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Magneto hydro dynamic generators: A solution for future energy crisis

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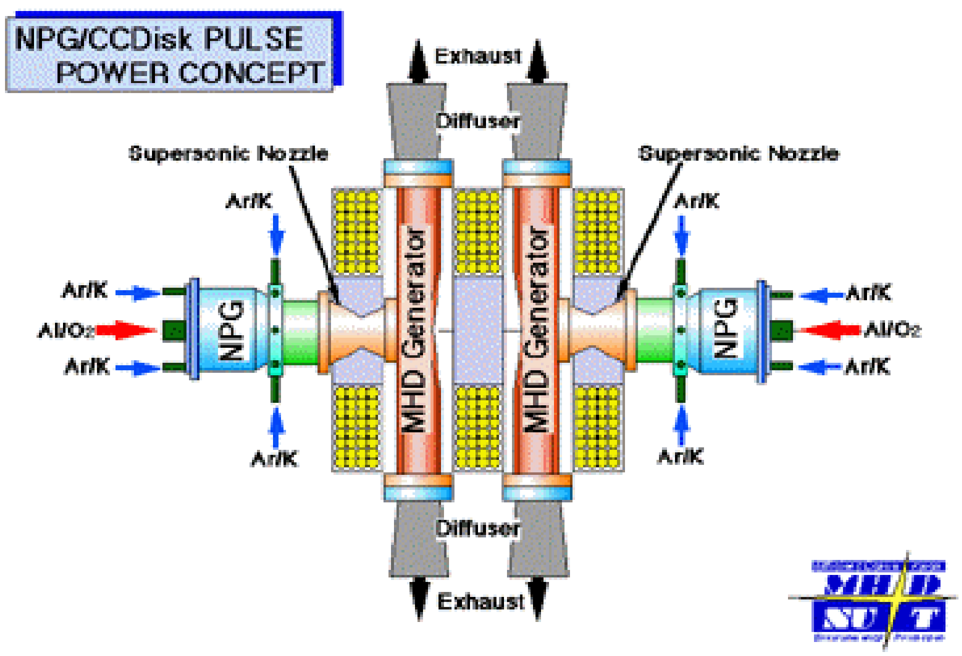
Abstract

Since a decade the demand for electricity is increasing at alarming rate and the demand for power is running ahead of supply. The present day methods of power generation are not much efficient & it may not be sufficient or suitable to keep pace with ever increasing demand. The recent severe energy crisis has forced the world to rethink & develop the Magneto Hydro Dynamic (MHD) type power generation which remained unthinkable for several years after its discovery. It is a unique & highly efficient method of power generation with nearly zero pollution. It is the generation of electric power directly from thermal energy utilizing the high temperature conducting plasma moving through an intense magnetic field. In advanced countries this technique is already in use but in developing countries it's still under construction. Efficiency matters the most for establishing a power plant. MHD power plants have an overall efficiency of 55-60% but it can be boosted up to 80% or more by using superconducting magnets in this process. Whereas the other non-conventional methods of power generation such as solar, wind, geo-thermal, tidal have a highest efficiency not more than 35%. Hence by using MHD power generation method separately or by combined operation with thermal or nuclear plants we hope to bring down the energy crisis at a high rate.

Keywords: MHD, Hall Generator, Disc Generato, Opoen cycle MHD, Closed Cycle MHD

1. Introduction

A Magneto Hydro Dynamic generator (MHD generator) is a magneto hydrodynamic device that transforms thermal energy and kinetic energy into electricity. MHD generators are different from traditional electric generators in that they operate at high temperatures without moving parts.



2. History

The first practical MHD power research was funded in 1938 in the U.S. by Westinghousein its Pittsburgh, Pennsylvania laboratories, headed by Hungarian BelaKarlovitz. The initial patent on MHD is by B. Karlovitz, U.S. Patent No. 2,210,918, "Process for the Conversion of Energy", August 13, 1940.World war II interrupted development.

In 1962, the First International Conference on MHD Power was held in Newcastle upon Tyne, UK by Dr. Brian C. Lindley of the International Research and Development Company Ltd. The group set up a steering committee to setup further conferences and disseminate ideas.

