MAGNETOHYDRODYNAMIC (MHD) POWER GENERATION: MORE ENERGY FROM LESS FUEL

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ISSUE DEFINITION

Magnetohydrodynamic (MHD) power generation is a method for converting heat directly into electrical energy without the use of a rotating electrical power generator. By eliminating the need for a rotating generator, an MHD plant may be able to produce as much as 50% more electricity per ton of coal consumed than is produced in conventional power plants or other advanced coal-based systems being developed. MHD systems also have the potential for decreasing the amount of sulfur dioxide released into the atmosphere when coal is burned and for decreasing the amount of cooling water needed to dissipate waste heat produced in power plant operation. Though MHD power generation systems are simple in principle, their successful development poses a number of major problems in materials sciences and in plasma physics. The Reagan Administration has requested no funds for MHD R&D in FY82, however, because it feels that further development of this process can best be handled by the private sector under the stimulus of the market.

At present, nearly all MHD research in the United States is funded through the Department of Energy. Proponents of MHD claim that, given sufficient funding, commercial power generation could begin in the early 1990s. The Department of Energy (DOE) has aimed at commercialization shortly after the year 2000. However, it has recently accelerated its development program, so that MHD commercialization might still occur in the 1990s if the current programs are continued.

MHD has been among the most active areas of joint U.S.-U.S.S.R. effort under the 1974 cooperation agreement in energy. This has proven useful for both participants. The Soviet Union is considerably ahead of the United States and will shortly begin construction of a commercial-scale MHD power plant.

BACKGROUND AND POLICY ANALYSIS

It may be possible to use MHD to convert heat from any intense source (including nuclear reactions and geothermal sources) into electricity. However, in the United States attention has focused on MHD systems which use coal combustion as the heat source.

Coal-Fired, Open-Cycle MHD Systems

The principles behind MHD power generation are simple and have been known since 1831. However, the engineering necessary to generate electricity cheaply by MHD is complex. In the first stage of a coal-fired open-cycle MHD power plant, coal is burned in a combuster and a material called a seed (generally potassium carbonate, K_2CO_3) is added. The seed mixes with the gaseous products of combustion to produce a very hot gas that contains a large number of electrically charged particles. (Electrically charged gases are called plasmas.) This electrically charged gas is allowed to escape from the combustion chamber through a nozzle. This produces a high velocity stream of positively and negatively charged particles, which are directed to pass between the coils of a very large and powerful electromagnet. The magnetic field separates the charged particles, forcing the positive and negative particles to move in opposite directions so that they collide with two different electrical collector plates, one of which becomes the positive, and the other the negative, electrical terminal of the MHD generator. This produces a direct current (D.C.), which must then be converted to an alternating current (A.C.) to be compatible with current utility systems.

The main advantage of this process of electricity generation over the usual method of generation using steam or gas turbines is that there are no moving parts, and no parts exposed to high temperature steam corrosion. This enables the gases to enter the generator at temperatures as high as 2800 degrees Celsius (5000 degrees Farenheit) as opposed to 1700 degrees Celsius for advanced turbine systems being developed. According to the laws of thermodynamics, this higher temperature makes more of the energy released by the burning of the coal available for conversion to electricity.

Not all of the plasma gas is utilized in the MHD process. The excess gas flows out of the MHD generator at a temperature of approximately 2100 degrees Celsius. The substantial heat energy remaining in the gas must be used for the process to be economically feasible. Part is used in the air preheater which raises the temperature of the air going into the combuster so that the coal can be burned at the high temperatures required. However, most of the heat from the combustion gases is used to heat water to run a steam turbine similar to those in conventional power plants. In a commercial open-cycle MHD power station, about half of the electricity will be generated in the MHD "topping cycle" and the other half of the power will be produced in the steam "bottoming cycle."

The system described above is referred to as open-cycle, because the combustion gases are exhausted to the atmosphere through smokestacks after as much heat energy as possible has been extracted.

At least 95% of the seed must be recovered from the exhaust gases in order to be recycled to achieve maximum economy and for environmental considerations. The technology for removing seed particles from the exhaust gases appears to be well in hand.

The integration of all the subsystems, especially the combuster, generator, and heat recovery systems, is a complex affair. The performance criteria achievable by each subsystem affects the design of the other subsystems, and many tradeoffs must be made.

