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# Integration of Magnetohydrodynamics (MHD) Power Generating Technology with Thermal Power Plants for Efficiency Improvement

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**Abstract:** The electricity necessities of the world are increasing at alarming rate and the power demand has been running ahead of supply. It is also now widely recognized that the fossil fuels and other conventional resources, presently being used for generation of electrical energy, may not be either sufficient or suitable to keep pace with ever increasing demand of the electrical energy of the world. The recent severe energy crisis has forced the world to develop new and alternative methods of power generation. Magnetohydrodynamics (MHD) is a highly efficient and unique method for power generation, which is based on plasma physics and its working principle is based on Faraday's Law of electromagnetic induction. The electricity is directly extracted from thermal energy of plasma (ionized gas) which is passing through the strong magnetic field. The flow of conducting plasma (ionized gas) through a magnetic field at high velocity causes a voltage to be generated across the electrodes which are placed at suitable position in the stream of ionized gas and thus the electrical energy is generated directly through thermal energy. In this paper the processes and technology involved in MHD power generation with different type of MHD generators, their functions and by utilizing it for increasing the efficiency of existing conventional thermal power plants are discussed.

**Key words:** Magnetohydrodynamics (MHD) · Plasma · System integration · Energy conversion · MHD-steam combined cycle

## INTRODUCTION

The whole world is already familiar with the conventional power generating resources like hydal, thermal and nuclear resources etc. In all the conventional systems the potential or thermal energy is first converted into mechanical energy and then this mechanical energy is converted into electrical energy. The conversion of potential energy into mechanical energy is significantly high i.e. 70-80% but conversion of thermal energy into mechanical energy is significantly poor i.e.40-45%. This requires huge capital cost as well as maintenance cost [1].

All across the world researches are trying to convert thermal energy directly into electrical energy by eradicating the mechanical process involved in energy conversions which have significant energy losses. Research is now focusing its efforts on conversion process that do not involve mechanical energy conversion step. In the absence of moving mechanical part may allow in achieving the operating temperature much higher than the typical conventional processes to attain effective power generating systems. These processes are known as direct conversion systems in which primary or secondary energy is directly converted into electrical energy without passing through the stage of mechanical energy [2]. Some of the direct conversion methods are described below:

- Magnetohydrodynamics generation (MHD) [3]
- Photovoltaic generation system (solar cells) [4]
- Electrochemical energy conversion (Fuel cells) [5]
- Thermoelectric power generation[6]

The reason for using new and direct energy conversion methods is to overcome the flaws in the conventional energy generating systems. The possibility of using new sources of energy seems enhanced by the development of new direct energy converters. There are many methods of converting direct thermal energy to electrical energy. In the following section one of the main direct energy converting technology (Magnetohydrodynamics) is discussed in detail.

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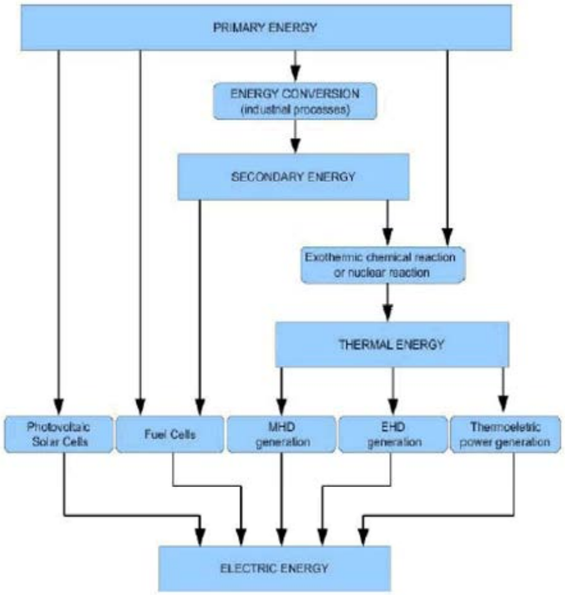


Fig. 1: Direct energy conversion stages [1].

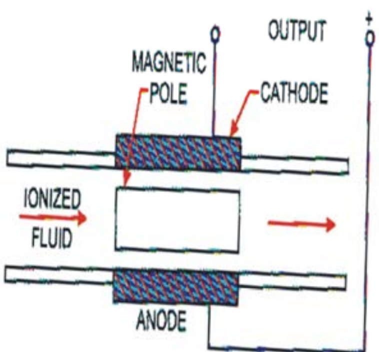


Fig. 2: Basic Principle.

