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Conceptual Design of the MHD Engineering Test Facility

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Abstract

This report summarizes the reference conceptual design of the MHD Engineering Test Facility (ETF), a prototype 200 MWe coal-fired electric generating plant designed to demonstrate the commercial feasibility of open cycle MHD. Main elements of the design are identified and explained, and the rationale behind them is reviewed. Major systems and plant facilities are listed and discussed. The report also presents construction cost and schedule estimates, and identifies the engineering issues that should be reexamined.

Introduction

The MHD Engineering Test Facility (ETF) Project is a major element in the DOE program to demonstrate the commercial readiness of MHD/steam power generation systems. Its objective is to design, construct, and operate an ETF by providing a prototype of an early commercial MHD-topping/steam-bottoming powerplant. The project is in the design definition phase which will end when a contract is awarded for design and construction. This paper summarizes the forthcoming Conceptual Design Engineering Report (CDER), which completes one element of the design definition. The CDER develops and elaborates on the previously reported design concept[1,2] which was based on a variety of preliminary system engineering studies and component design studies.

This ETF conceptual design is distinct from other reported design studies of MHD powerplants in that it is intended to be a reference design for the MHD Program and be representative of the potential which is inherent in the engineering under development. It does not explore new concepts, but documents in detail a design incorporating the best features of the other studies. Designs of components, not currently available from vendors, were restricted to those under active development in DOE programs having schedules consistent with the ETF schedule. These components include the coal combustor, MHD channel, diffuser, power inverter, superconducting magnet, and the heat and seed recovery boiler. Designs of these components were prepared in collaboration with the organizations responsible for their development. Design requirements for the components were prepared by the ETF Project from overall plant requirements, but the performance requirements were reviewed with the other organizations, and interface requirements were coordinated between organizations. An architect engineering firm integrated the resulting designs into a complete plant conforming to electric utility standards.

A number of design decisions were made, in the course of preparing the conceptual design, on a presumptive basis because an evaluation of the alternatives could not be made in a timely manner. These decisions were recorded as "issues" to be reviewed after the completion of the design; the Issues section of this paper contains a partial listing of them.

The design process imposes arbitrary decisions on a variety of issues that must ultimately be resolved by the MHD development programs. Selection of component designs and their features for incorporation in the ETF represents only the best judgement of the authors.

Plant Design Summary

The ETF conceptual design is for a self-sufficient, 200 MWe powerplant consisting of a coal-fired MHD topping cycle integrated with a steam bottoming cycle. Baseload is the primary mode of operation, but it is capable of cycling and part-load (down to 75% of full load) operation. Performance of the plant, under commercial power generation conditions, is expected to meet or surpass existing utility standards for operating costs, plant availability, safety, and durability. The plant is also expected to meet or surpass all applicable federal, state and local environmental regulations.

The ETF power summary[3] is given in Table 1. At full load, 87 MWe gross power is generated by the MHD channel and 128 MWe gross power is generated by the turbine generator. Plant auxiliaries require 12.8 MWe, leaving a net power generation of 202.2 MWe. Plant efficiency is 38.0%. This is a conservative value; subsequent studies predict improved performance for both the MHD generator and the air separation plant which

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would lead to an overall net plant efficiency of 38.6%. During test operation, a capacity factor of 23 percent (2,000 operating hours a year) is expected. During commercial operation, however, this factor should improve to 65 percent.

Table 1

ETF SYSTEM POWER SUMMARY

MHD ELECTRICAL POWER: MW	
MHD DC Power Output	87.1
Inverter/Transformer Loss	-2.6
MHD AC Electrical Power Output	84.5
STEAM CYCLE ELECTRICAL POWER: MW	
Total Steam Shaft Power	168.6
Cycle Compressor	-23.4
ASU Compressor	-12.3
Boiler Feed Pump	-2.6
Net Shaft Power	130.3
Turbogenerator Loss	-2.3
Electrical Power Output	128.0
GROSS PLANT ELECTRICAL OUTPUT: MW	212.5
AUXILIARY POWER REQUIREMENTS: MW	-10.2
NET PLANT ELECTRICAL OUTPUT: MW	202.3

The ETF configuration[3], shown schematically in Figure 1, is similar to those of the large early commercial MHD plant designs prepared by Avco Everett Research Laboratory[4] (AERL) and General Electric[5] under contract to NASA. The ETF design parameters are listed in Table 2. It has a single subsonic MHD power train which generates nearly half of the total electric power. The energy in the MHD exhaust generates steam in the heat and seed recovery boiler to produce additional electric power and to drive the oxidant supply compressors. The oxidant is oxygen enriched air which is preheated to 1100° F using the MHD exhaust. Oxygen is obtained from an high-efficiency on-site air-separation plant. Seed reprocessing is assumed to be performed off-site in this design, but on-site capability may be added later.