Closed-Cycle MHD Systems

In closed-cycle MHD generating systems heat from the combustion of fossil fuels or other sources such as a nuclear reactor is transferred to a separate working fluid. The working fluid may be a seeded gas or a liquid, but must be a conductor of electricity. The generation process is the same, though the working fluid is not allowed to leave the system and is recycled. The containment of the working fluid in a closed cycle allows the use of substances which are better suited for MHD power generation than seeded combustion gases. However, the extra step of transferring heat from the original source to the working fluid requires lower operating temperatures, thus sacrificing the main advantage of open-cycle systems over turbine systems. Few people believe this approach to be as promising as the open-cycle approach for base load power generation. However, since it may have advantages under other load conditions and because the problems involved are quite different than those to be solved for open-cycle systems, closed-cycle systems continue to receive attention.

Efficiency

Proponents of MHD stress the efficiency advantage of MHD systems over alternatives. Power plant efficiency is the ratio of the electrical energy produced to the heat energy liberated from the fuel consumed. Commercial MHD power plants are expected to have efficiencies of about 50%, and perhaps even 60% as designs are improved. This compares favorably with a maximum efficiency of 40% for turbine systems. Thus MHD systems could get as much as one and one-half times as much electricity from a ton of coal as competing systems. The higher efficiency also means that MHD systems would release less waste heat into the environment per ton of coal burned.

Comparison With Other Power Systems

Phase II of the Energy Conversion Alternatives Study (ECAS), completed in 1976 and jointly funded by the Energy Research and Development Administration, National Science Foundation, and the National Aeronautics and Space Administration, examined conceptual designs of 11 coal-based power systems, including an open-cycle MHD system with a steam bottoming cycle. The MHD system was found to have the highest overall efficiency of the systems studied. ECAS also found that the cost of electricity produced by MHD using 1976 fuel prices was one of the lowest of the systems studied. MHD power might be relatively cheaper at today's inflated fuel prices because of its high fuel efficiency.

The ECAS also estimated the development time needed before construction of a commercial power plant could begin. The MHD system had the longest development time, at 19 years, of the systems studied. In addition, the study rated 21 intangible criteria which influence power plant selection. In the category of "probability of develoment success," the MHD system rated "poor." This largely reflects the long estimated development time and the ECAS team's view that several technological advances are necessary before commercialization can begin. Proponents of MHD disagree with this view and claim that commercialization is only a matter of design and scaling up of present experimental systems with no problems remaining which require a breakthrough in current knowledge.

Environmental Considerations

The high efficiency of MHD power systems should result in significant reductions in thermal pollution. Advanced MHD systems could produce as little as 44% as much waste heat per kilowatt as other coal-based technologies and only 25% as much as present nuclear power plants. The reduced requirements of cooling water needed for MHD plants which this implies could be an important consideration in many regions. In addition, high efficiency in MHD systems would require less coal to be mined than for other coal-based systems. This might reduce the substantial environmental and health problems associated with coal mining.

Low levels of emissions of sulfur oxides is another environmental advantage of MHD systems relative to other coal-based systems. As the combustion products in an MHD plant cool, the sulfur from the coal combines chemically with the potassium from the seed and forms potassium sulfate (K_2SO_4). This solid material is much easier to remove from the power plant exhaust than the gaseous oxides of sulfur which normally result from coal combustion. No flue gas scrubbing system available today can remove sulfur dioxide as effectively as the potassium seed reaction in the MHD process.

The high temperature of combustion in MHD systems can produce higher levels of oxides of nitrogen (a component of photochemical smog) than produced in other coal burning processes. However, it is expected that this can be controlled by introducing a 2-stage combustion process. It appears that control of nitrogen oxide emission levels to levels below those proposed by EPA for the 1980s will not impose a significant penalty on performance nor require expensive add-on pollution control devices.

Fly ash, the small non-combustible particles which are carried along with the exhaust gases of coal combustion, is a potential pollution problem for all coal burning systems. The high temperature combustion in MHD systems produces particles which are much smaller than those produced in conventional power plants and which may have a higher percentage of harmful trace elements. It appears that it will be more costly to remove these particles from the MHD stack emissions than from those of conventional coal burning systems.

Department of Energy Baseline MHD Development Program

The Department of Energy has been criticized by Congress for the lack of a comprehensive program development plan for MHD, which would include detailed timetables for achieving specified objectives, plans for utilization of facilities, cost estimates, and opportunities to evaluate the program. A draft program plan produced by the DOE in March 1979, described a baseline plan for progress towards commercialization of MHD in the late 1990s proceeding through three phases. The first phase was to be development and testing of MHD core components at up to 50 MWt (MWt is thermal megawatts, the power released by the coal combustion). The second phase was to be a pilot-scale plant with an MHD topping cycle and a steam bottoming plant. This plant, called the Engineering Test Facility (ETF) is mandated by P.L. 93-404 to be built in the State of Montana. The 1979 draft program plan called for construction of this plant of approximately 250 MWt to begin in 1986. Operation of the 250 MWt ETF was to lay the groundwork for the third phase of development; a full-scale commercial demonstration plant of about 1000 MWe (electrical megawatts generated), which, according to the 1979 plan, would begin operation in 1997.

