MAGNETO HYDRODYNAMIC POWER GENERATION

The **MHD generation** or, also known as **magneto hydrodynamic power generation** is a direct energy conversion system which converts the heat energy directly into electrical energy, without any intermediate mechanical energy conversion, as opposed to the case in all other power generating plants. Therefore, in this process, substantial fuel economy can be achieved due to the elimination of the link process of producing mechanical energy and then again converting it to electrical energy.

Principle of MHD Generation

The principal of **MHD power generation** is very simple and is based on Faraday's law of electromagnetic induction, which states that when a conductor and a magnetic field moves relative to each other, then voltage is induced in the conductor, which results in flow of current across the terminals. As the name implies, the magneto hydro dynamics generator shown in the figure below, is concerned with the flow of a conducting fluid in the presence of magnetic and electric fields. In conventional generator or alternator, the conductor consists of copper windings or stripswhile in an MHD generator the hot ionized gas or conducting fluid replaces the solid conductor. A pressurized, electrically conducting fluid flows through a transverse magnetic field in a channel or duct. Pair of electrodes are located on the channel walls at right angle to the magnetic field and connected through an external circuit to deliver power to a load connected to it. Electrodes in the MHD generator perform the same function as brushes in a conventional DC generator. The MHD generator develops DC power and the conversion to AC is done using an inverter.

The power generated per unit length by MHD generator is approximately given by,

$$P = \frac{\sigma u B^2}{P}$$

Where, u is the fluid velocity, B is the magnetic flux density, σ is the electrical conductivity of conducting fluid and P is the density of the fluid.

It is evident from the equation above, that for the higher power density of an MHD generator there must be a strong magnetic field of 4-5 tesla and high flow velocity of conducting fluid besides adequate conductivity.

MHD Cycles and Working Fluids

The **MHD cycles** can be of two types, namely

1. Open Cycle MHD.
2. Closed Cycle MHD.

The detailed account of the types of MHD cycles and the working fluids used, are given below.

Open Cycle MHD System

In open cycle MHD system, atmospheric air at very high temperature and pressure is passed through the strong magnetic field. Coal is first processed and burnet in the combustor at a high temperature of about 2700^{o}C and pressure about 12 ATP with pre-heated air from the plasma. Then a seeding material such as potassium carbonate is injected to the plasma to increase the electrical conductivity. The resulting mixture having an electrical conductivity of about 10 Siemens/m is expanded through a nozzle, so as to have a high velocity and then passed through the magnetic field of MHD generator. During the expansion of the gas at high temperature, the positive and negative ions move to the electrodes and thus constitute an electric current. The gas is then made to exhaust through the generator. Since the same air cannot be reused again hence it forms an open cycle and thus is named as open cycle MHD.

Closed Cycle MHD System

As the name suggests the working fluid in a closed cycle MHD is circulated in a closed loop. Hence, in this case inert gas or liquid metal is used as the working fluid to transfer the heat. The liquid metal has typically the advantage of high electrical conductivity, hence the heat provided by the combustion material need not be too high. Contrary to the open loop system there is no inlet and outlet for the atmospheric air. Hence, the process is simplified to a great extent, as the same fluid is circulated time and again for effective heat transfer.

Advantages of MHD Generation

The advantages of MHD generation over the other conventional methods of generation are given below.

1. Here only working fluid is circulated, and there are no moving mechanical parts. This reduces the mechanical losses to nil and makes the operation more dependable.
2. The temperature of working fluid is maintained by the walls of MHD.
3. It has the ability to reach full power level almost directly.
4. The price of **MHD generators** is much lower than conventional generators.
5. MHD has very high efficiency, which is higher than most of the other conventional or non-conventional method of generation.

Principle of MHD Power Generation:

The magneto hydrodynamic (MHD) power generation is one of the examples of a new unique method of power generation and provides a way of generating electrical energy directly from a fast moving stream of ionized gases without the need for any moving mechanical parts—no turbines and no rotary generators.

The basic principle of MHD generation is the same as that of a conventional electrical generator i.e., the motion of a conductor through a magnetic field induces an emf in it—called the Faraday's law of electromagnetic induction. In conventional steam power plants, the heat released by combustion of fuel is transformed into internal energy of steam. The steam turbine, then, converts steam energy into mechanical energy used in driving a generator.

Thus, the mechanical energy is converted into electrical energy. The repeated conversion of various forms of energy involves losses and, therefore, the overall efficiency of thermal power plants is inherently very low. In MHD technology, electrical energy is directly generated from the hot gases produced by the combustion of fuel without mechanical moving parts.

