LECTURE 7

MAGNETO HYDRO DYNAMIC [MHD] POWER GENERATION

Magneto Hydro-Dynamics Generator:

The principle of Magneto Hydrodynamics (MHD) power generation enables direct conversion of thermal energy to electrical supply. MHD power generation works on Faraday's principle: When electric conductor moves across a magnetic field, a voltage is induced in it which produces an electric current. In MHD generators, the solid conductors are replaced by a fluid which is electrically conducting. The working fluid may be either an ionized gas or a liquid metal. The hot, partially ionized and compressed gas is expanded in a duct, and forced through a strong magnetic field. Electric potential is generated in the gas. Fig. Shows the principle of MHD power generations. Electrodes placed on the side of the duct pick up potential generated in the gas. In this manner, direct current is obtained which can be converted into A.C with the aid of an inverter.

Ionized gas can be produced by heating it to a high temp. As the gas is heated, the outer electrons escape from its atoms or molecules. The gas particles acquire an electric charge and the gas passes into the plasma state. High temps. in excess of 2800^0 C are needed to produce necessary ionization of the gas. However, to achieve thermal ionization of products of combustion of fossil fuels or inert gases, extremely high temps. are needed. Seeding the gas with potassium or cesium helps in ionization and reduces temp. requirement. The exhaust from MHD generator is at a temp. of about 2500 K and can be used as the heating medium for raising steam in a conventional boiler. This system of power generation is simple and has moving parts, it has high reliability. It can be brought to full power from a standby conditions in 45 seconds. The output can be changed from no load to full load in fraction of a second. An experimental power plant of 5 MW of thermal input has been commissioned at Tiruchirapalli.

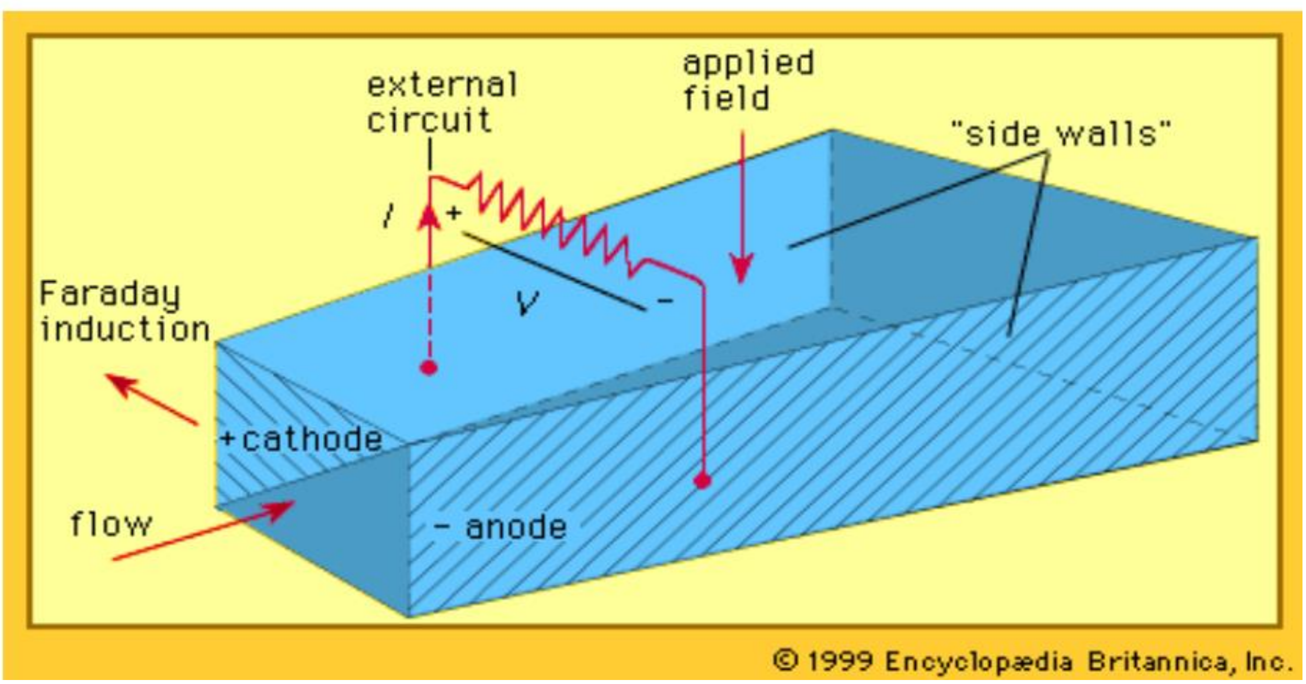
80% of total electricity produced in the world is hydel [hydro electric] while remaining 20% is produced from nuclear , thermal , solar , geothermal energy from MHD generator. MHD power generation is a new system of electric power generation with high efficiency and low pollution.

