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MHD—plasma technology for electric power

Marsha Freeman reviews the technology that will replace steam turbines.

On Aug. 23 of this year, the largest coal-fueled magnetohydrodynamics (MHD) generator in the world produced its first electric power at the Component Development and Integration Facility (CDIF) in Butte, Montana. MHD technology is ready for industrial application, and a consortium of companies and utilities has proposed building the first commercial coal-fired MHD generator at a power plant in Billings, Montana.

MHD, which is a plasma technology, will replace the 100-year-old steam turbine electric generating technology of Thomas Edison's era. A plasma is a gas made up of positive ions and negatively charged electrons, and will conduct an electrical current and interact with magnetic fields. For MHD direct conversion, the plasma can be made of a coal gas that is burned at a high temperature, or even the hydrogen plasma fuel that is used to produce fusion energy.

Plasmas at very high temperatures, in the hundreds of thousands up to millions of degrees, are the raw material for thermonuclear fusion, in the stars, and in the laboratory. In MHD, the plasma is only a few thousand degrees. This relatively low-temperature plasma energy—which can be used to produce electricity, refine metals, and create new isotopes and new materials—will be the bridge to the 21st-century technologies that fusion will make available.

The deficit of electric generating capacity worldwide is overwhelming, and makes the introduction of MHD conversion technology immediately necessary. In the United States alone, over 600 power plants of 1,000 MW capacity each would have to be added to the electric power grid over the next decade if the rate of real economic growth of the 1960s were to be obtained for the next 10 years.

Along with the beginning of the mass production of nuclear power plants, described in previous articles, it is crucial to also increase the productivity and efficiency of the power plants already on-line and the ones that will become operational in the near future. Today the typical coal, oil, natural gas, or nuclear power plant has an efficiency of conversion from heat to electricity of less than 35%.

One advantage of magnetohydrodynamics, is the possibility of increasing that efficiency of conversion to 60-70%. That would mean that every unit of fuel burned in a plant would produce twice as much electrical power as before. The capacity of already-existing plants could be nearly doubled by adding MHD systems to them, and new plants would start out with this greater efficiency, meaning that a smaller number of new plants would have to be built to meet this need for large-scale power increases.

MHD direct conversion

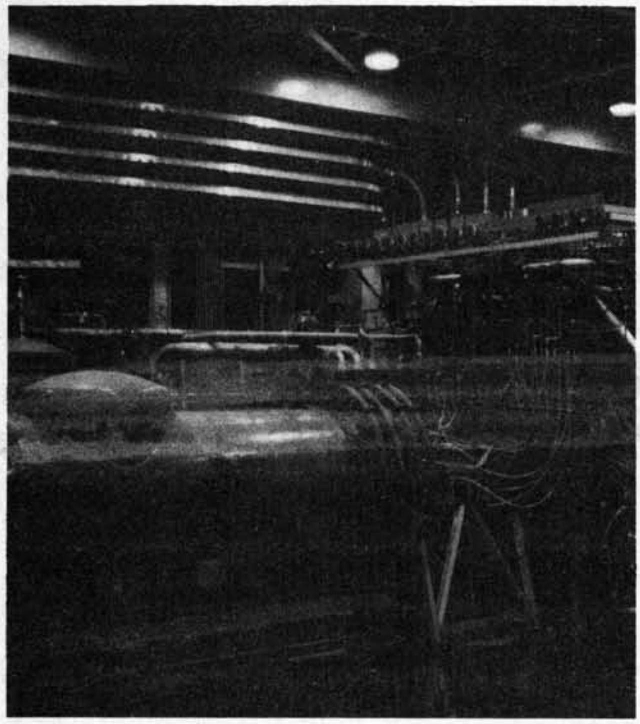
Electricity is generated by moving an electrically conductive material across magnetic field lines. In today's power plants, this is accomplished by rotating huge turbines, driven by steam, alternately past the north and south poles of a magnet. Moving these multi-ton turbines with steam results in a loss of two-thirds of the heat energy from burning the fuel.

In MHD conversion, the only moving part is an electrically conducting plasma, or other fluid. This working fluid is pushed through a channel at supersonic speed, about 3,000 feet per second. The channel is surrounded by a powerful superconducting magnet, and the postively charged ions are separated from the negative electrons in the fluid. An electrical potential is created across the channel, and when a load is placed on the electrodes on each side of the channel, electrical current flows.