**Historical Overview:** In 1893, Michael Faraday was the first person who gives the idea of energy conversion in MHD. Almost for the half of century no work was done on this concept. Later on in 1938, Westing house research laboratory (USA) took the first step in utilizing the concept for developing a MHD generator. "Process for the Conversion of Energy" was the initial patent on MHD given by B. Karlovitz, in 1940. Further research in 1960s was done by R. Rosa which established the practicality of MHD with fossil-fuel systems. The International Conference on MHD Power was held in Newcastle upon Tyne, UK by Dr. Brian C in 1962. After words in early 1970's the MHD-steam power plant U-25 having a capacity of 75MW of which 25 MW is generated through MHD was implemented. [7]. In 1975, the pilot plant was installed in Tiruchirapalli by BARC. The Japanese program in the late 1980s concentrated on closed-cycle MHD. The belief was that it would have higher efficiencies and smaller equipment, especially in the clean, small, economical plant capacities near 100 megawatts (electrical) which are suited to Japanese conditions. Open-cycle coal-powered plants are generally thought to become economical above 200 megawatts. In 1986 morse developed a constant velocity DC faraday generator in which nitrogen, sodium and NaK are used as working fluid and Italians took interests in the development of this technology.

**Working Principle of Mhd Generators:** When an electric conductor moves across a magnetic field, a voltage is induced in it which produces an electric current. This is the principle of the conventional generator where the conductors consist of copper strips. In MHD generator, the solid conductors are replaced by a gaseous conductor (an ionized gas). If such a gas is passed at a high velocity through a powerful magnetic field, a current is generated and can be extracted by placing electrodes in suitable position in the stream. The principle can be explained as follows:

"An electric conductor moving through a magnetic field experiences a retarding force as well as an induced electric field and current."

This effect is a result of Faradays Law of Electro Magnetic Induction.

- The induced EMF is given by

$$Eind = u \times B \qquad [1]$$

where

u = Velocity of the conductor.
B = Magnetic field intensity.

- The induced current is given by

$$Iind = C \times Eind \qquad [2]$$

where

C = Electric conductivity

- The retarding force on the conductor is the Lorentz force given by

$$Find = Iind \times B \qquad [3]$$

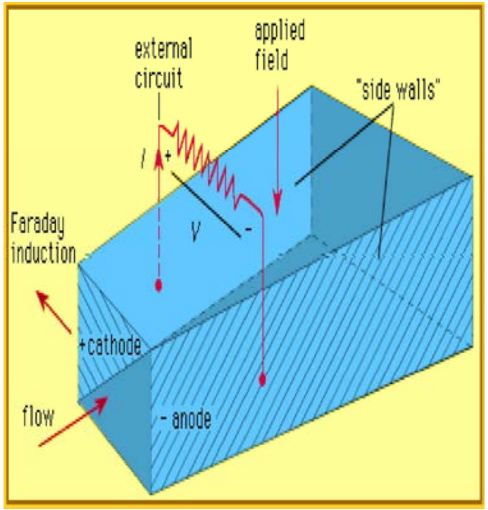


Fig. 3: Faraday generator

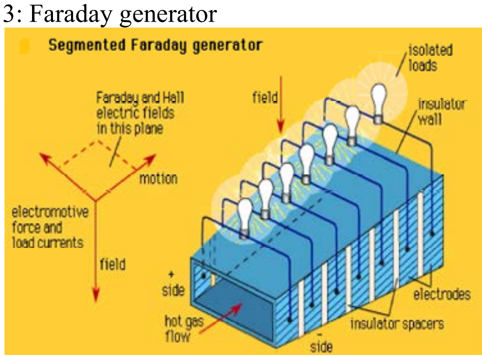


Fig. 3: Segmented Faraday Generator.

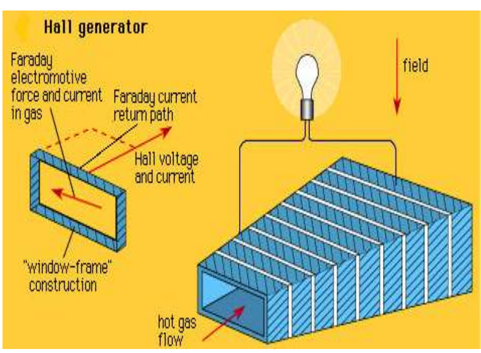


Fig. 4: Hall generator.