Although the ETF design is similar to those developed in studies of large commercial plants, a number of parameters are significantly different. At ETF size, the steam bottoming cycle is predominant, and the efficient utilization of the relatively large amount of heat lost to the walls of the MHD components is critical. These factors led to the selection[6,7] of a lower oxygen enrichment (30% vs 35%) and a shorter channel and magnet (12 m vs 17 m) than did earlier studies. Performance is maintained, but the ETF is simpler, cheaper, and easier to build.

Plant equipment was selected and/or designed to facilitate startups and shutdowns. Rates are established by the conventional components such as the steam drum and turbine and are comparable to those of conventional plants.

Table 2

ETF SYSTEM DESIGN PARAMETERS

PLANT	Baseload
Power	202 MWe Net
Load range	100 - 75% of rating
Efficiency	38.0%
Thermal input (coal)	532 MWt
FUEL	Montana Rosebud Coal
Moisture	22.7% typical, 5% dry
Ash	8.7% typical
Sulfur	0.85% typical
HHV	8,920 Btu/lb, typical
Size, pulverized	70% through 200 mesh
OXIDANT	Oxygen enriched air
Oxygen content	30% by volume
Temperature	1100°F
ASU efficiency	221 kWh/ton equivalent pure oxygen
COAL COMBUSTOR	Two stage
Air/fuel equiv. ratio	0.90
Thermal input (coal)	532 MWt
Slag rejection	65%
Discharge pressure	66.4 psia
Discharge temperature	4,380°F
MHD GENERATOR	Diagonally-connected Faraday
Channel length	12.1 m, active 16.0m, overall
L/D, inlet	27.0
Mach number	0.90 constant
Gross power output	87.1 MWe
Diffuser pressure recovery factor	0.46
Inverter type	Line commutated
Current consolidation	6 sources
MAGNET	Rectangular saddle
Peak field	6 tesla
Length	12.1 m between 4 tesla and 3.5 tesla points
HEAT & SEED RECOVERY	Radiant boiler, convection pass and ESP
Radiant boiler	Slagging
NO_x control	2.2 sec residence above 2900°F
Afterburner	Final air/fuel ratio - 1.05
Ash recovery	50%
Convection pass	Super and reheater, oxidant heater, and H.T. economizer
ESP Efficiency	99.6% capture
STEAM POWER	Subcritical, reheat
Conditions at turbine	1815 psi/1000°F/1000°F
Condensor pressure	2.0 in. Hg
Cycle efficiency	39.7%

Plant Site and Facilities

The ETF is designed for a hypothetical site typical of potential powerplant sites in Montana. It is at an elevation of 3300 feet where the standard temperature and pressure are 42°F and 13.0 psia. The site is relatively flat, with good soil properties and adequate surface water supplies.

The ETF plant is shown in Figures 2 and 3 and is described in this section. Several major facilities are designed to meet the special requirements of an MHD/steam combined-cycle power plant.

MHD Building

The combustor, nozzle, channel, diffuser, consolidation network, and magnet assemblies are located in the MHD Building shown in Figures 4 and 5. Because high voltages and magnetic fields will be present, access to the area will be restricted during operation. Therefore, the placement of equipment and instruments will require special attention to facilitate normal maintenance during operating periods.

Equipment and subsystems in this building are expected to be high maintenance items during the early phases of operation and require ready access. Cranes, hoists, and specialized tools and techniques will be used to minimize repair and replacement time.

Turbine Generator Building

The main power equipment of the steam system is located in this four level structure. Besides the main turbine generator, the building houses the main condenser, feedwater and booster pumps, electrical equipment, piping, cables, and the control complex. A traveling bridge crane services the turbine hall area.