Most of the experimental work on MHD conversion in the United States has involved the use of coal as the fuel, and as the working plasma fluid. Soviet research has concentrated on natural gas systems, and the Japanese have been interested in MHD for oil-burning plants. MHD systems have been designed for use with conventional nuclear power plants, and with the advent of thermonuclear fusion energy, the plasma which is the fusion fuel, would be directly used as the working fluid in the conversion to electricity.

Figure 1 shows a general design for a coal-fired MHD power plant. In the fossil fuel MHD systems, the coal, oil, or gas is combusted at a higher-than-usual temperature, in the range of 4,500° F. At this temperature, more of the gas produced through combustion will be ionized, or stripped of its electrons, than at lower temperatures. In the coal systems, potassium is added as a seeding material to increase the rate of ionization of the coal gas.

This ionized coal gas is then accelerated through a nozzle, and is propelled through the MHD channel. Each side of the channel, in one design, is dotted with insulated electrodes, which gather the electrical charge.



CDIF Photo

A coal-fueled magnetohydrodynamic (MHD) power system

Around the channel of a commercial MHD generator will be a superconducting magnet, producing a 5-7 Tesla magnetic field, depending upon the size of the system. One Tesla is 10,000 Gauss, and the Earth's magnetic field is about one-half a Gauss.

The magnetic field required for the MHD channel is obtainable by an iron-core, water-cooled magnet, but the amount of electrical power the magnet would need would seriously cut into the net power produced by the generator. Superconducting magnets, which are kept at near absolute zero temperature and are cooled by liquid helium, run with almost no loss of power.

For example, a 6 Tesla superconducting magnet will consume about .3 MW of electric power to produce its field. The iron-core magnet used at the CDIF in Montana, has a maximum field strength of 2.92 Tesla, but will consume 5.3 MW of power. The CDIF will use a superconducting magnet in the future.

When the ionized coal gas, or plasma, has passed through the MHD channel, producing electric power, the temperature of the gas has dropped by about 2,000°. The remaining heat can then be transferred to a conventional steam turbine system. In this configuration, the MHD generator is referred to as the "topping cycle" of the power plant, and the turbine as the "bottoming cycle."

Making coal clean

In this coal-burning design, the remaining coal gas from the steam turbines would be vented to the environment, as it is in a regular coal-burning plant, but in this case, the effluent would be very clean. MHD plants will not require the stack gas scrubbers and other pollution-control equipment that reduces the reliability, availability, and efficiency of today's coal-burning power plants.