The electromagnetic induction principle is not limited to solid conductors. The movement of a conducting fluid through a magnetic field can also generate electrical energy. When a fluid is used for the energy conversion technique, it is called MAGNETO HYDRO DYNAMIC (MHD), energy conversion.

The flow direction is right angles to the magnetic fields direction. An electromotive force (or electric voltage) is induced in the direction at right angles to both flow and field directions. The conducting flow fluid is forced between the plates with a kinetic energy and pressure differential sufficient to overcome the magnetic induction force Find. The end view drawing illustrates the construction of the flow channel. 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.

**Types of Mhd Generators:** A system with MHD generator has high potential of an ultimate efficiency i.e. 60 to 65% which is much improved than the efficiency of conventional thermal power station i.e. 30 to 35%. Output power of MHD generator for each cubic meter channel volume is directly proportional to square of gas velocity and gas conductivity and square of the strength of the magnetic field through which the gas flows. Moreover, for its competitive good performance the electrical conductivity of the plasma (ionized gas) must be above the temperature range of 2000K. Usually a number of issues like generator efficiency, economics, toxic products etc are occurred during the working of MHD generator.

MHD generator is classified in three different designs which are mentioned below:

- Faraday generator.
- Hall generator.
- Disk generator.
    - Faraday generator:

This type of generator consists of a non-conductive wedge-shaped pipe or tube. When ionized plasma (conductive fluid) flows through the tube in the presence of an intense magnetic field than current is induced, which can be extracted by placing electrodes on the sides of wedged shaped pipe or tube at 90-degree of magnetic field.

The main practical issue with faraday generator is differential voltages and currents in the fluid short through the electrodes on the sides of the tube.

**Hall Generator:** A number of generator configurations have been devised to accommodate the Hall Effect. In a Faraday generator, the electrode walls are segmented and insulated from each other to support the axial electric field and the electric power is taken out in a series of loads. In the alternate configuration known as a Hall generator, the Faraday field across each sector of the channel is short-circuited and the sectors are connected in series. This allows the connection of a single electric load between the ends of the channel. Consideration of the electric potentials at different points in the channel

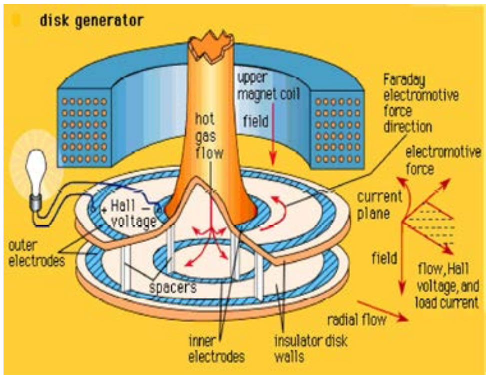


Fig. 5: A Disk generator.

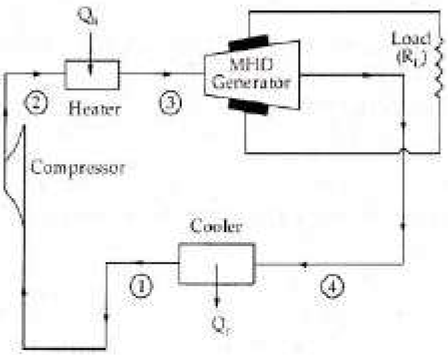


Fig. 6: Power cycle for MHD generator

leads to the observation that an equipotential runs diagonally across the insulator walls and that electrodes may be appropriately staggered to match the equipotential. The series connection of these electrodes in this diagonal generator permits a single electric load to be used.

In the Hall generator losses are less than the Faradays generator and due to less shorting of induced current, obtained voltages are high. However, this design has some issue due to speed plasma (ionized gas) or fluid require the middle electrode to catch the Faradays current. Which make generator efficiency very sensitive to its load.

**Disk Generator:** The disc generator is the most efficient design. This design currently grasps the efficiency and energy concentration records for MHD generation. A disc generator has plasma (ionized gas) or fluid flowing between the center of a disc and a duct wrapped around the edge. The magnetic excitation field is made by a pair of circular Helmholtz coils above and under the disk. The Faraday currents flow in a perfect dead short around the edge of the disk. The Hall effect currents flow between ring electrodes near the center and ring electrodes near the edge.