In 1964, the group set up a second conference in Paris, France, in consultation with the European Nuclear Energy Agency.

Since membership in the ENEA was limited, the group persuaded the International Atomic Energy Agency to sponsor a third conference, in Salzburg, Austria, July 1966.

Negotiations at this meeting converted the steering committee into a periodic reporting group, the ILG-MHD (international liaison group, MHD), under the ENEA, and later in 1967, also under the International Atomic Energy Agency. Further research in the 1960s by R. Rosa established the practicality of MHD for fossil-fueled systems.

In the 1960s, AVCO Everett Aeronautical Research began a series of experiments, ending with the Mk. V generator of 1965. This generated 35 MW, but used about 8MW to drive its magnet.

In 1966, the ILG-MHD had its first formal meeting in Paris, France. It began issuing a periodic status report in 1967. This pattern persisted, in this institutional form, up until 1976. Toward the end of the 1960s, interest in MHD declined because nuclear power was becoming more widely available.

In the late 1970s, as interest in nuclear power declined, interest in MHD increased. In1975, UNESCO became persuaded the MHD might be the most efficient way to utilize world coal reserves, and in 1976, sponsored the ILG-MHD.

In 1976, it became clear that no nuclear reactor in the next 25 years would use MHD, so the International Atomic Energy Agency and ENEA (both nuclear agencies) withdrew support from the ILG-MHD, leaving UNESCO as the primary sponsor of the ILG-MHD.

3. 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 a 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.

The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associate dc current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to Flemings right Hand Rule, Lorentz Law describing the effects of a charged particle moving in a constant magnetic field can be stated as

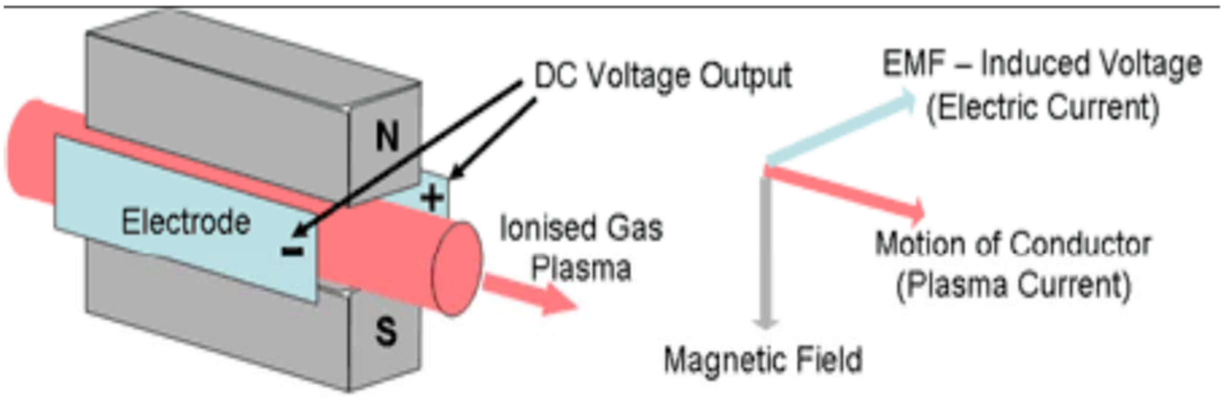
$F = QvB$ Where

Fis the force acting on the charged particle

Qis charge of particle

vis velocity of particle

Bis magnetic field



Magnetohydrodynamic Power Generation (Principle)

4. 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.

