REVIEW OF MAGNETOHYDRODYNAMICS POWER GENERATION

Prof. Sandeep C. Abhang[1], Prof. Anil S. Gawhale[2], Prof. Sandip S. Madan[3]

Department of Mechanical Engineering, CSMSS College of Polytechnic, Aurangabad. Maharashtra, (India)

ABSTRACT

Magneto hydrodynamics (MHD), the interaction between an electrically conducting fluid and a magnetic field, offers an interesting cross-point study between electrodynamics and hydrodynamics. Objective of this study is to calculate an MHD flow, affected by a non-homogeneous localized magnetic field (magnetic obstacle), through a dielectric duct in the laminar (Re = 100 and Re = 400) and a dielectric channel in the turbulent (Reτ = 180) regime, and for different values of the magnetic interaction parameter (N = 4 and N = 11.25). Flow in the turbulent regime is calculated using the large eddy simulation (LES) with dynamical Smagorinsky sub-grid model, and all calculations are performed on multiple processors using the message parsing interface (MPI). Channel turbulence is created on the minimal flow unit, which is also used as a generator for performing turbulent MHD. The results obtained in the laminar regime are compared to direct numerical simulation (DNS) by Votyakov et al. (Phys.Rev.Let vol. 98, 2007), and results obtained for channel turbulence are compared to DNS data by Moser et al. (Phys.Fluids vol. 11, 1998). A fully unstructured computational fluid dynamics (CFD) code was extended for solving the MHD equations in the low magnetic Reynolds number regime (Rem ¿ 1). In this report, we compare the laminar MHD flow patterns as calculated by independent codes, we show that our LES simulations closely approximates turbulence DNS data, and demonstrate the effect of a magnetic obstacle on a fully turbulent channel flow. The significance of the agreement in the laminar case is that 1) it validates the prediction of a zero, two, and six vortex pattern as created behind a magnetic obstacle, 2) the effect of the sub-grid model is negligible in this regime, and 3) it validates our parallel MHD solver. The turbulent channel flow as performed 1) validates our parallel solver in the fully turbulent regime, and 2) provides further support for the validity of the LES with dynamical Smagorinsky approach for turbulent flows.

Index Terms: Electromagnetic induction, Hall effect, Plasma

I. INTRODUCTION

We all are aware of power generation using hydel, thermal and nuclear resources. In all the systems, the potential energy or thermal energy is first converted in to mechanical energy and then the mechanical energy is converted in to electrical energy. The conversion of potential energy in to mechanical energy is considerably high (70 to 80%) but conversion of thermal energy in to mechanical energy is considerably poor(40 to 45%).In addition to this the mechanical components required for converting heat energy in to mechanical energy are large in number and considerably costly. This requires huge capital cost as well as maintenance cost also. The

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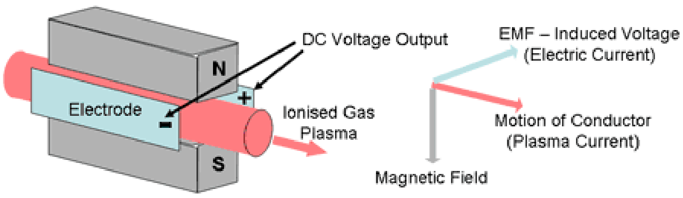
scientists are thinking to eliminate the mechanical system and convert thermal in to direct electrical energy for the last 50- years and more. Unfortunately, no system is yet developed in large capacity (MW) to compete with conventional systems. In addition to this the efficiency of such conversion remained considerably poor(less than10%) therefore; these power generating systems are not developed on large scale.[1]

II. WORKING PRINCIPLE

The MHD generator can be considered to be a fluid dynamo. This is similar to a mechanical dynamo in which the motion of a metal conductor through a magnetic field creates a current in the conductor except that in the MHD generator the metal conductor is replaced by conducting gas plasma.

When a conductor moves through a magnetic field it creates an electrical field perpendicular to the magnetic field and the direction of movement of the conductor. This is the principle, discovered by Michael Faraday, behind the conventional rotary electricity generator. Dutch physicist Antoon Lorentz provided the mathematical theory to quantify its effects.



Magnetohydrodynamic Power Generation (Principle)

Fig. 2.1

The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associated current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to Fleming's Right Hand Rule

Lorentz Law describing the effects of a charged particle moving in a constant magnetic field can be stated as

$$F = Q\,v\,B$$

Where,

F -is the force acting on the charged particle

Q- is charge of particle

v -is velocity of particle

B -is magnetic field

The vector F is perpendicular to both v and B according to Fleming's Right Hand Rule. When a conductor moves through a magnetic field it creates an electrical field perpendicular to the magnetic field and the direction of movement of the conductor. This is the principle, discovered by Michael Faraday, behind the conventional rotary electricity generator. Dutch physicist Anton Lorentz provided the mathematical theory to quantify its effects. The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associated current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to 'Fleming's Right Hand Rule'. Summarizing the above explanation we can say that in a MHD system the kinetic energy of the working fluid is converted to electric energy. The figure given below shows a

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comparison between a turbo generator and MHD generator.

