.16 shows such arrangement.

13.17 Power of Battery

The power of a battery (*i.e.* the rate at which stored energy is withdrawn) in *watts* is equal to the product of the emf. in volts and the current in amperes ; thus,

Power (watts) = EMF (volts) × current (amperes)

Specific power is the maximum rated power output per kg of battery can supply. Rating various batteries by specific power permits rapid performance comparison of different kinds of batteries.

13.17.1 Energy efficiency (η) of battery.

It is given by :

$$\eta = \frac{\text{Useful energy out put (watt hours)}}{\text{Re charge energy (watt hours)}}$$

13.17.2 Cycle life of battery

The cycle life of battery is the number of times the battery can be charged and discharged under specified conditions.

13.18 Principal and analysis of H_2, O_2 (Hydrogen-oxygen) fuel cell

This cell is quite commonly used. Fuel cells are particularly suitable for low voltage and high current applications. Fuel cells are chemical devices in which the chemical energy of fuel is converted directly into electrical energy chemical energy is the free energy of the reactants used.

Fig. 13.17 shows a hydrogen oxygen fuel cell.

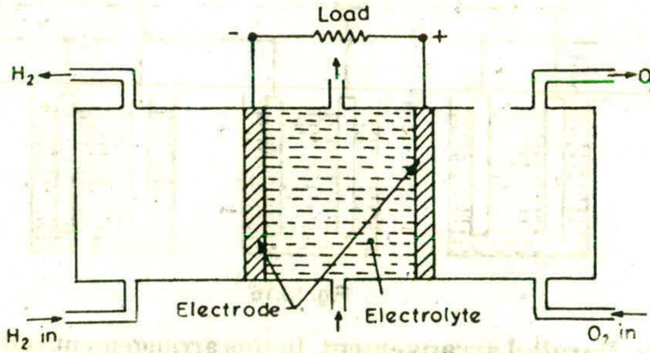


Fig. 13.17 A Hydrox (H_2, O_2 cell).

The main components of a full cell are as follows.

(*i*) Fuel electrode (anode)

(*ii*) an oxidant or air electrode (cathode)

and (*iii*) an electrolyte. The electrolyte is typically 40% KOH because of its high electrical conductivity and it is less corrosive than acids.

In most fuel cells, hydrogen (pure or impure) is the active material at the negative electrode and oxygen (from the oxygen or air) is active at the positive electrode. Since hydrogen and oxygen are gases, a fuel cell requires a solid electrical conductor to serve as a current collector and to provide a terminal at each electrode. The solid electrode material is generally porous.

Porous nickel electrodes and porous carbon, electrodes are generally used in fuel cells. Platinum and other precious metals are being used in certain fuel cells. The porous electrode has a larger number o f sites, where the gas electrolyte and electrode are in contact ; the electro chemical reactions occur at these sites. The reactions are normally very slow, and catalyst is included in the electrode to expedite them. The best electro chemical catalysts are finely divided platinum or platinum-like metal deposited on or incorporated with the porous electrode material.

The reactions which take place are as follows :

$4KOH \rightarrow 4K^+ + 4\,(OH)^-$

Anode : $2H_2 + 4(OH)^- \rightarrow 4H_2O + 4e$

Cathode : $O_2 + 2H_2O + 4e \rightarrow 4(OH)^-$

Cell reaction : $2H_2 + O_2 \rightarrow 2H_2O$

The electrons liberated at the anode find their way to the cathode through the external circuit. This transfer is equivalent to the flow of a current from the cathode to the anode. The movement of electrons constitutes a current passing through an external load. Thus useful work is obtained directly from the chemical process.

The gases in the hydrogen oxygen cell must be free from carbon-dioxide, because this gas can combine with the potassium dydroxide electrolyte to form potassium carbonate. If this occurs, the electrical resistance of the cell is increased and its output voltage is decreased. Consequently, when air is used to supply the required oxygen, carbon dioxide must first be removed by scrubbing with an alkaline medium (*i.e.* lime).