The focus of phase I of the development program is the Component Development and Integration Facility (CDIF). Plans are for major MHD components, such as combusters and generators, to be designed and built by several contractors, and then integrated with other components at this facility where performance tests necessary for the improvement of these components and ultimate scale-up to the size of the ETF will be made. Construction of the CDIF in Butte, Montana, is nearing completion and the first combuster has arrived on the site. Electricity generation is scheduled to begin in April 1981.

Another DOE-supported testing facility is the coal-fired flow facility (CFFF) to complement the work at the CDIF with simulation of complete MHD/steam systems at lower power levels. A heat and seed recovery system will also be developed at the CFFF. This facility, is being operated by the University of Tennessee Space Institute. Supporters have claimed that commercialization could be speeded up by several years with a more ambitious program. Early in 1979, the Electric Power Research Institute presented a conceptual design for a commercial MHD plant which would be smaller and less efficient than the first commercial plant of the DOE baseline plan, but which might be developed earlier. Based on work done by the STD Research Corp. and Westinghouse Electric Corp., a 500 MWe plant estimated to cost $940/kwe in 1978 dollars to build was described.

In December 1979, DOE announced that it would be asking Congress to approve funding for an accelerated MHD development program. This new plan calls for doubling the capacity of the CDIF to 100 MW(t) beginning in 1982 and doubling the size of the ETF, which will be developed beginning in 1984, to 500 MW(t). According to this plan, the ETF would include some of the simplified first-generation ideas of the EPRI design and would be the final step required before private industry could move forward with commercial MHD plants in the early 1990s. This new plan, while increasing DOE's MHD development budget by about $120 million during the 1980s, according to the Department, could save $1 billion dollars of Federal funds and speed the introduction of commercial MHD by eliminating an additional demonstration stage after the ETF.

This new development plan has replaced the old baseline development plan and some program milestones sketched out in the FY81 DOE Fossil Energy Program Summary Document (gold book). However, a detailed program development plan incorporating the new schedule has not been issued.

In addition to DOE's development program, early commercial application of MHD technology could be possible if efforts underway by Southern California Edison Co. and Roldiva Inc. of Pittsburgh are successful. These companies are considering retrofitting a 50-75MW MHD generator to an existing 125MW oil-fired plant. Initially this plant would burn oil, but would switch to coal when a suitable combustor becomes available. This might occur before 1990. While it is unlikely that at this stage of development the costs of the added power would be competitive with 75 MW of new power from conventional sources, it would have the potential advantage of converting the existing Southern California oil-fired plant to coal and expanding their capacity without obtaining a new site. This plant could be operational as early as 1985.

Major MHD Contractors

About 25 institutions in 15 states receive funding from the Department of Energy as part of the MHD development program. Half of these are private, industrial concerns and most of the rest are universities and Government laboratories. Some of the major contractors and their primary contributions are given below:

Argonne National Laboratory - Magnet design, program coordination, cooperation with Soviet Union.

Arnold Engineering Development Center (U.S. Air Force) - Short duration generator testing at high power.

Avco Everett Research Laboratory - Design, fabrication, and development of generators, combusters, and other components.

Babcock and Wilcox Inc. - Heat and seed recovery system for the CFFF.

Fluidyne Engineering Corp. - Air preheater development.

General Electric Company - Conceptual system design, closed-cycle study.

Kaiser Engineers - Construction of the CDIF.

Massachusetts Institute of Technology - Magnet development, system studies, theoretical studies.

Montana Energy and MHD Research and Development Institute (MERDI) - Preparations for and operation and management of the CDIF, environmental studies.

Pittsburgh Energy Research Center - Combuster development.

Ralph M. Parsons Co. - Design of the CDIF.

Reynolds Metals Co. - Electrode design.

Rocketdyne Division of Rockwell International - Combuster development.

Stanford University - High magnetic field generator development.

STD Research - Systems analyses and performance assessments.

TRW - Combuster development.

University of Tennessee Space Institute - Construction and operation of CFFF. Design and fabrication or procurement of components for the CFFF.

Westinghouse Electric Corp. - Electrode development, CDIF testing integration, generator fabrication.