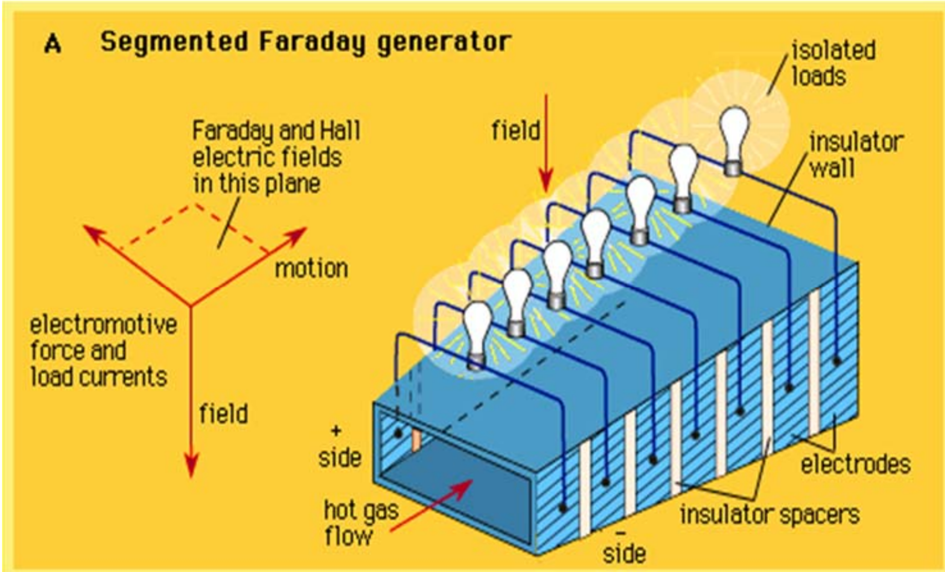
The expansion nozzle reduces the gas pressure and consequently increases the plasma speed (Bernoulli's Law) through the generator duct to increase the power output (See Power below). Unfortunately, at the same time, the pressure drop causes the plasma temperature to fall (Gay-Lussac's Law) which also increases the plasma resistance, so a compromise between Bernoulli and Gay-Lussac must be found.

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.

5. Power generation

Typically, for a large scale power station to approach the operational efficiency of computer models, steps must be taken to increase the electrical conductivity of the conductive substance. The heating of a gas to its plasma state or the addition of other easily ionizable substances like the salts of alkali metals can accomplish this increase. In practice, a number of issues must be considered in the implementation of an MHD generator: generator efficiency, economics, and toxic byproducts. These issues are affected by the choice of one of the three MHD generator designs: the Faraday generator, the Hall generator, and the disc generator.

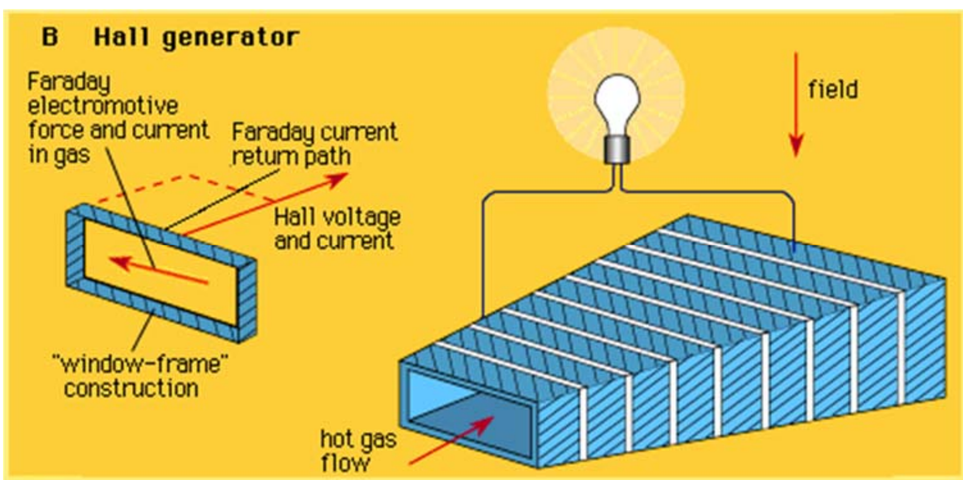
Faraday's Generator



The Faraday generator is named after the man who first looked for the effect in the Thames river (see history). A simple Faraday generator would consist of a wedge-shaped pipe or tube of some non-conductive material. When an electrically conductive fluid flows through the tube, in the presence of a significant perpendicular magnetic field, a charge is induced in the field, which can be drawn off as electrical power by placing the electrodes on the sides at 90 degree angles to the magnetic field. There are limitations on the density and type of field used. The amount of power that can be extracted is proportional to the cross sectional area of the tube and the speed of the conductive flow. The conductive substance is also cooled and slowed by this process. MHD generators typically reduce the temperature of the conductive substance from plasma temperatures to just over 1000 °C.

