Abstract—Efficiencies of the all modern thermal power plant technologies lie between 35% and 40% since they need to reject large amount of thermal energy to the ambient. Among the renewable power generation systems, owing to its high power production, high efficiency (about 60 percent) and proper response to the problem of thermal pollution and air pollution, utilizing the technology of magnetohydrodynamics (MHD) has gained particular attention. The beneficial environmental aspects of MHD are probably of equal or even greater significance when compared to conventional power stations. The process of MHD has not only the capacity of producing the power but also it is applicable to aeronautical thrust systems. MHD promises a dramatic improvement in the cost of generating electricity from oil and gas and is beneficial to the growth of the national economy. Paper presented here, reviewed the fundamentals of power generation through this technology and the pertinent equations.

Keywords—Renewable energies, direct power generation, magnetohydrodynamics (MHD)

I. INTRODUCTION

Energy conversion is the process of changing energy from one form to another and can be classified into two groups: direct and indirect. Direct energy conversion encompasses the transformation of one type of energy such as sunlight to another one which is usually the electricity without passing through an intermediate stage such as steam turbines. Figure (1) depicts the process of some direct and indirect energy conversion from various sources to the electricity. While direct energy conversion techniques other than technologies illustrated in Figure (2) exist, we will concentrate on MHD that show potential for large-scale power production and that could reach commercialization in the next few decades. Furthermore, we can mention fuel cells, solar photovoltaic, thermoelectric and thermionic systems as another form of direct energy conversion.

An MHD generator, like a turbogenerator, is an energy conversion device and can be used with any high-temperature heat source such as chemical, nuclear and solar. Advantages of MHD power generation can be mentioned as follows [3]:

- simple structure
- working at high-temperatures
- high Carnot-cycle efficiency
- easy to realize combined cycle with other systems

At 1831, Faraday was the first person who immersed electrodes into the Thames River at either end of the Waterloo Bridge in London and connected the electrodes at mid span on the bridge through a galvanometer. Faraday reasoned that the electrically conducting river water moving through the earth's magnetic field should produce a transverse electromotive force (emf).

II. FUNDAMENTAL EQUATIONS

Here, we will consider briefly the behavior of electrons in an ionized gas in the presence of electromagnetic fields and the equations pertaining to an ideal generator [4,5].

A. Electron Behavior in a Magnetic Field

In a gas at or near equilibrium, atoms, ions, and electrons are in random motion. At any given spatial position their velocities are distributed about a mean velocity that increases with increase in the local temperature. Considering just one of the free electrons moving, without collision, in a plane normal to a uniform magnetic field, as in Figure (3) the electron experiences a constant force $F$ equal to

$$ F = q\mathbf{u} \times \mathbf{B} \quad (1) $$

normal to its path according to equation (1). Here, $q$ is the charge of the electron, $\mathbf{u}$ is its velocity and $\mathbf{B}$ is the magnetic field.
The electron experiences a constant force $q c_\theta B$ normal to its path according to Equation (1). Here, $q$ is the charge of the electron and $c_\theta$ the magnitude of its velocity. Because the force is normal to its path, the electron travels with constant velocity on a circular path around magnetic lines of force. By Newton's Second Law, the force on the electron is

$$F = m c_\theta^2 / r = q c_\theta B$$  \hspace{1cm} (2)$$

It follows that the angular frequency of the electron about a line of force $c_\theta / r$, called its cyclotron frequency, is

$$\omega = c_\theta / r = qB / m_\theta$$  \hspace{1cm} (3)$$

The electron cyclotron frequency is independent of electron velocity and is dependent on the magnetic field strength and electron properties. Although the cyclotron motions of electrons exist in gases when strong magnetic fields are present, the circular paths of the electrons may be disrupted by collisions with other particles.

The likelihood of collisions between particles depends on their effective sizes. Larger particles will collide more frequently. The probability of collision is taken as proportional to the collision cross-section $Q$ of the particle, which may be thought of as its area. The frequency of collision of electrons $\omega_c$ is given by the product of the electron number density per volume, $n_\theta$, the collision cross-section, $Q$, and the velocity, $c_\theta$:

$$\omega_c = n_\theta Q c_\theta = 1 / \tau$$  \hspace{1cm} (4)$$

Here, the mean time between collisions, $\tau$, is the inverse of the collision frequency. The ratio of the cyclotron frequency to the collision frequency, $\omega / \omega_c$, is called the Hall parameter. It indicates the relative importance of the magnetic field and collisions in controlling electron motion in the ionized gas. The Hall parameter is related to the magnetic field intensity by

$$\omega / \omega_c = qB / m_\theta n_\theta Q c_\theta$$  \hspace{1cm} (5)$$

It is proportional to the number of cyclotron loops made per collision.