MHD is concerned with the flow of conducting fluid in the presence of magnetic and electric field. The fluid may be gas at elevated temperature or liquid metal like Sodium or potassium . An MHD generator is A device for converting heat energy of a fuel directly into electrical energy without a conventional electric generator . An MHD converter system is a heat engine in which heat is taken up at a higher temperature and partly converted into useful [electrical] work and the remainder ids rejected at a lower temperature.

The thermal efficiency of an MHD converter is increased by supplying the heat at the highest practical temperature and rejecting it at the lowest practical temperature.
MHD generation is the most promising of the direct conversion techniques for the large scale production of electric power.

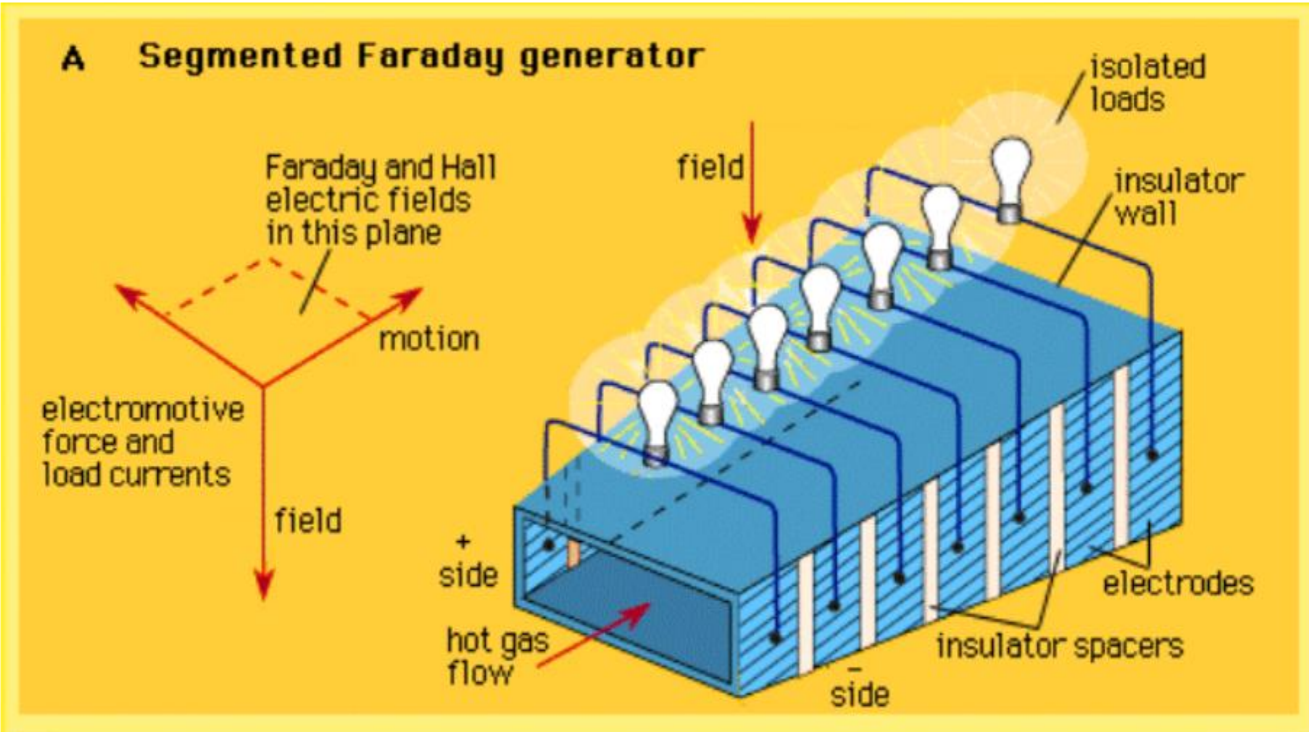
PRINCIPLE OF MHD POWER GENERATION:
The principle of MHD power generation is simply that of Faraday's law according to which when an electric conductor moves across a magnetic field, a voltage is induced in it which produces an electric current. It is Faraday's law of electromagnetic induction.