The main practical problem of a Faraday generator is that differential voltages and currents in the fluid short through the electrodes on the sides of the duct. The most powerful waste is from the Hall effect current. This makes the Faraday duct very inefficient. Most further refinements of MHD generators have tried to solve this problem. The optimal magnetic field on duct-shaped MHD generators is a sort of saddle shape. To get this field, a large generator requires an extremely powerful magnet. Many research groups have tried to adapt superconducting magnets to this purpose, with varying success.

Hall Generator



The most common solution is to use the Hall effect to create a current that flows with the fluid. The normal scheme is to place arrays of short, vertical electrodes on the sides of the duct. The first and last electrodes in the duct power the load. Each other electrode is shorted to an electrode on the opposite side of the duct. These shorts of the Faraday current induce a powerful magnetic field within the fluid, but in a chord of a circle at right angles to the Faraday current. This secondary, induced field makes current flow in a rainbow shape between the first and last electrodes. Losses are less than a Faraday generator, and voltages are higher because there is less shorting of the final induced current. However, this design has problems because the speed of the material flow requires the middle electrodes to be offset to "catch" the Faraday currents. As the load varies, the fluid flow speed varies, misaligning the Faraday current with its intended electrodes, and making the generator's efficiency very sensitive to its load.

Disc Generator

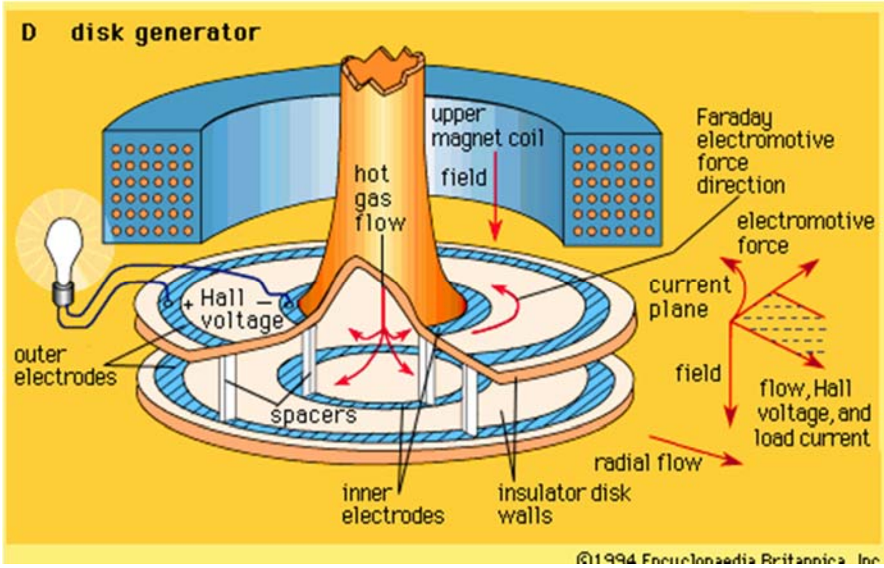


Diagram of a Disk MHD generator showing current flows

The third and, currently, the most efficient design is the Hall effect disc generator. This design currently holds the efficiency and energy density records for MHD generation. A disc generator has 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 below the disk. The Faraday currents flow in a perfect dead short around the periphery of the disk. The Hall effect currents flow between ring electrodes near the center and ring electrodes near the periphery. Another significant advantage of this design is that the magnet is more efficient. First, it has simple parallel field lines. Second, because 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.[citation needed] Finally, the generator is compact for its power, so the magnet is also smaller. The resulting magnet uses a much smaller percentage of the generated power.