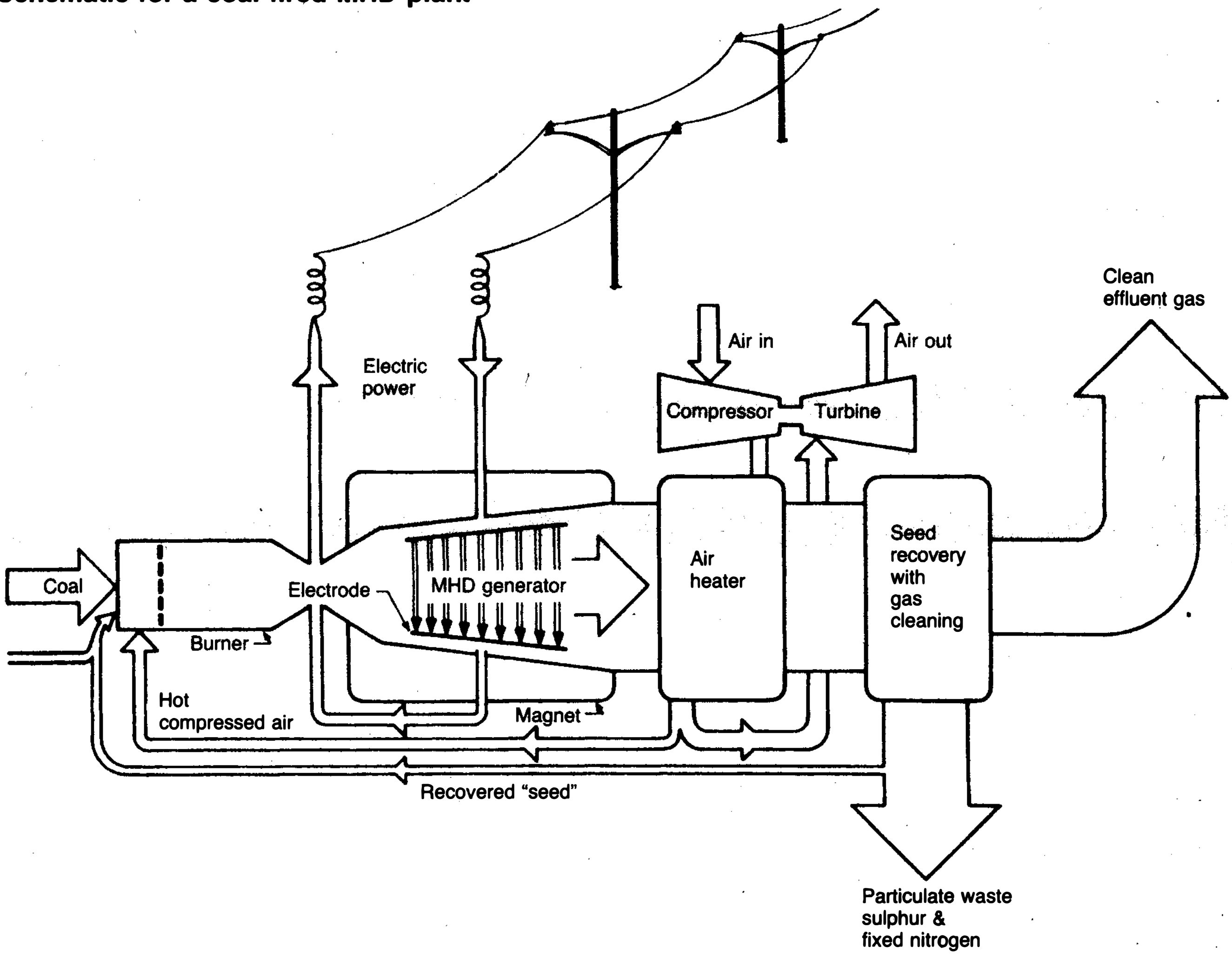
The sulfur present in much U.S. coal is removed as part of the MHD process, as it chemically combines with the potassium used as the seed material. The sulfur can then be separated from the potassium, and used as an industrial chemical, while the potassium seed is recycled. Recent experiments at the University of Tennessee Space Institute in Tulahoma have demonstrated that both sulfur and nitrogen emissions were lower than anticipated, and were only about one-half the level allowed by the Environmental Protection Agency (see figure 2).

The nitrogen oxides that are produced by the burning of coal can be quite precisely controlled in the MHD system. They can be reduced by decreasing the amount of air in the coal combustor, or even increased to be recovered, as fixed nitrogen (that is, combined with oxygen), which is a valuable raw material for fertilizer production.

Because the MHD system operates at increased efficiency, there is less "thermal pollution" or heat rejected to the environment. Siting can be more flexible, as cooling requirements are reduced by at least one-third.

FIGURE 1

Schematic for a coal-fired MHD plant



In this combined cycle plant, the coal is burned with hot compressed air, and the potassium seed material is added. The coal gas flows through the MHD generator, with electrodes on each side. Electric power is drawn from the electrodes onto the power grid. The exhaust gas from the MHD section continues to an air heater and is then fed to a conventional steam turbine for additional power generation, the seed is recovered to be reused, and the remaining effluent gas, which is clean, is vented to the atmosphere. Initially, about half of the power would be generated from the MHD section, and half from the turbine.

Various estimates have been made of the economic advantages of MHD systems over conventional steam turbines. The capital cost of the MHD equipment itself is difficult to determine precisely, because industries do not yet exist to produce its unique components—such as superconducting magnets, high-temperature coal combustors, specialty materials for electrodes and channels, etc. The MHD components that have been made thus far have been made on a one-of-a-kind basis. Nonetheless, it is clear that the capital investment for the system will be at least 10% more than a comparably-sized steam turbine system. The fuel cost, however, is potentially half, since the conversion efficiency is double. In addition, the reliability and availability of the MHD coal plant should be significantly greater than steam turbine plants, which have been burdened with pollution-control devices.

One estimate of comparative cost, is that the cost of delivered electric power could be 30% less with MHD, as the technology matures.