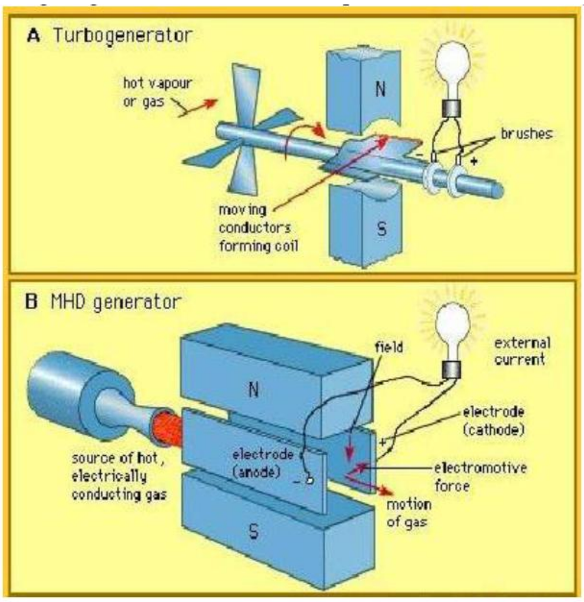

Fig. 2.2

Here, in turbo generator, the conductor moving inside the magnetic field is solid, while in MHD generator the conductor moving inside the magnetic field is in gaseous state. But both them on are working on the same principle, doing the same work, giving the same output. However, the efficiency of both of them varies, as MHD generator gives much better and more output than the turbo generator, hence it is more efficient. The MHD conversion is known as direct energy conversion because it produces electricity directly from heat source (derived from combustion of fuel) without the necessity of the additional stage of steam generation as in a steam power plant.

2.1 The MHD System

The MHD generator needs a high temperature gas source, which could be the coolant from a nuclear reactor or more likely high temperature combustion gases generated by burning fossil fuels, including coal, in a combustion chamber. The diagram below shows possible system components.

The expansion nozzle reduces the gas pressure and consequently increases the plasma speed (Bernoulli's Law) through the generator duct to increase the power output (See Power below).

Unfortunately, at the same time, the pressure drop causes the plasma temperature to fall (Gay-Lussac's Law) which also increases the plasma resistance, so a compromise between Bernoulli and Gay-Lussac must be found.

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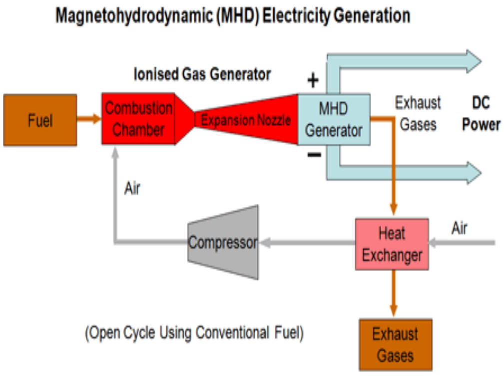

Fig. 3.1

The exhaust heat from the working fluid is used to drive a compressor to increase the fuel combustion rate but much of the heat will be wasted unless it can be used in another process. [2]

2.2The Plasma

The prime MHD system requirement is creating and managing the conducting gas plasma since the system depends on the plasma having a high electrical conductivity. The plasma can be likened to the fourth state of matter after the solid, liquid and gaseous states, in which the atoms or molecules are stripped of their electrons leaving positively charged ions. Suitable working fluids are gases derived from combustion, noble gases, and alkali metal vapours.

2.3 The Gas Plasma

To achieve high conductivity, the gas must be ionized by detaching the electrons from the atoms or molecules leaving the positively charged plasma. The plasma flows through the magnetic field at high speed, in some designs, more than the speed of sound, the flow of the positively charged particles providing the moving electrical conductor necessary for inducing a current in the external electrical circuit..

2.4 Methods of Ionizing the Gas

Various methods for ionizing the gas are available, all of which depend on imparting sufficient energy to the gas. It may be accomplished by heating or irradiating the gas with X rays or Gamma rays. It has also been proposed to use the coolant gases such as helium and carbon dioxide employed in some nuclear reactors as the plasma fuel for direct MHD electricity generation rather than extracting the heat energy of the gas through heat exchangers to raise steam to drive turbine generators. Seed 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 of combustion gas plasmas.

2.5 Containment

Since the plasma temperature is typically over 1000 °C, the duct containing the plasma must be constructed from non conducting materials capable of withstanding these high temperatures. The electrodes must of course be conducting as well as heat resistant.