Generator Efficiency

As of 1994, the 22% efficiency record for closed-cycle disc MHD generators was held by Tokyo Technical Institute. The peak enthalpy extraction in these experiments reached30.2%. Typical open-cycle Hall & duct coal MHD generators are lower, near 17%. These efficiencies make MHD unattractive, by itself, for utility power generation, since conventional Rankine cycle power plants easily reach 40%.However, the exhaust of an MHD generator burning fossil fuel is almost as hot as the flame of a conventional steam boiler. By routing its exhaust gases into a boiler to make steam, MHD and a steam Rankine cycle can convert fossil fuels into electricity with an estimated efficiency up to 60 percent, compared to the 40 percent of a typical coal plant. A magneto hydrodynamic generator might also be heated by a Nuclear reactor (either fission or fusion). Reactors of this type operate at temperatures as high as 2000 °C. By pumping the reactor coolant into a magneto hydrodynamic generator before a traditional heat exchanger an estimated efficiency of 60 percent can be realised. One possible conductive coolant is the molten salt reactor's molten salt, since molten salts are electrically conductive.

MHD generators have also been proposed for a number of special situations. In submarines, low speed MHD generators using liquid metals would be nearly silent, eliminating a source of tell-tale mechanism noise. In spacecraft and un attended locations, low-speed metallic MHD generators have been proposed as highly reliable generators, linked to solar, nuclear or isotopic heats

MHD Cycles and Working Fluids

The MHD cycles can be of two types, namely

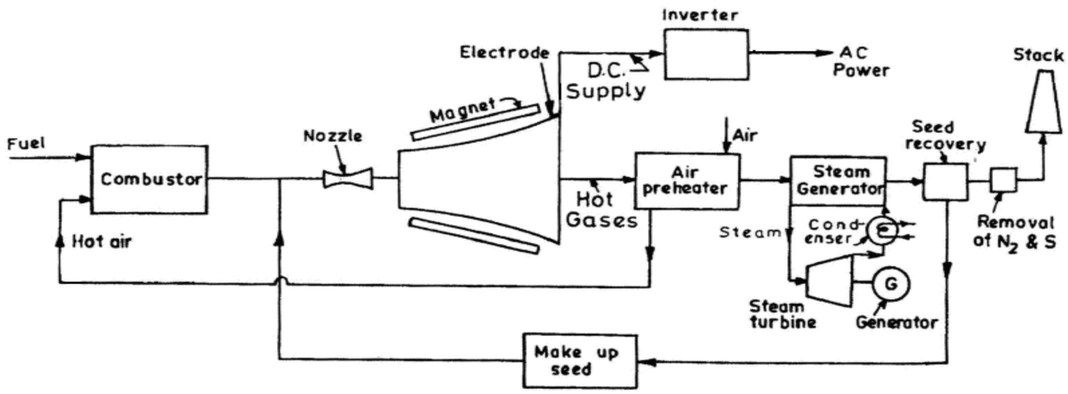
1) Open cycle MHD.

2) Closed Cycle MHD.

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

1) Open Cycle MHD System

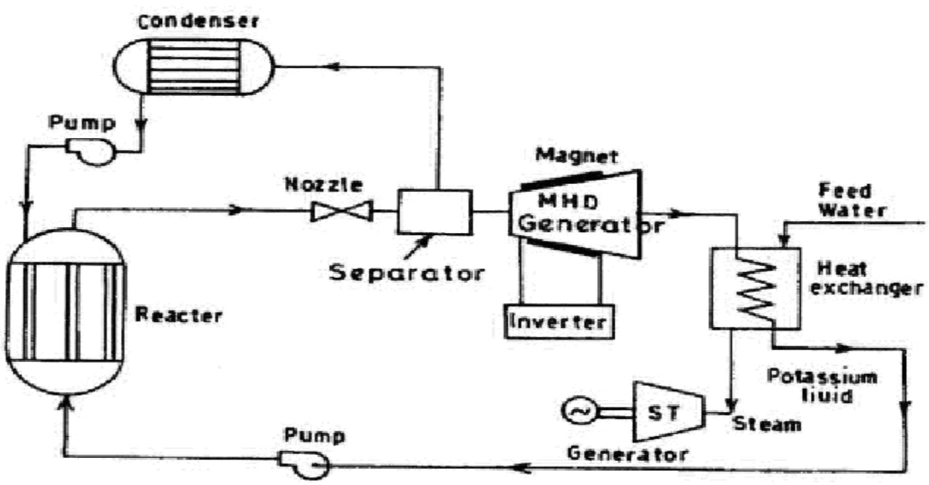
In open cycle MHD system, atmospheric air at very high temperature and pressure is passed through the strong magnetic field. Coal is first processed and burnet in the combustor at a high temperature of about2700°C and pressure about 12 atp with pre-heated air from the plasma. Then a seeding material 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