Soviet and Other Foreign MHD Programs

The Soviet Union has directed its efforts in MHD towards rapid development of commercial plants using natural gas as the fuel. It plans to use knowledge gained from operation of these plants to tackle the more difficult problem of coal burning in the second generation of power plants. The Soviet U-25 system is presently the largest continuously operating MHD facility in the world. This and another Soviet experimental MHD facility are the only two MHD plants to provide power to a utility grid on a regular basis. The two facilities supply the Moscow power grid with about 25 MW of electricity. Ground has been broken for a 500 electrical megawatt commercial demonstration plant at Ryazan (about 120 miles southeast of Moscow). Completion of this plant, which will produce about two to three times as much electricity as the ETF, is scheduled for 1985.

There has been significant cooperation between the United States and the U.S.S.R. in MHD since 1973. About 5% of the FY79 spending on MHD was devoted to the U.S./U.S.S.R. cooperative program. A most important step was the supply of a 40-ton superconducting magnet built by the Argonne National Laboratory to the Soviet U-25 facility in 1977. Americans have been present at all tests using this magnet. U.S. participants in the cooperation program generally agree that significant knowledge is gained by both sides.

U.S.-Soviet cooperation in MHD has been slowed by the U.S. response to the Soviet invasion of Afghanistan. Shipment to Moscow of a 27-foot MHD channel, designed by MEPPSCO of Boston and built by Westinghouse at a cost of $10 million, which was scheduled for Jan. 20, 1980, has been postponed indefinitely by the U.S. State Department. Analysis of the most recent test results from the U-25 facility using the American magnet is proceeding. According to the cooperation agreement, the Soviet Union must notify the United States six weeks before conducting future tests at this facility. The State Department has announced that U.S. participation in future tests will be decided on a case by case basis.

The United States and the Netherlands have recently agreed to cooperate in the development of a closed-cycle MHD system. The United States will provide key components for a joint test facility to be installed at the Technical University of Eindhoven in the Netherlands.

In addition to the United States, the U.S.S.R. and the Netherlands, several other countries, including Australia, Austria, the People's Republic of China, the Federal Republic of Germany, India, Italy, Japan, and Poland, have MHD programs. Exchanges of information and conferences are organized by the OECD Nuclear Energy Agency and the International Atomic Energy Agency.

Funding

Although the principle of MHD power generation has been known since 1831, it was not until 1959 that an MHD generator, built at the Avco Everett Research Laboratory, was able to produce electric power. Throughout the 1960s, research continued at several private industrial research laboratories with only occasional funding supplied by the Federal Government and utility companies. In 1967, a group of private companies proposed that the Federal Government share half the cost of a development program leading to a pilot plant. This proposal was not successful partly because the emphasis within the Government was on nuclear power at that time. Significant Federal funding of MHD research and development began in 1971 under the Office of Coal Research (OCR) in the Department of the Interior. As the table below indicates, Federal involvement in MHD has continued to grow under the OCR and later the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE).

Year	Appropriation (millions)	
FY 1971	$ 0.6	OCR
FY 1972	1.0	"
FY 1973	3.5	"
FY 1974	7.5	"
FY 1975	14.3	"
FY 1976 plus TQ	37.3	ERDA
FY 1977	40.0	"

FY 1978	71.5	"	
FY 1979	77.0	DOE	
FY 1980	79.0	"	
FY 1981	67.0	"	
FY 1982	60.0	"	(Carter budget request)
FY 1981	60.5	"	(Reagan revision)
FY 1982	0.0	"	(Reagan request)

Nearly all of the funding for MHD development in recent years has been provided by the Federal Government, with less than 2% coming from the electric utility industry. Most of the funding is for open-cycle MHD. In FY81 only $1 million was appropriated for the closed-cycle program.

HEARINGS

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Fossil and Nuclear Energy Research, Development and Demonstration. MHD Program review. Oversight Hearings, 95th Congress, 2d session. May 2, 4, and Aug. 3, 1978. Vol. II. 470 p. No. 76.

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CHRONOLOGY OF EVENTS

03/11/81 -- The Reagan budget revision reduced the MHD program's planned FY81 obligations to $60.5 million from an appropriated level of $67.0 million, and eliminated all funds for MHD research in FY82.

06/00/80 -- Representatives from more than 12 countries attended the Seventh International Conference on MHD Electrical Power Generation at the Massachusetts Institute of Technology. Frank McCracken of Southern California Edison remarked that MHD suffers from an almost total lack of interest by utility companies and commercialization may not occur until after the year 2000.