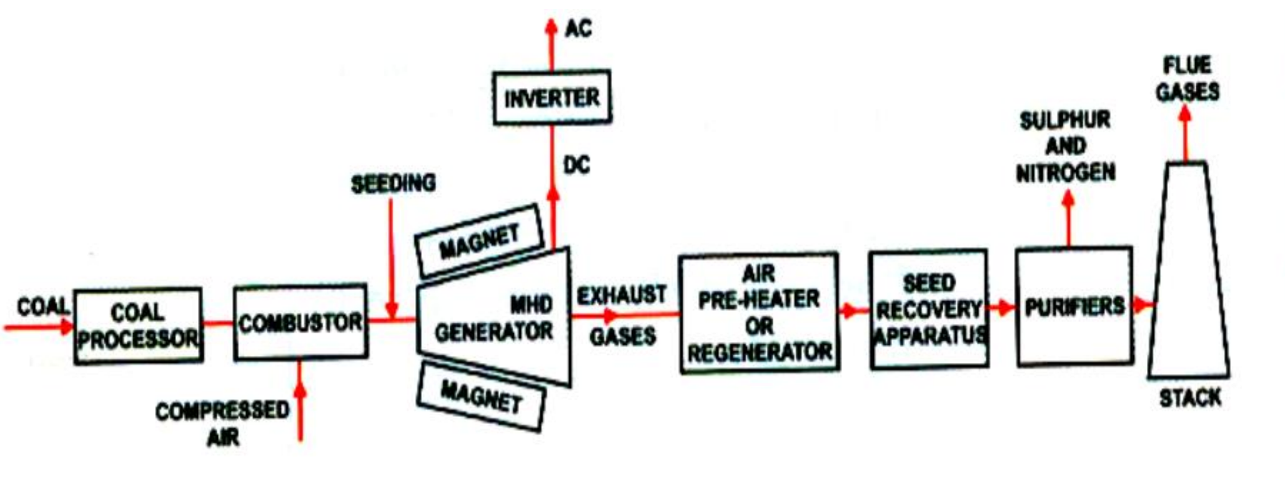
In MHD generator , a gaseous conductor is ionized and passed through a powerful magnetic field at a high velocity , a current is generated and can be extracted by placing electrodes in a suitable position in the stream. This arrangement as shown in figure provides DC power directly.



Principle of MHD Power Generation

Thus , kinetic energy is directly converted into electrical energy by the flow of an electrically conducting fluid, usually a gas or a gas-liquid combination , through a stationary magnetic field. If the flow direction is at right angles to the magnetic field direction, an emf is induced in the direction at right angles to both flow and field directions ,





Schematic of an open cycle MHD Generators

Ionization is produced either by thermal means at elevated temperature or by sending 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.

Thermal efficiency= Work output / Heat input

Factors which reduce the efficiency of the converter :

1. Dissipation of energy in the internal resistance of the ionized gas
2. A space charge barrier at the electrode surface
3. Heat transfer through the electrode and insulator walls.
4. Various losses due to fluid friction, etc .
5. Hall effect losses resulting in current induction in the direction of the flow.

To achieve a large power output, the gas must have a high velocity of 1000 m/s and the applied magnetic field density must be as large as possible. One of the major problems is to achieve adequate conductivity in the gas (> 10 mho/ m). To achieve equilibrium conductivities in the pure gas , thermal ionization temperature of tens of thousands of degrees are required. By seeding the gas with elements which have low ionization potentials , such as caesium and potassium , it is possible to achieve reasonable conductivities at gas temperatures in the region of 2000 ^{o} C.

An MHD generator is a device for converting heat energy directly into electrical energy without a conventional electrical energy without a conventional electric generator . High thermal efficiencies is possible . MHD conversion systems can operate as either open or closed cycle system.