Another major benefit of this design is that the magnet is more efficient. Firstly, it has simple parallel field lines. Secondly, the fluid is processed in a disk, the magnet can be closer to the fluid and magnetic field strengths increase as the 7th power of distance. Finally, the generator is compact for its power, so the size of magnet is reduced. As a result magnet uses a much smaller percentage of the generated power.

**Power Cycle Phenomenon for Mhd Generator:** The power cycle of MHD generator is basically a thermal power cycle. Schematic diagram illustrate MHD-gas turbine combined cycle together with the energy balance. MHD generator replaced the gas turbine which is used in the conventional cycle a compressor is used to elevate the pressure and then heat is added to increase temperature of gas for ionization than ionized gas is accelerated by passing through the nozzle before entering MHD generator after passing through MHD generator the ionized gases decelerated and electrical energy is obtained. Thermal efficiency of MHD is given by:

$$\eta = \frac{Workoutput}{Heatinput} = \frac{(h_3 - h_4) - (h_2 - h_1)}{(h_3 - h_2)}$$

where; indicated enthalpies are stagnation values of kinetic energy of flowing gas. The stagnation enthalpy of the flowing gas is as follows:

$$h_o = h + \frac{u^2}{2}$$

Here; u is the flowing gas velocity.

In MHD generator, the velocity of the ionized gas is sufficiently high so that the kinetic energy of the flowing gas depicts the substantial portion of the total energy.

**Simplified Analysis of MHD Generator:** Following assumptions are made in the analysis of MHD generator:

- Flowing fluid or gas should be highly ionized.
- Velocity and pressure of fluid or flowing ionized gas must be kept constant.
- Magnetic flux also remains the same throughout.
- Maximum heat is utilized instead of transfer to the surroundings.
- Fluid or gas flow remains uniform.

**Working Systems of Mhd Generator with Other Thermal Power Generating Plants:** Following are the two distinct approaches to retrofitting a thermal power plant with MHD as topping cycle.

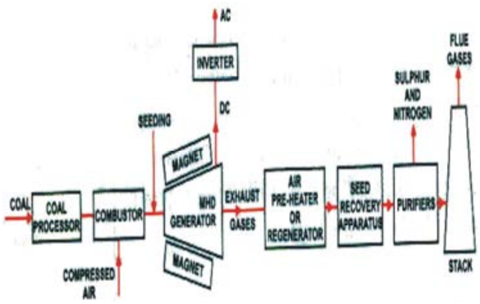


Fig. 7: An open cycle Coal fired MHD system

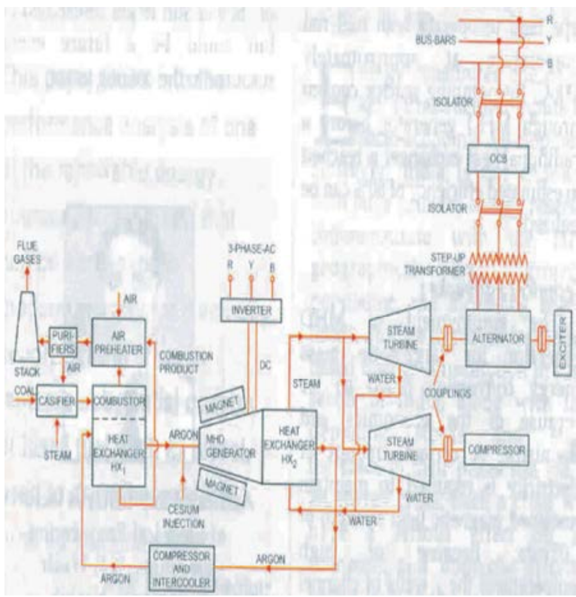

Fig. 8: A closed cycle MHD system

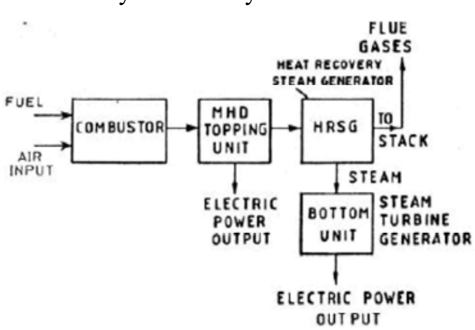


Fig. 9: A coal fired, MHD topping unit with steam turbine bottom unit.