Depending on the fuel used the main types of fuel cells are as follows :

(*i*) Hydrogen (H_2) fuel cell,

(*ii*) Hydrazine (N_2H_4) fuel cell

(*iii*) Hydrocarbon fuel cell, and
(*iv*) Alcohol (Methanol) fuel cell

13.19 Types

Hydrogen fuel cells (Hydrox) are of two types :

(*i*) *Low Temperature cell.* In this cell the electrolyte temperature is 90°C. It is sometimes pressurised, but not by a great amount, usually say upto 4 atmospheres.

(*ii*) *High Pressure cell.* In this cell pressure is upto about 45 atmospheres and temperatures upto 300°C say. A single "Hydrox" fuel cell can produce an e.m.f. of 1.23 volts at 1 atm and 25°C. By connecting a number of cells, it is possible to create useful potential of 100 to 1000 volts and power levels of 1 kW to 100 MW nearly.

13.20 Applications

Fuel cells are quite commonly used for the following applications.

(*i*) Automotive vehicles
(*ii*) Power stations
(*iii*) Space applications

13.21 Output

$$\Delta W = \text{work output}$$
$$= \Delta Q - \Delta H$$

where ΔQ = Heat transferred to the steady flow stream from the surroundings

ΔH = Change in enthalpy of the flow stream from entranel to exist

η = Efficiency of energy conversion of fuel cell

$$= \frac{\text{useful work}}{\text{Heat of combustion of fuel}} = \frac{\Delta W}{\Delta H}$$

Now H = Enthalpy

S = Entropy

G = Gibbs free energy = $H - TS$

$$\Delta G = \Delta H - Tds - SdT$$

Since temperature of flow stream at both entravncel and exit is T

$$\Delta G = \Delta H - T\Delta S$$

ΔW_m = Maximum workdone by flow stream on surroundings.

$$= -\Delta G$$

E = E.M.F. of cell

$$= \frac{\Delta W}{n.F} = -\frac{\Delta G}{n.F}$$

where n = Number of electrons transferred per molecule of the reactant

F = Faraday's constant

= 96500 Coulombs per gram molecule

Example 13.2. *In a hydrogen-oxygen fuel cell the reaction taking place is*

$$H_2 + \frac{1}{2}O_2 = H_2O$$

If $(\Delta G)_{25} = -56690$ cal/gm-mol of H_2 or -237.3×10^3 Joule/gm mole of H_2

Calculate the reversible voltage for the fuel cell

Solution.

E = Reversible voltage

$$= \frac{\Delta W}{n.F} = \frac{-\Delta G}{n.F} \quad \text{as } \Delta W = -\Delta G$$

$$= \frac{237.3 \times 10^3}{2 \times 96500} = 1.23 \text{ volt.}$$

Example 13.3. *At thermo electric power generator operator between the following parameters. Figure of merit of material* $= 2.1 \times 10^{-3}$ °K^{-1}. *Temperature of hot reservoir of source* = 610°K *Temperature of sink* = 310°K

Determine (*a*) efficiency of thermoelectric generator
(*b*) Carnot efficiency of generator

Solution.

η = Efficiency of thermoelectric generator

$$= \left(\frac{T_H - T_C}{T_H}\right)\left[\frac{M-1}{M + \frac{T_C}{T_H}}\right] \times 100$$

where T_H = Temperature of hot reservoir of source = 610°K

T_c = Temperature of sink = 310°

Z = Figure of merit = 2.1×10^{-3} °K^{-1}

$$M = \left[1 + \frac{Z}{2}(T_H + T_C)\right]^{\frac{1}{2}}$$

$$= \left[1 + \frac{2.1 \times 10^{-3}}{2}(610 + 310)\right]^{\frac{1}{2}} = 1.4$$

$$\eta = \frac{610 - 310}{600}\left[\frac{1.4 - 1}{1.4 + \frac{310}{610}}\right] \times 100 = 10.2\%$$

Example 13.4. *A thermionic generator works on the following data.*

Cathode work function	*= 2.6 volts.*
Anode work function	*= 2.0 volts.*
Temperature of cathode	*= 2000°K.*
Temperature of surroundings	*= 1000°K.*
Plasma potential drop	*= 0.1 volt.*

Emissivity for electrode materials = 0.2, calculate the efficiency of the generator and also compare with the Carnot efficiency.