In an open cycle system , the working fluid is used on the once through basis. The working fluid is discharged to the atmosphere through a stack after generating electrical energy.

In the closed cycle system , the working fluid is continuously re-circulated ; the discharged working fluid is reheated and recycled to the converter. In an open cycle system , the working fluid is air . In closed cycle system , helium or argon is used as the working fluid.

OPEN CYCLE MHD POWER GENERATION:

The arrangement of open cycle system , is shown schematically in FIG. Fuel used may be oil through an oil tank or gasified coal through a coal gasification plant. The fuel (coal, oil, or natural gas) is burnt in the combustor. The hot gases from combustor are then seeded with a small amount of an ionized alkali metal (cesium or potassium) to increase the electrical conductivity of the gas. The seed material, generally potassium carbonate, is injected into the combustor , the potassium is then ionized by the hot combustion gases at temperatures of 2300- 2700 ^{o} C.

To attain such high temperatures. the compressed air must be preheated to atleast 1100oC . A lower preheat temperature would be adequate if oxygen is used. An alternative is to use compressed oxygen alone for combustion of the fuel so that little or no preheating is required . The hot , pressurized working fluid leaving the combustor flows through a convergent divergent nozzle and the random motion energy of the molecules in the hot gas is largely converted into directed , mass motion energy . Thus , the gas emerges from the nozzle and enters the MHD generator unit at a high velocity.

The MHD generator is a divergent channel made of a heat – resistant alloy (e.g . Inconel) with external water cooling . The hot gas expands through the generator surrounded by powerful magnet. During the motion of the gas , the positive and negative ions move to the electrodes and constitute an electric current. The magnetic field direction is at right angle to the fluid flow. A number of oppositely located electrode pairs are current generated to an external load. An MHD generator produced DC . which can be converted to AC . by means of an inverter.

The seed material is recovered for successive use in seed recovery apparatus. Prior to the discharge of the working gas as flue gas from the steam boils to the atmosphere , The fly ash must be removed. It may be treated for recovery of the seed material which is mixed with ash . If sulphur is not removed from the coal , the original K_2CO_3 will have been converted into K_2SO_4 . This must be extracted from the fly ash and reconverted by chemical reactions into K_2CO_3. When oxygen alone is used for combustion of coal or other fossil fuel , nitrogen oxide formation does not arise

FACTORS FAVOURABLE FOR EFFICIENT OPERATION OF AN MHD SYSTEM

1. Air super heating arrangement to heat the gas to around 2500 ^{o} C so that the electrical conductivity of the gas is increased.
2. The combustion chamber must have low heat losses.
3. Arrangement to add a low ionization potential seed material to the gas to increase its conductivity.
4. A water cooled but electrically insulating expanding duct with long life electrodes.
5. Seed recovery apparatus – necessary for both environmental and economic reasons.