- Open cycle system
- Closed cycle system

Closed cycle system is further classified into two types:

- Liquid metal system
- Seeded inert gas system

**Open Cycle System:** In open cycle system heat exhausted by toping MHD plant is used in steam plants such plants are likely used as base load power plants. In this type of system potassium (K) is used as a working fluid. High magnetic flux density 4-6 Tesla and superconducting magnet are involved. Temperature ranges in between 2300 to 2700°C. Residual gases are exhausted into the atmosphere [14].

**Closed Cycle System:** In this type of system high magnetic flux density 4-6 Tesla and superconducting magnet are involved. Temperature of closed cycle system is quite lesser than that of open cycle system i.e. 1400°C.[15] Residual gases are recycled again in the plant by doing this efficiency of the plant increases.

**Integration of MHD with Conventional Thermal Systems:** The serious challenge of present time is to cope with the severe energy crises as well as fuel consumption. As we already know that the existing energy generating plants are failed to meet the rising demand of energy so repowering old power station with modern MHD plant could be satisfactory in technical sense. By integrating MHD power generating plant with conventional thermal power plants successfully meet the energy crises and also save the fuel consumption. The major aim of doing this is to increase the power capacity, efficiency and reduction of pollution.

The exhaust of MHD generator is almost as hot as the flame of conventional steam boiler by using the exhaust gases of MHD generator into a boiler to make the steam, both MHD and steam Rankine cycle can convert thermal energy of fossil fuels into electricity with an improving efficiency of typical coal fired thermal power plant from 35% to 60% or more. If triple cycle, including a MHD generator, a gas turbine and a steam turbine is utilized than efficiency greater than 65 to 70% could be achieved.

**Alliance of MHD Power with Gas-steam Plant:** The efficiency of any existing conventional thermal power plant can be improved by repowering MHD could be a very good option with steam plant as bottoming unit. After wide range of extensive research and studies carried out a number of combined cycle gas stream will offer 40 to 55% but on the other hand combined cycle MHD-steam plant could be able to achieve efficiency of 60% or more. If comparison is made between conventional combined cycle gas-steam plants and combined cycle MHD steam plants with coal gasification than MHD-steam plant would be a topping plant with steam bottoming.

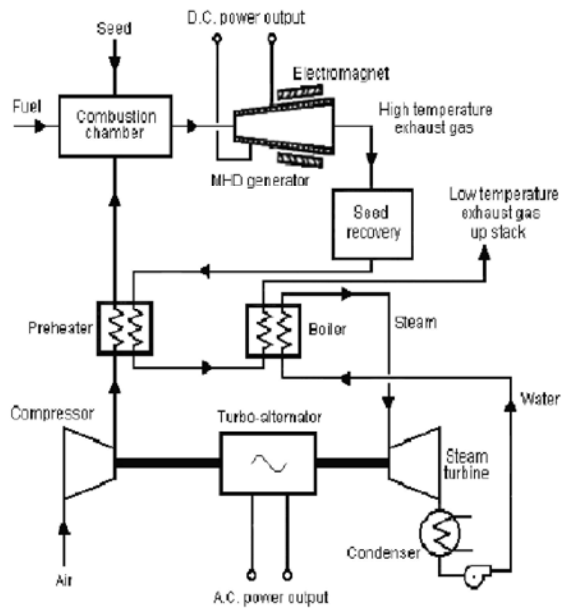


Fig. 10: A typical closed cycle scheme for nuclear source.