Solution.

ϕ_c = Cathode work function

= 2.6 volts.

ϕ_a = Anode work function

= 2.0 volts.

T_C = Temperature of cathode

= 2000°K

T_S = Temperature of surroundings

= 1000°K

ϕ_p = Plasma potential drop

= 0.1 volt

V = output voltage

$V = \phi_c - \phi_A - \phi_p = 2.6 - 2.0 - 0.1 = 0.5$ volt.

J = net current in the generator

$J = J_{cathode} - J_{anode}$

e = Charge of an electron = 1.6×10^{-19} Coulomb

K = Boltzmann constant = 1.38×10^{-23} Joule/K

One electron volt = 1.6×10^{-19} Joule

$$J_C = J_{\text{Cathode}}$$

Now $J_c = AT^2 e^{-e\phi_c/kT}$

$$= (1.20 \times 10^6)(2000)^2$$

$$\exp.\left[\frac{-(1.6 \times 10^{-19})\,2.5}{(1.38 \times 10^{-23})\,2000}\right]$$

$$= 2.4 \times 10^6 \text{ amp/m}^2$$

$$J_{anode} = AT^2 e^{-e\phi_a/kT}$$

$$= (1.20 \times 10^6)(1000)^2$$

$$\exp.\left[\frac{-(1.6 \times 10^{-19})\,2.0}{1.38 \times 10^{-23}\ 1000}\right]$$

$$= 1.2 \times 10^2 \text{ amp/m}^2$$

Net current J can be taken $= J_c$, as J_a can be neglected as compared to J_c.

i.e. $J = J_c = 2.4 \times 10^6$ amp/m^2

$$\frac{QC}{AC} = \text{heat supplied to the cathode}$$

$$= J\left(\phi_c + \frac{2kT_c}{e}\right) + \varepsilon\sigma\,(T_c^4 - T_s^4)$$

$$= (2.4 \times 10^6)\left[\frac{2.5 + 2\,(1.38 \times 10^{-23})\,2000}{1.6 \times 10^{-19}}\right]$$

$$+ 0.2,\ 5.67 \times 10^{-12},\ 10^{-4}\ (2000^4 - 1000^4)$$

$$= 6 \times 10^6 + 8.26 \times 10^5 \times 2 \times 10^5 = 7.026 \times 10^6 \ \text{watt/m}^2$$

Efficiency of the generator

$$\eta_g = \frac{JV}{Q_c/A_c}$$

$$= \frac{(2.4 \times 10^6)\,(0.5)}{7.026 \times 10^6} = 0.139 = 13.9\%$$ **Ans.**

Carnot efficiency this device

$$\eta_c = \frac{T_C - T_S}{T_C} = \frac{2000 - 1000}{2000} = 0.50$$

$$= 50\%$$ **Ans.**

PROBLEM

1. Sketch and describe the principle of thermo electric conversion system.
2. Define figure of merit in case of thermo electric conversion system.
3. Discuss the principle of thermionic generator.
4. Sketch and describe gas depramic generator.
5. Derive the expression for power output of MHD generator.
6. Describe materials for
   (*i*) electrodes
   (*ii*) channel in case of MHD generator
7. What is a battery. Discuss various types of batteries for electricity generation.
8. Discuss various arrangement of batteries.
9. Write short notes on

(*i*) Power of a battery
(*ii*) Life cycle of battery
(*iii*) Energy efficiency of battery

10. Discuss principle and analysis of $H_2 - O_2$ fuel cell.