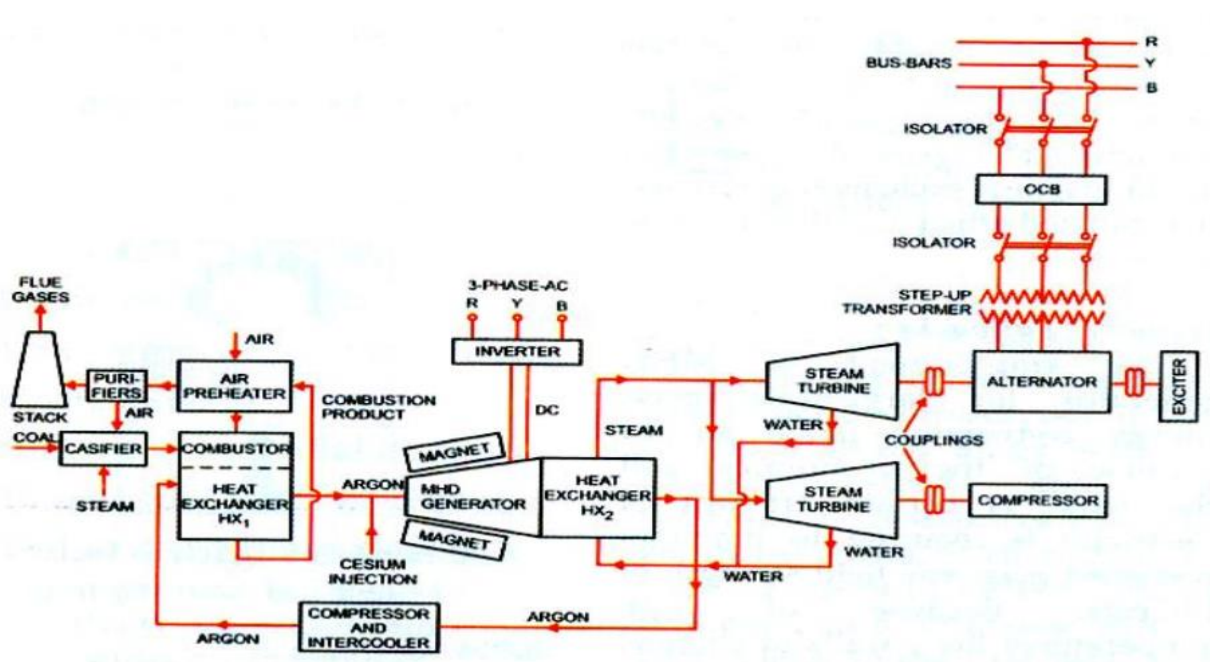
ADVANTAGES OF MHD SYSTEMS

1. The conversion efficiency of an MHD system is around 50 % when compared to 40 % for the most efficient steam plants.
2. Large amount of power is generated .
3. It has no moving parts and therefore high reliability .
4. Pollution –free-power.
5. It has the ability to reach full power as soon as its started.
6. The size of the plant (m2/kw) is considerably small than conventional fossil fuel plants
7. Capital costs of MHD plants will be competitive
8. Less operational costs
9. Elimination of boiler & gas turbine reduces the losses of energy
10. Better fuel utilization leading to conservation of energy sources
11. It is possible to use MHD for peak power generation with rapid start to full load.

CLOSED CYCLE SYSTEM

- Two general types of closed cycle MHD generators are being investigated.
- Electrical conductivity is maintained in the working fluid by ionization of a seeded material, as in open cycle system.
- A liquid metal provides the conductivity.
- The carrier is usually a chemical inert gas, all through a liquid carrier is been used with a liquid metal conductor. The working fluid is circulated in a closed loop and is heated by the combustion gases using a heat exchanger. Hence the heat sources and the working fluid are independent. The working fluid is helium or argon with cesium seeding.

SEEDED INERT GAS SYSTEM



- In a closed cycle system the carrier gas operates in the form of Brayton cycle. In a closed cycle system the gas is compressed and heat is supplied by the source, at essentially constant pressure, the compressed gas then expands in the MHD generator, and its pressure and temperature fall. After leaving this generator heat is removed from the gas by a cooler, this is the heat rejection stage of the cycle. Finally the gas is recompressed and returned for reheating.
- The complete system has three distinct but interlocking loops. On the left is the external heating loop. Coal is gasified and the gas is burnt in the combustor to

provide heat. In the primary heat exchanger, this heat is transferred to a carrier gas argon or helium of the MHD cycle. The combustion products after passing through the air preheated and purifier are discharged to atmosphere.

- Because the combustion system is separate from the working fluid, so also are the ash and flue gases. Hence the problem of extracting the seed material from fly ash does not arise. The fuel gases are used to preheat the incoming combustion air and then treated for fly ash and sulfur dioxide removal, if necessary prior to discharge through a stack to the atmosphere.
- The loop in the center is the MHD loop. The hot argon gas is seeding with cesium and resulting working fluid is passed through the MHD generator at high speed. The dc power out of MHD generator is converted in ac by the inverter and is then fed to the grid.

LIQUID METAL SYSTEM

- When a liquid metal provides the electrical conductivity, it is called a liquid metal MHD system.
- An inert gas is a convenient carrier
- The carrier gas is pressurized and heated by passage through a heat exchanger within combustion chamber. The hot gas is then incorporated into the liquid metal usually hot sodium to form the working fluid. The latter then consists of gas bubbles uniformly dispersed in an approximately equal volume of liquid sodium.