12/11/79 -- Acting Assistant DOE Secretary George Fumich told the Senate Energy Committee that DOE will be asking Congress for a $17.5 million supplemental appropriation for MHD for FY80 for an accelerated development program. The plan calls for doubling the size of both the CDIF and the ETF. The ETF would then be the final step before commercialization of MHD which could begin in the early 1990s.

11/19/79 -- Avco Everett Research Laboratory, Inc. announced that it has successfully operated a 20 MW(t) MHD coal combustor at over 5000 degrees fahrenheit and nearly four atmospheres of pressure. The combustor is one of three competitive designs funded by DOE prior to awarding a contract for the 50 MW(t) combustor for the CDIF.

06/20/79 -- The Department of Energy announced that it has selected Babcock and Wilcox Inc. for a contract to develop the heat and seed recovery system to be tested at the Coal Fired Flow Facility. Information gained from this effort will be used to design a similar system for the ETF. The four-and-a-half year contract is targeted at $20 million.

03/00/79 -- The Division of Magnetohydronamics of the Department of Energy produced a Draft Program Plan For Open Cycle Magnetohydrodynamics.

03/00/79 -- Roldiva Inc. of Pittsburgh and the Southern California Edison Co. agreed to retrofit a 50-75 megawatt coal-burning MHD generator to an existing oil-fired powerplant, if feasibility studies are favorable. The studies began in 1977 and a contract for construction could be negotiated by the end of 1979.

02/00/79 -- Avco Everett Research Laboratory fed 200 kw of electricity, produced from an MHD generator, into the power grid of the Massachusetts Electric Co. for 15 hours. This was the first MHD-generated electricity to be fed into a utility grid in the United States.

11/14/78 -- The Department of Energy announced that a combuster designed and built by the Avco Everett Research Laboratory arrived in Butte, Montana. This is the first major component for the CDIF to be delivered.

10/00/78 -- The Avco Everett Research Laboratory completed a 500-hour test of a MHD generator with a power output of 220 kilowatts. The relatively minor damage to the electrodes indicates that a generator which can operate for 2000 hours is within reach.

08/03/78 -- The Subcommittee on Fossil and Nuclear Energy Research, Development, and Demonstration of the House Committee on Science and Technology completed hearings on oversight of the U.S. MHD program.

01/18/78 -- The University of Tennessee Space Institute reported on experiments that reduced nitrogen oxide emissions in their coal-fired MHD system to well below EPA standards through control of the combustion process.

07/00/77 -- A superconducting magnet weighing 40 tons built at the Argonne National Laboratory was delivered to the Soviet Institute of High Temperatures. It will be used in joint U.S.-Soviet tests at the U-25 MHD facility.

05/00/77 -- THe University of Tennessee Space Institute announced that tests have shown that the potassium used as a seed in MHD power generating systems will remove at least 95% of the sulfur from the coal burned, thereby eliminating the need for additional costly pollution control devices.

04/00/77 -- Soviet scientists operated the U-25 MHD pilot power plant for 250 hours at 12.4 MWt. This was the longest operation of an MHD plant at this power level.

12/00/76 -- The last part of the Phase II ECAS report was issued. It showed MHD to be among the most promising energy conversion alternatives available.

05/15/76 -- ERDA held a groundbreaking ceremony for the MHD Component Development and Integration Facility (CDIF) in Butte, Montana.

09/05/75 -- ERDA announded the creation of a Division of Magnetohydrodynamics under its Fossil Energy Directorate.

08/31/74 -- Public law 93-404 was enacted. It appropriated funds for MHD research for FY75 and stipulated that they be used in part to initiate design of an MHD Engineering Test Facility with an output of at least 500 MW to be located in Montana.

07/00/73 -- United States and Soviet experts prepared a program of cooperation in MHD power generation within the framework of the 1972 general agreement on U.S.-U.S.S.R. scientific and technical cooperation.

03/00/71 -- The world's largest MHD facility, the Soviet U-25 facility, began operation.

04/30/69 -- The Office of Science and Technology issued a report entitled MHD for Central Station Power Generation. This report was the stimulus for the initiation of the MHD research program in the Office of Coal Research.

00/00/59 -- The world's first successful MHD generator, the Mark I, designed and built by the Avco Everett Research Laboratory, achieved a power level of 10 kilowatts for 10 seconds.

00/00/1831 -- Michael Faraday conducted experiments which proved that electricity could be generated by a conducting fluid moving through a magnetic field. This is the principle of magnetohydrodynamic power generation.

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