In an MHD generator, electrically conducting gas at a very high temperature is passed at very high velocity through a strong magnetic field at right angle to the direction of its flow, thereby generating electrical energy. The electrical energy is then collected from stationary electrodes placed on the opposite sides of channel. The current so obtained is direct current which can be converted into an ac by an inverter.

Ionized gas can be produced by heating it to a high temperature. On heating of a gas, the outer electrons escape out from its atoms or molecules. The particles acquire an electric charge and the gases passes into the state of plasma. However, to achieve thermal ionization of products of combustion of fossil fuels or inert gases, extremely high temperatures are necessary.

Air becomes highly ionized at temperature of 5,000° to 6,000°C. To have a reasonable value of electrical conductivity of gases at temperatures around 2,000 to 3,000 K by reasonable ionization, the gases are seeded with additives of easily ionizing materials (alkali metals) such as cesium or potassium.

MHD system may be an open cycle system or a closed cycle system. In an open cycle system, the working fluid after doing useful work (generating electrical energy) is discharged to the atmosphere through a stack while in a closed cycle system the working fluid is recycled to the heat source and thus used again and again.

The operation of MHD generators directly on combustion products is an open cycle system using air as working fluid. In closed cycle systems gases used on the working fluid are helium or argon.

The use of a nuclear reactor employing solid fuel elements to supply heat energy for an MHD process needs that the working fluid should have the following properties:

(i) It should be capable of providing heat transfer under reactor working conditions.

(ii) It should not require excessive compressor work.

(iii) It should not be rendered active within the reactor.

Almost all of the above three requirements are fulfilled by helium.

Advantages and Limitations of MHD Power Generation:

MHD power generation offers several advantages over other conventional methods of power generation.

Some of these are given below:

(i) Since high temperatures are involved, operation efficiency is high. MHD system is normally designed to be a topping power system to a conventional steam power plant. At present, the conversion efficiency of an MHD system is around 50% which can be increased to 60% with the improvements in experience and technology.

(ii) No moving part, so more reliable.

(iii) Conceptually such generators are much simpler.

(iv) As there is no limitation to the size of the duct, so high capacity generators are possible.

(v) The walls can be cooled below temperature of working gas.

(vi) Direct conversion of heat into electrical energy results in elimination of the gas turbine (compared with a gas turbine power plant) and both the boiler and the turbine (compared with a conventional steam power plant) and thus in reduction of energy losses.

(vii) Ability of reaching the full power level instantly.

(viii) The more efficient heat utilisation reduces the amount of heat discharged to environments and thus the cooling water requirements are reduced.

(ix) The MHD process is industrially attractive because of the reduced cooling water requirements and atmospheric pollution.

(x) MHD power generation process is applicable to all kinds of heat sources such as oil, coal, gas, nuclear, solar and thermonuclear fusion.

(xi) MHD power generation offers the flexibility of operation in different modes such as base load, peak load or semi-peak load.

(xii) The capital costs of the MHD plants are estimated to be competitive with those of coal fired steam power plants.

(xiii) The overall costs of the MHD power generation are also estimated to be lower (roughly 20%) than those of conventional power plants. This is because of higher efficiency of MHD power generation.

(xiv) The reduced fuel consumption that is obtained because of higher efficiency or better fuel utilisation, offer additional economic and social benefits and also lead to conservation of energy sources.

Inspite of numerous inherent advantages the MHD system has not been accepted commercially because of the following limitations:

1. The efficiencies attained so far have been relatively low.

2. The power output of MHD generator is proportional to the square of the magnetic field density. The electromagnets need very large power for creating strong magnetic fields. The MHD technology is waiting for development of superconducting materials which will need very little power even at ambient temperatures.

3. The combustor, MHD duct, electrodes, and air preheaters are exposed to very corrosive combustion gases at very high temperatures. So, the life of these equipments has been reduced.

4. The ash (or slag) residue from the burning coal is carried over with the combustion gases and tends to cause erosion of exposed surfaces. However, deposition of the slag on such surfaces may also provide some protection.

5. There is a serious problem of separation of seed material from the fly ash and reconversion of potassium sulphate to potassium carbonate.

6. Special fuel gas and preheating of air are required to provide adequate working fluid temperatures.

7. There are serious problems associated with the fabrication of MHD duct, high temperature and high pressure heat exchangers and reactors.

Development of MHD programmes has been undertaken by different countries during the last two decades. In India also considerable studies have been carried out in this field by a team of scientists under the National Council of Science and Technology (NCST).