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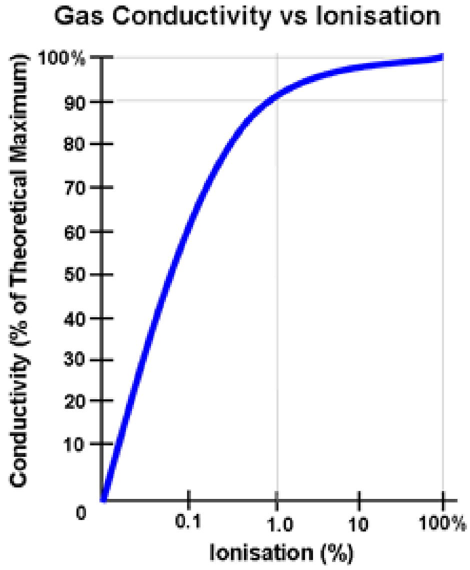

Fig. 3.2

2.6 The Faraday Current

A powerful electromagnet provides the magnetic field through which the plasma flows, and perpendicular to this field are installed the two electrodes on opposite sides of the plasma across which the electrical output voltage is generated. The current flowing across the plasma between these electrodes is called the Faraday current. This provides the main electrical output of the MHD generator.[7]

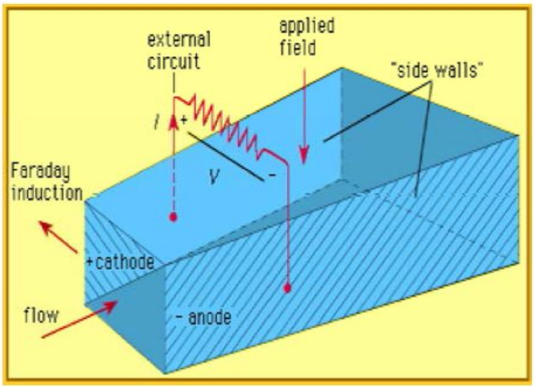

Fig. 3.3 Faradays generator

2.7 The Hall Effect Current

The very high Faraday output current which flows across the plasma duct into the load itself reacts with the applied magnetic field creating a Hall Effect current perpendicular to the Faraday current, in other words, a current along the axis of the plasma, resulting in lost energy. The total current generated will be the vector sum of the transverse (Faraday) and axial (Hall Effect) current components. Unless it can be captured in some way, the Hall effect current will constitute an energy loss .

Various configurations of electrodes have been devised to capture both the Faraday and Hall Effect components of the current in order to improve the overall MHD conversion efficiency.

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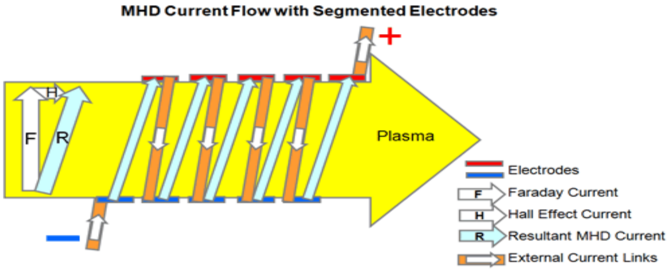

Fig. 3.4

One such method is to split the electrode pair into a series of segments physically side by side (parallel) but insulated from each other, with the segmented electrode pairs connected in series to achieve a higher voltage but with a lower current. Instead of the electrodes being directly opposite each other, perpendicular to the plasma stream, they are skewed at a slight angle from perpendicular to be in line with the vector sum of the Faraday and Hall effect currents, as shown in the diagram below, thus allowing the maximum energy to be extracted from the plasma.

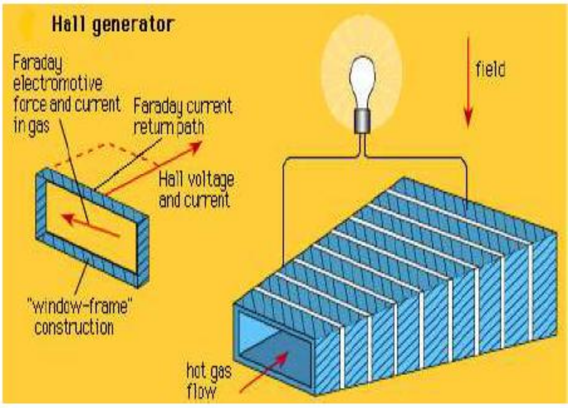

Fig. 3.5 Hall generator

2.8 Power Output

The output power is proportional to the cross sectional area and the flow rate of the ionized plasma. The conductive substance is also cooled and slowed in this process. MHD generators typically reduce the temperature of the conductive substance from plasma temperatures to just over 1000 °C.

An MHD generator produces a direct current output which needs an expensive high power inverter to convert the output into alternating current for connection to the grid.