Coal-burning MHD generator development in the United States has advanced to the point that the only thing really left to do is to make a commitment and finally build a commercial

FIGURE 2
MHD's reduction of atmospheric pollution

	Present steam turbine	MHD	EPA standards
Sulpher dioxide	450	4.5	120
Nitrogen oxides	80	20.0	74
Particulate matter	105	10.0	20

Based on 1000 MW power plant burning coal containing 3% sulpher (units for pollutants in tons/day)

This comparison of the polluting emissions from steam turbines and MHD generators demonstrates one of the economic advantages of MHD. Recent tests done at the University of Tennessee Space Institute, substantiated that these ten-fold improvements in polluting emissions are obtainable. With MHD systems, there is no need for costly and counter-productive scrubber systems to reduce pollution in order to meet EPA standards.

demonstration project, and create the advanced technology industries that can manufacture these new power-conversion systems.

The first observation of electricity produced through magnetohydrodynamic effects was in 1832, by Michael Faraday. The slightly saline flowing water of the Thames River was the electrically conducting fluid, and the external magnetic field was that of the Earth. Faraday was able to measure a slight electric current with a galvanometer.

Experiments with various electrically conducting fluids continued throughout the latter half of the 19th century, and patents for MHD devices began to appear in the early part of this century. Without advanced materials and supplies of higher-temperature fluids, however, no appreciable amounts of electrical power were produced.

By the mid 1950s, Arthur Kantrowitz and a group of researchers at Cornell University were experimenting with shock tubes, and studying the electrical properties of ionized gases and their interaction with magnetic fields. When fusion research was brought into the public domain in the late 1950s, interest increased in plasma-based, direct-conversion MHD.

At the Avco Everett Research Laboratory, which Kantrowitz founded, experiments demonstrated the potential for this revolutionary new conversion process for both coal and nuclear power. Starting with clean fuels such as alcohol, the Mark V generator at AVCO demonstrated a peak power of 32 MW for one to two seconds, in 1965.

Since then, the remaining requirements for MHD to become viable for electric utilities are, first, high-temperature materials with a long lifetime for the channel lining, the electrodes inside the channel, and other hot parts. Second, commercially available superconducting magnets, and the materials and cryogenic industries that are necessary for the mass production of such magnet systems. Third, control of the dirty material in coal, which becomes the slag, and which can coat the electrodes, making them non-functional.

Throughout the 1960s coal research was performed by the Department of the Interior, which was not really interested in electric generating technologies. The Atomic Energy Commission, responsible for all nuclear research, did not give support to MHD, as many thought this increased efficiency would not be needed with nuclear systems.

The early 1970s saw a boost in U.S. MHD research, as the Soviets began to unveil their ambitious experimental program at the Institute for High Temperatures in Moscow, and in 1974 an agreement was signed for U.S.-Soviet cooperation in MHD.

But since the Carter administration, the MHD pioneers and industry have been battling, first, zero-growth, and, now, free-enterprise ideology, which have led to the failure to bring any new large-scale technology into commercial application, including advanced nuclear projects.

MHD for nuclear power

Though the focus for MHD development worldwide has been for use with fossil fuels, it is even more important that MHD topping cycles for nuclear reactors be brought to realization, since these power plants will be the foundation for new electric generating systems in developing nations that have little if any fossil fuel reserves, and will be the majority of new plants built by most industrialized nations.

Nuclear power plants today make electricity the same way coal-fired plants do—the heat is used to boil water for steam turbines. With nuclear power plants, the radioactive "combustion" materials would not be used as the MHD working fluid, directly. The fission energy could be used to heat a noble gas or a liquid metal, which would be sent through the MHD channel.

The high-temperature gas-cooled reactor uses a noble gas, helium, as the coolant. It would be possible to design an MHD generator where the hot helium would be seeded with a material such as cesium to ionize it. This ionized coolant could then be used directly as the working fluid for the generator. Noble gas MHD systems, which would be "closed cycle" in that the gas coming out of the generator would not be released to the environment but reused, have also been examined for fossil fuel systems, because the gas can be ionized at a temperature about 2,000° less than is necessary with a coal gas.