HR/SR Building

This building shelters the boiler section of the HR/SR unit and provides access to the equipment. Normal boiler enclosure practice is followed.

Air and Oxidant Compressor Building

The oxidant and air-separation-unit (ASU) compressors reside in this building separated by concrete blast walls. The ASU itself is located on an adjacent concrete slab.

Inverter Building

The inverter-bridge thyristor stacks, their smoothing reactors, and buswork are housed in this building and cooled by a forced air system. It is a high voltage hazard area. The inverter transformers and filter capacitors are located outside.

Control Complex

Operation of the plant is controlled and monitored from the main control room. It is designed to provide a safe evacuation zone in the event of plant malfunctions which could endanger operating personnel.

Administration and Service Building

This building contains offices, dispensary, study rooms, training area, lavatory facilities, cafeteria, meeting rooms, storage area, janitorial facilities, and a machine shop.

Coal Handling and Preparation

Major components of the yard-coal-handling facilities include two 30-day compacted piles of raw coal, thawing sheds, unloading facilities, conveyors, and bulldozers to prepare and move coal. Preparation facilities include buildings for coal pulverizing, drying, and feeding.

Cooling Towers

The plant uses a cooling tower complex having eight mechanical-draft, evaporative-type cooling tower cells.

Other Facilities

Other facilities include:

1. Yard Seed and Slag Handling
2. Chemical Treatment Buildings
3. Water Intake and Discharge Structures
4. Water Treatment Building
5. Storage Areas
6. Guard House
7. Machine Shops
8. Shipping and Receiving
9. Oil Storage and Pumphouse
10. Gas Turbine (Backup) Power Installation
11. Auxiliary Boiler Building

Oxidant Supply

The system supplies pressurized oxidant, air enriched to 30% oxygen by volume, to the HR/SR where it is preheated en route to the coal combustor. The oxidant is prepared by blending air with medium purity (70%) oxygen produced in a cryogenic ASU. Its design is based on previously reported performance and economic studies[8,9] and is nearly identical to the blast furnace oxygen enrichment system at Schwelgern[10] which has been operating reliably since 1973. The high efficiency of the ETF unit results from the use of an ASU producing 70% oxygen, the use of an uncooled axial-flow oxidant compressor instead of separate air and oxygen compressors, and the use of an intercooled aftercooled axial-radial compressor to supply air to the ASU. Steam turbines power the compressors.

The oxidant supply incorporates several features for plant startup, testing, and reliability. It uses three 50%-capacity oxidant compressors. Unit 3 is driven by an electric motor to provide oxidant prior to the availability of steam. It also allows operation of the ASU while the plant is down by supplying air to the ASU via a bypass. On startup, this eliminates the several-day wait which would otherwise be required to cool the ASU. The system also provides for the manufacture and storage of liquid oxygen product which can be used during startup, peaking, and ASU maintenance periods.

MHD Power Train

The power train design is an assembly of component designs based on technology to be tested at the Component Development and Integration Facility (CDIF). The MHD generator (channel, diffuser and consolidation circuitry) is adapted from the 280 MWt ETF design prepared by AERL[11] (its channel is a scale up of the CDIF 1A1 channel). The ETF channel is of the diagonally-connected Faraday type with barwall insulator walls. It incorporates the following modifications recommended by the AERL staff:

1. Extension of the electrode structure to regions of magnetic fields of less than 0.5 tesla to prevent electrical shorting of the Hall potential,

2. Reduction of electrode segmentation from 100 to 58 electrodes/meter,

3. Addition of external trusses to the primary structure,

4. Provision of current consolidation between transverse anode segments to limit fault power dissipation to approximately 1 kw,

5. Utilization of the diffuser for steam generation.

Outline diagrams and design parameters for the coal combustor were provided by the TRW Defense and Space Systems Group, based on their development work at 20 MWt. The combustor is a two-stage unit combining two first-stage combustors with one second-stage combustor. Combustion gases from the first-stage combustors spiral toward each other, turn through 90° as they merge into one stream, pass through the second-stage combustor, and discharge through the nozzle to the MHD generator. The first-stage combustors gasify the coal and remove the coal ash as slag, while the second-stage completes combustion and produces the plasma. This design provides

1. relatively low heat loss and pressure drop,

2. high carbon utilization,

3. effective slag rejection, and

4. good operational characteristics, including rapid startup and shutdown.