A large Hall parameter compared with one indicates magnetic-field-dominated motion of electrons, while a small value implies that collisions quickly break up ordered motions produced by the magnetic field.
A. Faraday Generator

The essential elements of a simplified MHD generator are shown in Figure (4). This type of generator is referred to as a continuous electrode Faraday generator. A field of magnetic induction $B$ is applied transverse to the motion of an electrically conducting gas flowing in an insulated duct with a velocity $u$. Charged particles moving with the gas will experience an induced electric field $u \times B$ which will tend to drive an electric current in the direction perpendicular to both $u$ and $B$. This current is collected by a pair of electrodes on opposite sides of the duct in contact with the gas and connected externally through a load. Neglecting the Hall effect, the magnitude of the current density for a weakly ionized gas is given by the generalized Ohm's law as

$$J = \sigma(uB - E)$$

The electric field $E$, which is added to the induced field, results from the potential difference between the electrodes. For the purposes of our initial discussion in this section we shall assume that both $u$ and $\sigma$ are uniform.

In terms of the one axes coordinate system in Figure (3)

$$J = \sigma(uB - E_x)$$

At open circuit $J = 0$, and so the open circuit electric field

$$E = \frac{2000 V}{m}$$

For the characteristic conditions $u = 1000 m/s$ and $B = 2 T$, the open circuit electric field is $uB = 2000 V/m$. At short circuit $E_x = 0$, and the short circuit current is $J = \sigma u B$. For general load conditions, it is conventional to introduce the loading parameter

$$K = \frac{E_x}{uB}$$

where $0 \sim K \sim 1$, and write $f = -\sigma u B (1 - K)$. The negative sign indicates that the conventional current flows in the negative $y$ direction. Since the electrons flow in the opposite direction, the bottom electrode must serve as an electron emitter, or cathode, and the upper electrode is an anode.

The electrical power delivered to the load per unit volume of a MHD generator gas is

$$P = -J \cdot E$$

For the generator shown in Figure (4),

$$P = \sigma u^2 B^2 K (1 - K)$$

This power density has a maximum value

$$P = \sigma u^2 B^2 / 4$$

for $K = 1/2$. The rate at which directed energy is extracted from the gas by the electromagnetic field per unit volume is $-u \cdot (J \times B)$. The electrical efficiency of a MHD generator is defined as

$$\eta_e = \frac{J \cdot E}{u \cdot (J \cdot B)}$$

For the generator being discussed

$$\eta_e = K$$

III. POWER GENERATION

The fuel is burnt in the presence of compressed air in a combustion chamber. During combustion seeding materials are added to increase the ionization and this ionized gas (plasma) is made to expand through a nozzle into the generator. Magnetic field, a current is generated and it can be extracted by placing electrodes in a suitable stream. This generated emf is a direct current.

Various methods for ionizing the gas are available, all of which depend on imparting sufficient energy to the gas. The ionization can be produced by thermal or nuclear means. Materials such as Potassium carbonate or Cesium are often added in small amounts, typically about 1% of the total mass flow to increase the ionization and improve the conductivity, particularly combustion of gas plasma.

Figure (5) shows proposed energy re-circulating type MHD power generation system with LNG heat source. The system
does not combined with any other system and is called closed cycle MHD single system. We can see that plant efficiency is expected over 60% even the enthalpy extraction ratio of the MHD generator is only 30%. Thermal input to the MHD generator is 200 unit and electric output is 60 unit in spite of only 100 unit input thermal energy to the system because 100 unit of the heat is recovered by regenerator. Enthalpy extraction ratio of above 30% was achieved by experiments with shock tube facility. So this estimation of efficiency is considered to be realistic in near future.

Because in a nuclear/gas-turbine system, highest working temperature is considered to be 850 owing to requirement from difficulty in developing high-temperature gas-cooled reactor (HTGR), its efficiency is relatively low. A system using MHD generator to achieve higher efficiency is proposed as shown in Figure (6). This system is a special power generation system driven by HTGR directly connected with MHD single power generation system for space applications [3].

![Figure 5. A 200MW class gas core reactor with MHD energy conversion in a closed Rankine cycle [7]](image)

![Figure 6. Energy re-circulating type MHD single system with nuclear reactor as heat source [8]](image)

IV. CONCLUSION

The direct energy conversion methods that nowadays are taken into account in terms of industrial application are:

- Photovoltaic generation systems (Photovoltaic Solar Cells)
- Electrochemical energy conversion (Fuel Cells)
- Magnetohydrodynamic generation (MHD)
- Electrogasdynamic generation (EGD)
- Thermoelectric power generation

Magnetohydrodynamics (MHD) is the study of the dynamics of electrically conducting fluids such as salt water as a direct form of energy conversion. The principle of operation of MHD power generator is based on the Faraday’s induction law which was presented along with the two of the future power cycles. Various advantages of MHD power generating system are:

- Large amount of electric power generation is possible
- It is highly reliable, as the system is having no moving parts.
- Closed-cycle system of MHD power generation is pollution free.
- The size of the power plant is small
- The efficiency of the plant is high about 50% compared to other systems of generation
- It is possible to run the standby power plant in conjunction with MHD power generation scheme
REFERENCES