The working fluid is introduced into the MHD generator through a nozzle in the usual ways. The carrier gas then provides the required high direct velocity of the electrical conductor

- After passage through the generator, the liquid metal is separated from the carrier gas. Part of the heat exchanger to produce steam for operating a turbine generator. Finally the carrier gas is cooled, compressed and returned to the combustion chamber for reheating and mixing with the recovered liquid metal. The working fluid temperature is usually around 800’c as the boiling point of sodium even under moderate pressure is below 900’c.
- At lower operating temp, the other MHD conversion systems may be advantageous from the material standpoint, but the maximum thermal efficiency is lower. A possible compromise might be to use liquid lithium, with a boiling point near 1300’c as the electrical conductor lithium is much more expensive than sodium, but losses in a closed system are less.

ADVANTAGES

- The conversion efficiency of a MHD system can be around 50% much higher compared to the most efficient steam plants. Still higher efficiencies are expected in future, around 60 – 65 %, with the improvements in experience and technology.
- Large amount of power is generated.
- It has no moving parts, so more reliable.
- The closed cycle system produces power, free of pollution.
- It has ability to reach the full power level as soon as started.
- The size if the plant is considerably smaller than conventional fossil fuel plants.

- Although the cost cannot be predicted very accurately, yet it has been reported that capital costs of MHD plants will be competitive to conventional steam plants.
- It has been estimated that the overall operational costs in a plant would be about 20% less than conventional steam plants.
- Direct conversion of heat into electricity permits to eliminate the turbine (compared with a gas turbine power plant) or both the boiler and the turbine (compared with a steam power plant) elimination reduces losses of energy.
- These systems permit better fuel utilization. The reduced fuel consumption would offer additional economic and special benefits and would also lead to conservation of energy resources.
- It is possible to use MHD for peak power generations and emergency service. It has been estimated that MHD equipment for such duties is simpler, has capability of generating in large units and has the ability to make rapid start to full load.

FUEL CELLS :

Fuel cells are electrochemical devices for the continuous conversion of the portion of the free energy change in a chemical reaction to electrical energy. It differs from a battery in that it operates with continuous replenishment of the fuel and the oxidant at active electrode area and does not require recharging. The main components of a fuel cell are (i) a fuel electrode, (ii) an oxidant or air electrode and (iii) an electrolyte.

Hydrogen as a fuel gives the most promising results but cells consuming coal, oil or natural gas would be economically much more useful for large scale applications. Some of the fuel cells are hydrogen-oxygen,(H_2, O_2), Hydrazine-oxygen ($N_2 H_4$, O_2), Carbon or coal-oxygen (C, O_2), methane-oxygen (CH_4, O_2), etc. Hydrogen-oxygen fuel cells (Hydrox) are efficient and the most highly developed cells. A low pressure hydrogen-oxygen cell is shown in Fig.6. Two porous carbon or nickel electrodes, are immersed in an electrolyte. Catalyst is embedded in nickel electrodes. The electrolyte is typically 30% KOH because of its high electrical conductivity and it is less corrosive than acids.

Cell reactions are :

$$H_2 \xrightarrow{\text{Catalyst}} 2H^+ + 2e^-$$

$$2H^+ + 2OH^- \longrightarrow 2H_2O$$

$$O_2 \rightleftharpoons 2\,O$$

$$O + H_2O + 2e^- \longrightarrow 2OH^-$$

H_2 is fed to one electrode and is absorbed, gives free electrons and reads with hydroxyl ions (OH^-) of the electrolyte to form water. The free electrons travel towards oxygen electrode through the external circuit, two electrons arriving by the external circuit and one molecule of water form $2OH^-$ ions. These OH^- ions migrate towards to H_2 electrode and are consumed there. The electrolyte remains invariant. It is important that the composition of electrolyte should not change as the cell operates. The cell operates at or slightly above atmospheric pressure and at a temperature about 9^0 C. These type of cells are called low temp. cells. In high pressure cells, pressure is upto about 45 atmospheres and temp. upto 300^0 C.

A single hydrogen-oxygen cell can produce an emf of 1.23 Volt at atmospheric pressure and 25^0 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 nearly 100 MW.

Advantages of fuel cells

1.) It is a direct conversion process and does not involve a thermal process, so it has high operating efficiency. Currently, fuel cell efficiency is 38% and it is expected to reach 60%.
2.) The unit is lighter, smaller and needs less maintenance.
3.) Fuel power plants may further cut generation costs by reducing transmission losses.
4.) Little pollution and little noise so that it can be readily accepted in residential areas.