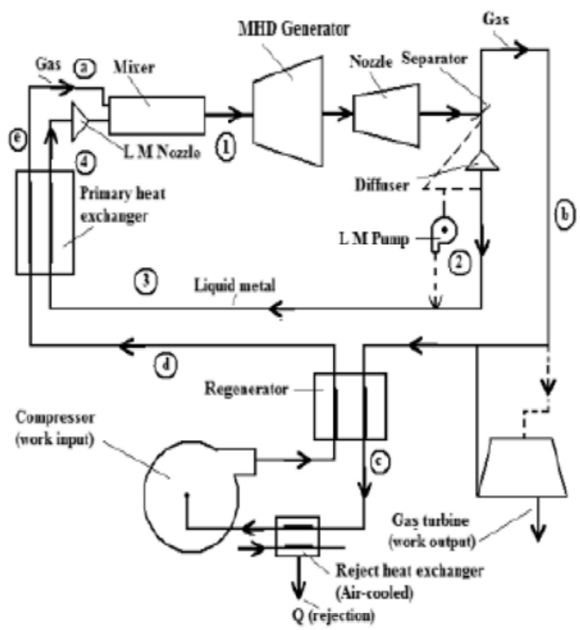


Fig. 11: Schematic two-phase cycle LMMHDEC system

**Alliance of MHD with Nuclear Power Plant:** Magnetohydrodynamics (MHD) is integrated with nuclear reactor either nuclear fission or fusion. Operating temperature of this type of reactors is about 2000°C. By pumping coolant of reactor into MHD generator before heat exchanger an estimated efficiency of 60% can be released. Power generation system with nuclear fission reactor must be increased in order to reduce CO2 emission.

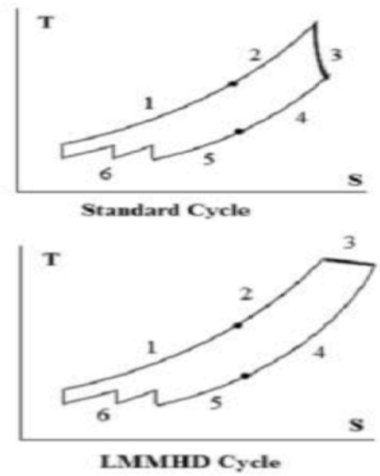


Fig. 12: Comparison of Standard Brayton cycle with with MHD Brayton cycle

**Possible Developments in Magnetohydrodynamics (MHD):** Since the invention of MHD power generating technology a lot of research and development is in progress. This paper also highlights the possible development in energy conversion using liquid metal instead of gases in MHD generators. In liquid metal Magnetohydrodynamics energy conversion (LMMHDEC) thermodynamic fluid i.e. gas or vapor is mixed with electro dynamic fluid i.e. liquid metal (Li) because heat capacity of liquid is greater than gases and as a result high thermal energy conversion reached approximately near to the ideal Carnot cycle [18].

Liquid metal Magnetohydrodynamics energy conversion (LMMHDEC) was proposed by Elliott is based upon high temperature Rankine cycle. In LMMHDEC lithium (Li) is used as MHD fluid and cesium (Cs) is used as a vaporizable fluid. This vaporizable fluid ionizes and accelerates the MHD liquid through a strong magnetic field at higher velocity. When MHD liquid passes through intensive magnetic field with high velocity its kinetic energy is directly converted into electrical energy. The MHD fluid and vaporizable fluid are separated before passing through MHD generator with the help of separator and remaining liquid fluid is allowed to pass through MHD generator to generate electricity. After leaving MHD generator the liquid metal returns back to the mixer nozzle. Passing through a diffuser and heat source device the vaporizable fluid which separates from liquid metal at separator flows through regenerative heat exchanger and condenser unit then returns back to mixer nozzle through pump and this mixer is ready to flow in a loop. A double cycle MHD system is displayed below which shows the liquid loop and vapor loop.

In LMMHDEC heat capacity of liquid phase is greater than gas phase and MHD fluid together expands and contracts almost isothermally. The result of higher thermal conversion efficiency is reached near the ideal Carnot cycle. The comparison is clearly judged from the figures below.

**Benefit of Using Liquid Metal Magnetohydrodynamic Energy Conversion (LMMHDEC):** Use liquid metal for MHD conversion enable low temperature application in compression to ionize gas MHD generator. The heat capacity of the liquid MHD generator is greater than gas MHD generator. As a result high conversion efficiency is obtained. MHD generator does not have any mechanical moving part therefore; reduction in the energy losses is quite visible. Efficiency, performance and heat rate of conventional power plants can be enhanced by operating in conjunction with the MHD generator. This is elegantly simple technology than the conventional ones and easing of legal environmental condition. To overcome the world energy crises MHD would be a good approach. MHD generators have low running cost and minimizing the need of new plants even.