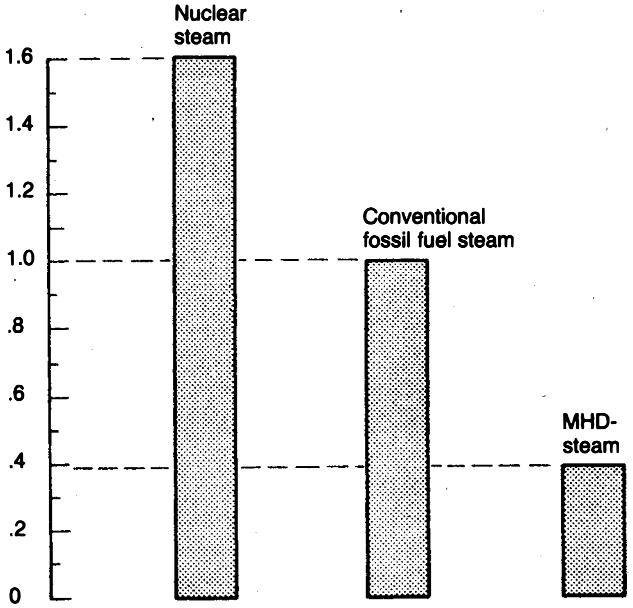
MHD systems for the liquid metal nuclear systems, such as breeder reactors, would make the important step of eliminating the liquid metal-to-water interface that now exists when steam turbines are used. The liquid metal coolant could transfer its heat to another liquid metal, which would be easily ionized. This would also be a closed cycle system.

Various designs, for gaseous core reactors, and other innovations, have been done over the past 20 years for nuclear-MHD systems. Experiments have been promising, and the

FIGURE 3

MHD's reduction of waste heat

Relative cooling water requirements



Cooling water requirements for power plants have generally dictated that they be sited on rivers, bays, lakes, or other large bodies of water. The two- to four-fold decrease in cooling water requirements for MHD systems means they could be sited more flexibly, where water would otherwise be a constraint in power plant construction.

lower operating temperatures remove some of the most difficult technical problems in coal-based MHD.

MHD will have important uses as portable power sources in remote areas, for military installations and other applications. In space, as larger power systems are required, especially for the Strategic Defense Initiative, MHD conversion with nuclear power sources will come back into examination.

Many new uses for this flexible and efficient power technology will be found in both the military and civilian spheres. New advances in MHD design can extend the application and attractiveness of this technology (see box).

The timetable

As with the development of the nuclear breeder reactor, and the high-temperature gas-cooled reactor, electric utilities in the United States were enthusiastic enough about MHD technology to contribute their own financial resources for its development. The industries that will build MHD generators and the companies that will use them have spent $80 million over the past two decades, along with funding from the federal government.

Since 1979, the proposal has been on the table to build a relatively small MHD generator, as a retrofit on an existing utility power plant, to demonstrate that the technology was ready and able to perform in a commercial utility setting. Over the past 10 years, the MHD program has suffered the same fate as many other advanced energy technologies.

During the Carter years, anything more complicated than turning down the thermostat was seen as a "technological fix" that could not hope to solve the "energy crisis." From the beginning of the Reagan administration, the idea that if a technology is promising it should be paid for by "free enterprise" has succeeded in killing the Clinch River Breeder Reactor, nuclear fuel reprocessing, and just might kill MHD.

Left with good experimental results and a handful of projects making steady progress in developing MHD technology, a group made up of the companies involved in MHD and utilities in the market for more efficient power plants has formed the MHD Development Corporation, to try to move the program forward. This group has submitted a proposal to the Department of Energy which is similar to the 1979 proposal, to retrofit an existing plant with an MHD topping cycle.

The Montana Power Company has volunteered the use of its Frank E. Bird plant in Billings. Though the 66 MW Bird plant used to burn oil and gas, it is not now operating, and could be modified to burn coal. It would have to be outfitted with a high-temperature coal combustor, the MHD channel, diffuser, magnet and other components, but could use the coal handling equipment from an adjacent operating coal-fired plant. The old Bird steam turbine could be used for the bottoming cycle.

Industry spokesmen estimate that within five years, an MHD topping cycle could be added, which would increase the plant's net capacity to 88 MW, or by 25%, not counting the electricity produced that would be used to power the magnet. This project would cost about $400 million, which the Development Corporation is proposing be split 50/50 with the Department of Energy.

Many aspects of MHD direct conversion push at today's technology frontiers. These include the commercial development of large superconducting magnets and attendant cryogenic technology; new materials for the channel lining, electrodes, and other equipment which must withstand a hot and corrosive coal-gas environment; and new power-conditioning approaches.

There is no other technology on the horizon which can supercede the century-old method of creating mankind's only universal form of energy—electricity. In terms of immediate need, MHD can potentially double the capacity of our already-existing power plants and the ones that will be built, and can do this with coal, nuclear and, eventually, fusion energy.

There is no reason not to proceed as quickly as possible to bring this promising technology to commercial realization.