The Department of Science and Technology of Govt., of India has sponsored research and development programmes on coal based MHD power generation. Bhabha Atomic Research Centre in collaboration with Bharat Heavy Electricals Ltd and Institute of High Temperature (USSR) is also executing Research and Development programmes in this field.

The specifications of a Japanese pilot plant (Tokyo) are given below:
Thermal Input : 24 MW

Electrical Input : 1 MW

Mass Flow of Gas : 2.8 kg/s

Flow Velocity : 900 m/s

Duct Length : 1.2m

Inlet : 8 x 10 cm

Output : 8 x 25 cm

Electrodes : 30 pairs

Inlet Pressure : 4 bar

Magnetic Flux Density : 3.5 T (Wb/m2)

Material for Electrodes : Graphite, Water Cooled Copper

Russia has been the pioneer of this new technology. The world's first U-02 MHD unit was designed by the Russian scientists and power engineers in 1964.

Under intergovernmental agreement, Indian scientists from BARC and power engineers from BHEL worked on a pilot plant of MHD of 5 MW capacity with close interaction with the scientists of the High Temperature Science Institute of Moscow. The pilot plant was set up at BHEL, Trichy.

BARC has developed special magnet MHD duct and power tap-off system. BHEL was responsible for the development and installation of fuel gas generator, oxygen plant, water treatment plant, high temperature regeneration air heaters and valves, the main combustion chamber, nozzles as well as seed injection and seed recovery system.

The main specifications of the pilot plant are as below:
Thermal Input I Stage : 5 MW

II Stage : 15 MW

Gas Temperature : 2,600° C

Flux Density : 3 T (Wb/m2)

Seeding Agent : Potassium Carbonate

Electrodes : Water Cooled Copper

Besides the use of MHD system for commercial electrical power generation, it has got other special uses. A major effort was made in USA to use MHD as the conversion system in a nuclear electrical system for space crafts. MHD conversion has also been considered for ship propulsion, airborne applications, and hypersonic wind tunnel experiments and for many other defence applications.

VOLTAGE AND POWER OUTPUT OF MHD GENERATOR:

Lorenz law describing the effects of a charged particle moving in a constant magnetic field can be stated as:

$F = QvB$ …(7.2)

Where F is the force acting on the charged particle, Q is charge of particle, v is velocity of particle and B is magnetic field.

The force on a charged particle moving in an electric field as well as magnetic field will be given as:

$F = Q(E + vB)$ …(7.3)

Where F, E, v and B are vectors.

The velocity in above equation is vector sum of gas velocity v and particle drift velocity u, so force F may be given as:

$F = Q(E + vB + u \times B)$ …(7.4)

$= Q(E' + u \times B)$ …(7.5)

Where $E' = E + vB$

Consider Fig. 7.5, the motion of gas is in x direction, magnetic field B is in y direction and force on the particle in z direction. A load resistance R_L is connected across the electrodes (plates P_1 and P_2).

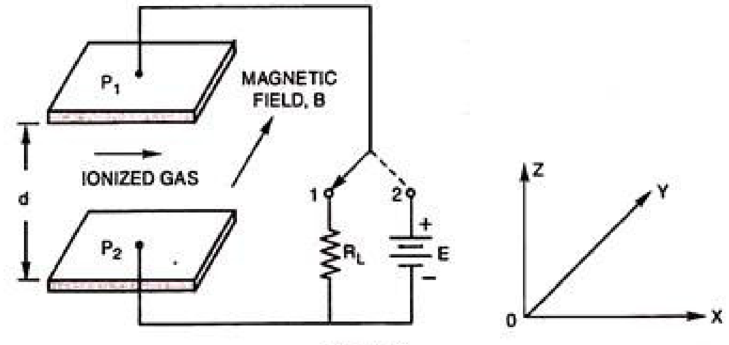

Fig. 7.5

When a current I flows through the load resistance R_L, then electric field intensity between the electrodes is given as:

$E_z = -V/d$ …(7.6)

Where d is the distance between the plates.

Total Electric Field $E'_z = E_z + Bv$

$= V/d + Bv = 1/d\,(Bvd - V)$….. (7.7)

The electromagnetic field E_z and B acting on the moving gas develops the same force on the ions as electromagnetic field E'_z and B develops on a gas with zero average velocity. Obviously the term Bvd provides the internal emf or open-circuit voltage E_0 of the MHD power generator i.e.,

$E_0 = Bvd$ …(7.8)

If R_G is the internal resistance of the generator, then maximum power output will be obtained when $R_G = R_L$.