2.9 Efficiency

Typical efficiencies of MHD generators are around 10 to 20 percent mainly due to the heat lost through the high temperature exhaust. This limits the MHD's potential applications as a stand alone device but they were originally designed to be used in combination with other energy converters in hybrid applications where the output gases (flames) are used as the energy source to raise steam in a steam turbine plant. Total plant efficiencies of 65% could be possible in such arrangements.

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III. POWERCYCLE FOR MHD-GENERATOR MHD.

Generator replaced the gas turbine used in conventional cycle is shown in Figure 2.2. A compressor is used to elevate the pressure and then heat is added to increase the gas temperature which is sufficient to ionize the gas. Then the gas flow is accelerated by passing through the nozzle before entering MHD generator. The gas passing through the MHD generator is decelerated and electrical energy is generated.

It is obvious that the MHD-cycle is thermal power cycle and the thermal efficiency is given by

$$\eta = \frac{Workoutput}{Heatinput} = \frac{(h3-h4)-(h2-h1)}{h2-h1}$$

where indicated enthalpies are stagnation values which takes into account the K.E of the flowing gas The stagnation enthalpy of the following gas is given by

$$h0 = h + \frac{u2}{2}$$

Where u is the velocity of the flowing gas. In actual MHD-generator, the gas velocity is sufficiently high (sonic and above) so that the K.E of the flowing gas represents substantial portion of the total energy

IV. ADVANTAGES OF MHD GENERATOR

- Conventional coal-fired generators achieve a maximum efficiency of about 35%. MHD generators have the potential to reach 50% - 60% efficiency.
- The higher efficiency is due to recycling the energy from the hot plasma gas to standard steam turbines. After the plasma gas passes through the MHD generator, it is still hot enough to boil water to drive steam turbines that produce additional power.MHD generators are also ecologically sound.
- Coal with high sulphur content can be used in the MHD without polluting the atmosphere. 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 reduce 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.

4.1 Necessity of MHD System

It is a well known fact that at present a plenty of energy is needed to sustain industrial and agricultural production, and the existing conventional energy sources like coal, oil, uranium etc are not adequate to meet the ever increasing energy demands. Consequently, sincere and untiring efforts have been made by scientists and engineers in exploring the possibilities of harnessing energy from several non-conventional energy sources. Magneto Hydro Dynamics (MHD) Generator is one of those energy sources. Today 80% of total electricity produced in the world is hydel, while remaining 20% is produced from nuclear, thermal, solar, geothermal energy and from magneto hydro dynamic power generation.

4.2 Applications

1) Power generation in space craft.
2) Hypersonic wind tunnel experiments.
3) Defense application.
4) Railway engines/Light weighted space vehicles.

The possibility to utilize MHD energy conversion systems in the space. We proposed a plasma MHD generator feed by fuel in liquid (Hydrogen, Oxygen, Nuclear fuel) or solid state. The MHD generator proposed in built in the supersonic nozzle of a rocket engine utilizing liquid Hydrogen and Oxygen. The MHD interaction is effective in a layer near the wall at a temperature of about 2600 k and at a pressure of 0.37 MPa. Hence, in order to increase the electrical conductivity, alkali metal (Potassium Carbonate or Cesium) seeding is used. We can also fed the small MHD generator to the railway engines for the increasing the better efficiency of railway engines, speed, and also increasing as well as controlling the energy.

V. CONCLUSIONS

With the increased industrial and agricultural activities, power demand is also highly increased. In the country is sure to fall short of the energy demand by the first decade of next century. This means an additional capacity of power is required next 10 year. The answer to this is in non- conventional energy. The MHD power generation is in advanced stage today and closer to commercial utilization significant progress has been made in development of all critical component and sub system technologies coal burning MHD combined steam power plant promise significant economic and environmental advantages compared to other coal burning power generate technologies.

Also, in order to reduce CO_2 emission, use nuclear power with high efficiency. We have to construct nuclear powered energy re-circulating type system. Also idea of CO_2 recovery type power generation system must be developed. Energy recalculating type Nuclear/MHD power system was proposed to achieve high efficiency using high operating temperature and eliminating bottoming cycle. For reduction of CO_2 emission, CO_2 recovery type generator system was proposed, which has special features of using coal synthesized gas burning with pure oxygen and heat recovery systems.

In the MHD generator the advantage of having no moving parts allows to work at higher temperatures than a conventional energy conversion. It is possible to work with temperature around 3000K, and a these temperature the maximum theoretical efficiency would be near 90%. In the section of near future MHD power generation system the plant efficiency can be increased by increasing the working temperature, do not use condenser of steam-turbine to reduce exhaust heat, and to construct energy re-circulating type system

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It can therefore be claimed that the development of MHD for electric utility power generation is an objective of national significance.

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