Hybrid MHD - Steam Part Open Cycle

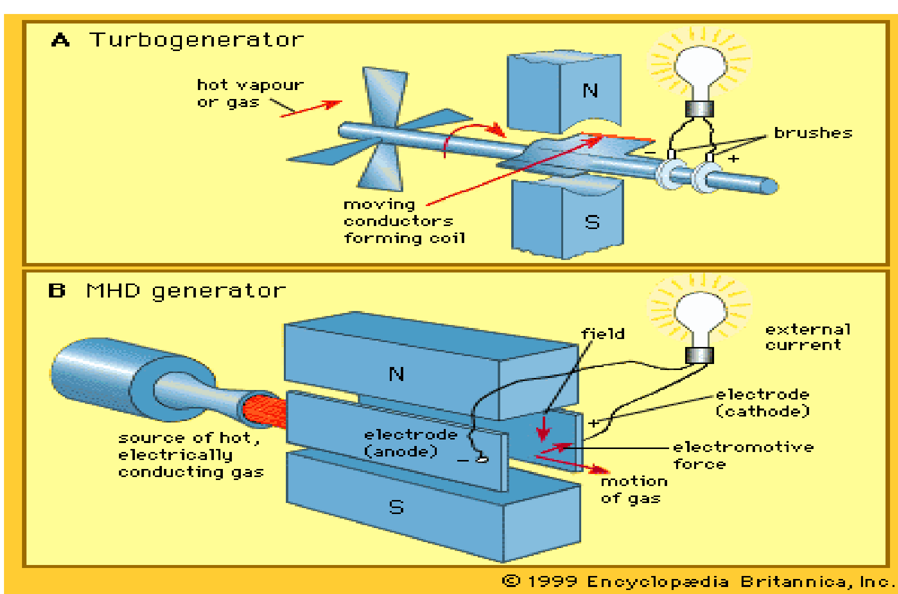
6. Closed Cycle MHD System

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.



Closed cycle MHD generator using liquid metal as working fluid coupled with steam genarator.

Comparison between Turbo Generator and MHD Generator



Economics

MHD generators have not been employed for large scale mass energy conversion because other techniques with comparable efficiency have a lower lifecycle investment cost. Advances in natural gas turbines achieved similar thermal efficiencies at lower costs, by having the turbine's exhaust drive a Rankine cycle steam plant. To get more electricity from coal, it is cheaper to simply add more low-temperature steam-generating capacity .A coal-fueled MHD generator is a type of Brayton power cycle, similar to the power cycle of a combustion turbine. However, unlike the combustion turbine, there are no moving mechanical parts; the electrically conducting plasma provides the moving electrical conductor. The side walls and electrodes merely withstand the pressure within, while the anode and cathode conductors collect the electricity that is generated. All Brayton cycles are heat engines. Ideal Brayton cycles also have an ideal efficiency equal to ideal Carnot cycle efficiency. Thus, the potential for high energy efficiency from an MHD generator. AllBrayton cycles have higher potential for efficiency the higher the firing temperature. While a combustion turbine is limited in maximum temperature by the strength of its air/water or steam-cooled rotating airfoils; there are no rotating parts in an open-cycle MHD generator. This upper bound in temperature limits the energy efficiency in combustion turbines. The upper bound on Brayton cycle temperature for an MHD generator is not limited, so inherently an MHD generator has a higher potential capability for energy efficiency. The temperatures at which linear coal-fueled MHD generators can operate are limited by factors that include: (a) the combustion fuel, oxidizer, and oxidizer preheat temperature which limit the maximum temperature of the cycle; (b) the ability to protect the side walls and electrodes from melting; (c) the ability to protect the electrodes from electrochemical attack from the hot slag coating the walls combined with the high current or arcs that impinge on the electrodes as they carry off the direct current from the plasma; and (d) by the capability of the electrical insulators between each electrode. Coal-fired MHD plants with oxygen/air and high oxidant preheats would probably provide potassium seeded plasmas of about 4200 deg. F, 10 atmospheres pressure, and begin expansion at Mach1.2. These plants would recover MHD exhaust heat for oxidant preheat, and for combined cycle steam generation. With aggressive assumptions, one DOE-funded feasibility study of where the technology could go, 1000 MWe Advanced Coal Fired MHD/Steam Binary Cycle Power Plant Conceptual Design, published in June 1989, showed that a large coal fired MHD combined cycle plant could attain a HHV energy efficiency approaching 60percent—well in excess of other coal-fueled technologies, so the potential for low operating costs exists.