Magnet

The superconducting magnet design, based on the results of studies conducted by MIT/FBNML[12], incorporates copper-stabilized niobium-titanium coils in a rectangular saddle configuration similar to those of the magnet being built by the General Electric Company for the DOE CDIF. The magnet has a tapered bore of rectangular cross-section, increasing in area toward the downstream end, and designed to accomodate the MHD channel, power takeoffs and cooling lines. A water-cooled warm bore liner protects the magnet from loss-of-containment in the channel. The magnet provides a 6 tesla peak magnetic field with a taper toward the downstream end corresponding to the spread in the saddle coils required to accomodate the taper in the warm bore. No racetracks or other special windings are used to shape the field.

The rectangular cross-section of the warm bore permits the coil size to be determined by the size of the channel structure. The long axis of the rectangle is horizontal and parallel to the field direction, so that space for leads and cooling lines is provided on both sides of the channel structure without encroaching on space required for the coils.

The overall magnet system is an integration of the magnet assembly, cryogenic support equipment power supply, protection and control circuitry, and vacuum pumping equipment. The magnet is provided with tracks and rollers to enable it to be rolled 34 feet to the side to permit channel changeout.

Heat Recovery/Seed Recovery

Gas discharges from the MHD power train at about 3500° F. Its energy is utilized by the HR/SR for steam generation and oxidant preheat. Seed recovery and emissions control are also accomplished in the HR/SR. The major components of the HR/SR are the Boiler and the electrostatic precipitator (ESP) and its design is based on conceptual design studies by Babcock and Wilcox[13,14].

Boiler

The boiler, shown in Figure 6, is a balanced-draft, subcritical, drum-type unit. It is comprised of a radiant boiler and a convection pass containing the superheater, reheater, economizer, and MHD oxidant heater.

Radiant Boiler The radiant boiler is of conventional membrane-wall construction, formed from vertical tubes placed on close centers. The radiant boiler is divided into two sections, a refractory-lined lower section where NO_x is reduced, and a bare-metal upper section where the combustion of the flue gas is completed (Afterburning). The refractory lining improves NO_x reduction by limiting the gas cooling rate, and reduces corrosion caused by the required reducing atmosphere. Afterburn air is added in the upper section to make the gas slightly oxidizing at a stoichiometry of 1.05. The slow rate of combustion plus high heat loss to the bare metal walls prevents the temperature from rising to levels at which NO_x could reform. A slag tap at the bottom of the boiler removes 40 percent of the slag carried over from the combustor.

Superheater Steam, formed in the boiler walls, is separated from the two phase mixture in the boiler drum and superheated to 1005° F in a three section superheater. Spray attemperation prevents overheating of the steam.

Reheater Cold reheat steam, discharged from the high-pressure turbine, is piped to a two section reheater for reheat to 1000°F. A spray attemperation unit prevents overheating of the steam.

Oxidant Heater The oxidant heater is a gas-to-gas heat exchanger which heats the oxidant discharged from the compressors to 1100° F. During startup, the oxidant is heated by an oil-fired vitiation heater which also serves to preheat the HR/SR and the turbines.

High Temperature Economizer The high temperature economizer heats feedwater using the MHD exhaust gases.

Electrostatic Precipitator (ESP)

The ESP removes 99.6% of the particulates (primarily seed) entrained in the gas discharged from the high temperature economizer.

Steam Power System

The steam generated in the HR/SR powers a conventional turbine generator to produce additional plant electrical power and powers turbines to drive the compressors and boiler feed pumps (BFP).

Main and Reheat Steam

The main steam piping conveys steam at 1815 psi and 1000°F to the high pressure (HP) turbine. Cold reheat steam from HP turbine exhaust is reheated to 1005° F and directed to the intermediate pressure (IP) turbine and to the compressor and BFP turbine drives. The steam discharge from the IP turbine is expanded in the low pressure (LP) turbine and discharged to the main condenser. Attemperation in the reheater is provided by the use of feedwater from an interstage bleed on the BFP, and in the superheater by use of feedwater from the BFP discharge. The main turbine generator is rated at 128,044 kW/153 kVA and is hydrogen cooled.