## CONCLUSION

All the conventional thermal and hydro power plants are associated with immense losses due to thermo mechanical and hydro mechanical operating systems. This causes various efficiency losses i.e. mechanical breakage, thermal leakage, frictional losses. The MHD power generation is in advanced stage today and closer to commercial utilization. Significant progress has been made in development of all critical components and sub system technologies. Coal burning MHD combined steam power plant promises significant economic and environmental advantages compared to other coal burning power generation technologies. It will not be long before the technological problem of MHD systems will be overcome and MHD system would transform itself from non- conventional to conventional energy sources. The conventional conversion systems have significant losses (thermodynamics conversion) and these traditional systems are also failed to fulfill the needs of energy of the modern world. So, the performance from the point of efficiency and reliability is limited which can be improved by the combined operation with MHD generators. MHD generator has no moving part which allows working at higher temperature i.e. around 3000°C without any mechanical losses. In near future, MHD power generation system can improve the efficiency of other conventional systems

## REFERENCES


1. Ajith Krishnan, R. and B.S. Jinshah, 2013. Magnetohydrodynamic Power Generation.
2. Ali ketani, M., 1970. Direct energy conversion/[by] M ali ketani.reading, Mass : Addison-weslay pub. Co.
3. Kirillov, I.R., C.B. Reed, L. Barleon and K. Miyazaki, 1995. Present understanding of MHD and heat transfer phenomena for liquid metal blankets fusion eng.des, pp: 27.
4. Allen L. Fahrenbruch, 1927. Bube, Richard H. Fundamental of solar cell: photovoltaic solar energy conversion/ Allan-L. Fafrenbruch, Richard H. Bube. Newyork: Academic press 1983.
5. V.S (Vladimir sergeevich) bagot Skii fuel cell: Problem and solution, Vladimir S. Bagotsky.hoboken, N.J john Wilson 2009.
6. Irving Bernard cadoff and Edward millar, 1960. Thermo electric materials and devices and lectures presented during the course on thermo electric material and devices supponsered by department of metallurgical engg. And co-operation with office of special services to business industry new york university, N.Y june 1959 and 1960 edited by cadoff and E. Miller. N.Y: Reinhold pub. Corp.
7. Vishal, D., Dhareppagol and Anand Saurav, 2013. The Future Power Generation With MHD generators Magneto Hydro Dynamic Generation.
8. HARADA, 2008. Magnetohydrodynamics for advanced powergeneration system" Nobuhiro Nagaoka University of Technology, The International Conference on Electrical Engineering.
9. Kazuhito Watanabe, Alessandro Liberati, Tomoyuki Murakami and Yoshihiro Okuno, 2009. Improvement in the performance of an MHD Electrical Power Generator with Contoured Chanel walls.
10. Ferdous, S.M., Enaiyat Ghani Ovy, Md. Rezaul Hasan, Walid Bin Khaled and Nayeemul Hasan, 2011. An Overview of Technical and Economical Feasibility of Retrofitted MHD power plants from the Perspective of Bangladesh.
11. Raj Kumar kapooria, 2009. Possible developments in energy conversion using liquid metal magnetohydrodynamics.
12. R.A (Ronald Alan) coombe and Ronald Alan coombe. Magneto hydrodynamic generation of electrical power / Ed by R.A. Coombe. Lond: Chapman and Hall, 1964.
13. Richard J. Rosa, 1987. Magneto hydrodynamic energy conversion / Richard J. Rosa. Washington: Hemisphere Pub. Corp, rev. print edition.

14. Naoyuki Kayukawa, 2004. Open-cycle magnetohydrodynamic electrical power generation: a review and futureperspectives. Progress in Energy and Combustion Science.
15. Harada, N., L.C. Kien and T. Tashiro, 2002. Closed Cycle MHD Generator using He/Xe working plasma, AIAA Paper, 2002-2014, Proc. of the 14th international coference on MHD power generation and high temperature technologies.
16. Tillack, M.S. and N.B. Morley, 1998. Magnetohydrodynamics, Standard Handbook for Electrical Engineers, 14th Edition- 1998.
17. R.A (Ronald Alan) coombe and Ronald Alan coombe. Magneto hydrodynamic generation of electrical power / Ed by R.A. Coombe. Lond: Chapman and Hall, 1964.
18. O.lielausis, liquid metal magneto hydro dynamics, atom. Energy rev. 1975 (527).