However, no testing at those aggressive conditions or size has yet occurred, and there are no large MHD generators now under test. There is simply an inadequate reliability track record to provide confidence in a commercial coal-fueled MHD design.

U25B MHD testing in Russia using natural gas as fuel used a superconducting magnet, and had an output of 1.4 megawatts. A coal-fired MHD generator series of tests funded by the U.S. Department of Energy (DOE) in 1992 produced MHD power from a larger superconducting magnet at the Component Development and Integration Facility (CDIF) in Butte, Montana. None of these tests were conducted for long-enough durations to verify the commercial durability of the technology. Neither of the test facilities were in large-enough scale for a commercial unit. Superconducting magnets are used in the larger MHD generators to eliminate one of the large parasitic losses: the power needed to energize the electromagnet. Superconducting magnets, once charged, consume no power, and can develop intense magnetic fields 4teslas and higher. The only parasitic load for the magnets are to maintain refrigeration, and to make up the small losses for the non-supercritical connections. Because of the high temperatures, the non-conducting walls of the channel must be constructed from an exceedingly heat-resistant substance such as yttrium oxide or zirconium dioxide to retard oxidation. Similarly, the electrodes must be both conductive and heat-resistant at high temperatures. The AVCO coal-fueled MHD generator at the CDIF was tested with water-cooled copper electrodes capped with platinum, tungsten, stainless steel, and electrically conducting ceramics.

Toxic Byproducts

MHD reduces overall production of hazardous fossil fuel wastes because it increases plant efficiency. In MHD coal plants, the patented commercial "Econoseed" process developed by the U.S. (see below) recycles potassium ionization seed from the fly ash captured by the stack-gas scrubber. However, this equipment is an additional expense. If molten metal is the armature fluid of an MHD generator, care must be taken with the coolant of the electromagnetic and channel. The alkali metals commonly used as MHD fluids react violently with water. Also, the chemical byproducts of heated, electrified alkali metals and channel ceramics may be poisonous and environmentally persistent.

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 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.

Disadvantages of MHD Generation

The disadvantage of MHD generation is as given below:

1) Suffers from reverse flow (short circuits) of electrons through the conducting fluids around the ends of the magnetic field.

2) Needs very large magnets and this is a major expense.

3) High friction and heat transfer losses.

4) High operating temperature.

5) Coal used as fuel poses problem of molten ash which may short circuit the electrodes. Hence, oil or natural gas are much better fuels for MHDs. Restriction on use of fuel makes the operation more expensive.

7. Conclusion

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 overcame and MHD system would transform itself from non- conventional to conventional energy sources.

Taken together, the motes would constitute a huge sensor network of smart dust, a network that would give engineers insight into how energy is used and how it can be conserved. In a dust-enabled building, computers would turn off lights and climate control in empty rooms. During peak energy usage times, air conditioners that cool servers -- which drain a lot of the tech world's power -- would be automatically shut off, and then turned on again if the servers get too hot. Thus it can very lead to world’s energy conservation solutions.

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