Other Types of Fuel Cells

- Alkaline fuel cell (AFC)
    - This is one of the oldest designs. It has been used in the U.S. space program since the 1960s. The AFC is very susceptible to contamination, so it requires pure hydrogen and oxygen. It is also very expensive, so this type of fuel cell is unlikely to be commercialized.
- Phosphoric-acid fuel cell (PAFC)
    - The phosphoric-acid fuel cell has potential for use in small stationary power-generation systems. It operates at a higher temperature than PEM

fuel cells, so it has a longer warm-up time. This makes it unsuitable for use in cars.

- Solid oxide fuel cell (SOFC)
    - These fuel cells are best suited for large-scale stationary power generators that could provide electricity for factories or towns. This type of fuel cell operates at very high temperatures (around 1,832 F, 1,000 C). This high temperature makes reliability a problem, but it also has an advantage: The steam produced by the fuel cell can be channeled into turbines to generate more electricity. This improves the overall efficiency of the system.
- Molten carbonate fuel cell (MCFC)
    - These fuel cells are also best suited for large stationary power generators. They operate at 1,112 F (600 C), so they also generate steam that can be used to generate more power. They have a lower operating temperature than the SOFC, which means they don't need such exotic materials. This makes the design a little less expensive.

Advantages/Disadvantages of Fuel Cells

- Advantages
    - Water is the only discharge (pure H_2)
- Disadvantages
    - CO_2 discharged with methanol reform
    - Little more efficient than alternatives
    - Technology currently expensive
        - Many design issues still in progress
    - Hydrogen often created using "dirty" energy (*e.g.,* coal)
    - Pure hydrogen is difficult to handle

Refilling stations, storage tanks, …

Thermionic Converter :

Thermionic Converter converts heat energy directly to electrical energy. This consists of 2 electrodes in a container filled with ionized cesium vapour. Heating one electrode boils out electrons that travel to the opposite colder electrode. The positive ions in the gas neutralize the space-charge effect of the electrons that normally prevent the flow of electrons. Ionized gas offsets space-charge effect that tends to repel migration of electrons.

Electrons which are emitted by heating cathode, are migrated to cooler anode collector and flow through outer circuits to develop electric power. The anode materials for thermionic converters should have low work function. Barium and strontium oxides are preferred for this purpose. Cathode material should have higher work function. For this, tungsten impregnated with a barium compound is a suitable material. Efficiencies of these tubes is of the order of 8%. Researchers expect to produce units working at thermal efficiencies of 30%. At this efficiency, the emitting cathode will be sized at 100 cm^2 for a

1 KW output. Potential will be about 2-3 Volts DC The present cathode is heated to about 1400^0 C.

This device is being designed for space power applications where high temp. operation is advantageous. It can be used for supplying power to boats and power tools, and irrigation pumps. These units can be connected in series or parallel for different plant voltages and capacities. These devices may be used as small power plants for peak load power in commercial power generation system.

Thermo Electric Generator :

The device converts heat directly into electric power. This eliminates the conversion of heat into kinetic energy of gas or steam flow. Its principle is based on the ***Seebeck Effect*** which states that if two dissimilar materials are joined to form a loop, and the two junctions are maintained at different temperatures, an emf will be developed around the loop. The magnitude of the emf (E) developed by the process is proportional to the temperature difference between the two junction

$$E \quad \alpha \quad (T_2 - T_1)$$

$$\therefore E = \alpha \; (T_h - T_c)$$

where T_h = temp. of hot junction
T_c = temp. of cold junction
α = Seebeck cofficient

The hot junction is maintained at temp. of T_h by the applied heat source which may be small oil or gas burner, a nuclear reactor, or direct solar radiation by paraboloidal concentrator and the cold junction is maintained at T_c by either water cooling or radiative heat transfer.

This is one method of producing electrical energy directly from the heat of combustion, where fuel is cheap. This device can generate power for standby or even base load plants. The thermal efficiency is of the order of 3% . New semiconductor materials are found which work more efficiently and or able to withstand at high temp. A peak load plant of 100 MW capacity can be developed where fuels are very cheap.