Then, power output, $P_{out} = I^2R_L$

$$= \left(\frac{E_0}{R_G + R_L}\right)^2 R_L \quad \because \quad I = \frac{E_0}{R_G + R_L}$$

Substituting $R_L = R_G$ in above equation, we have

$$P_{out\,(max)} = \left(\frac{E_0}{R_G + R_G}\right)^2 R_G = \frac{E_0^2}{4R_G} \qquad ...(7.9)$$

The internal resistance of the generator, R_G is equal to $\frac{d}{\sigma A}$ where σ is the conductivity of the gas and A is the area of plates, then from Eqs. (7.8) and (7.9), we have

$$P_{out\,(max)} = \frac{B^2v^2d^2}{4d/\sigma A} = \frac{B^2v^2dA\sigma}{4} \qquad ...(7.10)$$

Maximum power per unit volume

$$= \frac{B^2v^2\sigma}{4} \qquad ...(7.11)$$

Substituting $E_0 = Bvd$ in Eq. (7.9), we have

$$P_{out\,(max)} = \frac{B^2v^2d^2}{4R_G} \qquad ...(7.12)$$

MHD system is reversible process. If load resistance R_L is replaced by emf E greater than E_0 by shifting the switch from position 1 to position 2, the directions of flow of current and force experienced on the ions will be reversed and the system will accelerate the gas particles because energy would be supplied to gas.

Thus, the ejected gas would be at a higher velocity than the inlet gas. The reaction force experienced on the magnet would tend to push the MHD engine in the negative x direction and thus the electrical energy would be converted into mechanical energy.

Fuel cell

A fuel cell by definition is an electrical cell, which unlike storage cells can be continuously fed with a fuel so that the electrical power output is sustained indefinitely (Connihan, 1981). They convert hydrogen, or hydrogen-containing fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. The process is that of electrolysis in reverse. Overall reaction: 2 H2(gas) + O2(gas) → 2 H2O + energy Because hydrogen and oxygen gases are electrochemically converted into water, fuel cells have many advantages over heat engines. These include: high efficiency, virtually silent operation and, if hydrogen is the fuel, there are no pollutant emissions. If the hydrogen is produced from renewable energy sources, then the electrical power produced can be truly sustainable. The two principle reactions in the burning of any hydrocarbon fuel are the formation of water and carbon dioxide. As the hydrogen content in a fuel increases, the formation of water becomes more significant, resulting in proportionally lower emissions of carbon-dioxide.

The Base Structure of Fuel Cells

A fuel cell is an electrochemical device which converts the chemical energy of a fuel and an oxidant directly into electrical energy. The basic physical structure of a single cell consists of an electrolyte layer in contact with a porous anode and cathode on either side. In a typical fuel cell, gaseous fuels are fed continuously to the anode (negative electrode) and an oxidant (i.e., oxygen from air) is fed continuously to the cathode (positive electrode) compartment; the electrochemical reactions take place at the electrodes to produce an electric current In the case of a fuel cell with an acid electrolyte the electrochemical reactions are:

anodic reaction: $H_2 \rightarrow 2H^+ + 2e$catodic
reaction: $1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$
overall reaction: $H_2 + 1/2O_2 \rightarrow H_2O$ + heat (exothermic reaction,
□H=-286 kJ mol^{-1})

A fuel cell, although having components and characteristics similar to those of a typical battery, differs in several respects. The battery is an energy storage device and the available energy is determined by the chemical reactant stored within the battery itself. The battery will cease to produce electrical energy when the chemical reactants are consumed (i.e., battery discharged). In a secondary battery (fuel cell), the reactants are continuously supplied from an external source. The fuel cell, on the other hand, is an energy conversion device that theoretically has the capability of producing electrical energy for as long as the fuel and oxidant are supplied to the electrodes. Degradation, primarily corrosion, or malfunction of components are the limits to the practical operating life of fuel cells

1.2. The Advantages and Disadvantages of Fuel Cells

If compared with conventional fossil fuel propelled electric generators, the use of fuel cells brings about many advantages

- Higher volumetric and gravimetric efficiency
- Low chemical, acoustic, and thermal emissions
- Modularity and siting flexibility
- Low maintenance
- Fuel flexibility (depending on type of fuel cell)
- No production of pollutants

Fuel Cells Technologies

Actually there are many technologies of fuel cells available on the market, and each one of those is characterized by: the operative temperature range, the type of fuels which can be used, the type of catalyst used by the cell and the efficiency ratio of the energy conversion. The main technologies available are as follows:-

- Polymeric Electrolyte Membrane Fuel Cells (PEMFC):
- Direct Methanol Fuel Cells (DMFC)
- Alkaline Fuel Cells (AFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Molten Carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)