Steam Bypass and Startup

This system bypasses the HP turbine by directing steam from the superheater header to the cold-reheat header, and bypasses the IP and LP turbines by directing steam from the hot-reheat header to the main condenser. Attemperation is provided for both the HP bypass steam and LP bypass steam by feedwater taken from the BFP discharge. Interlocks prevent steam bypassing if water flow is interrupted. The main condenser is protected by pressure and temperature switches that close the bypass valve during abnormal operation.

The HP bypass control valves can be regulated during cold or warm startup to control generated steam pressure. Once steam flow is established through the reheater, the turbine metal temperatures can be increased at the required rate.

Extraction Steam

Steam is extracted from the main turbine cycle at four stage points and used for feedwater heating.

Condensate

Exhaust steam from the LP turbine and the BFP turbine drives is condensed in the main condenser. Steam from the compressor-drive turbines is condensed in individual condensers. The condensate drains to the main condenser. Condensate is pumped from the main condenser hotwell and is utilized for cooling in the steam-seal exhauster. Condensate quality is maintained by passing through a full flow demineralizer prior to entering a deaerating feedwater heater.

Boiler Feedwater

Boiler feedwater is pumped from deaerator storage to the cooling passages of the MHD channel. It then cools about one third of the gas leaving the ESP in the low temperature economizer, and after being raised to boiler pressure by the BFP, passes through three stages of feedwater heating. Finally it is used to cool the flue gas in the high temperature economizer and cool the MHD combustor before being converted to steam in the HR/SR.

Feedwater Heater Drips

This system maintains normal condensate levels in the feedwater heaters and controls flow of condensate to the deaerator. An important function of this system is to prevent water-slug surges from entering the turbine blading stages via the extraction-steam piping to the heaters.

Feedwater-Heater and Miscellaneous Drains, Vents, and Reliefs

This system drains and vents the feedwater heaters to the main condenser, and conveys condensate from miscellaneous steam line drains to the main condenser.

Condenser Air Removal

Non-condensable gases are exhausted from the main and auxiliary condensers by steam-jet-air-ejector and rotary-vacuum-pump systems which can be used singly or in parallel.

Circulating Water

This system supplies cooling water to the main and auxiliary condensers to the compressor intercoolers and aftercoolers, and to the closed cycle heat exchangers. The returning water is cooled by the evaporative cooling towers.

Auxiliary Systems

Auxiliary Steam

Auxiliary boilers provide up to 270,000 pounds per hour of 115 psi, 350°F steam for plant heating and auxiliary services during plant startup and operation.

Boiler Flue Gas

After particulates are removed from the boiler flue gas by the ESP, the flow is split into separate streams and used for

1. coal drying and transport,
2. coal (pressurized) injection,
3. afterburn air heating and dilution, and
4. feedwater heating.

Flue gas, after being used for coal drying and transport, is stripped of coal fines in the bag house. The recombined streams of flue gas are exhausted from the plant stack to the atmosphere by induction fans. The boiler-flue-gas system includes flue gas ducts from the boiler discharge through the ESP, the low temperature economizer, to exhaust to atmosphere.

Coal Management

At baseload, the ETF requires processing of 102 tons of coal per hour which is delivered in unit trains. There are provisions for thawing, dumping, weighing, and transporting the coal to storage bunkers. Excess coal is compacted in two 30 day capacity storage piles. Coal to be fired is transported to active storage in bunkers, weighed, and fed to the pulverizers. It is then pulverized to 70 percent through 200 mesh, dried, and transported to pressurized lockhoppers by flue gas. Pressurized flue gas then fluidizes and transports the pulverized coal through the injection lines to the combustor.

Seed Management

New potassium-carbonate seed (K_2CO_3) is delivered to the site in sealed rail cars and moved to a sealed storage silo. Reclaimed seed, primarily potassium sulfate (K_2SO_4), is similarly loaded into a storage silo with excess seed going to on-site storage. Measured amounts of K_2CO_3 and K_2SO_4 are transported through the pulverizing mills by an air stream. Cyclones then separate the seed from the transport air and drop the seed into pressurized lockhoppers. Seed is injected into the combustor by pressurized oxidant.

Slag Management

A maximum of 14 tons of slag per hour generated by coal combustion is removed by this system. The slag removal equipment is designed for the removal of 10 tons per hour of slag from the pressurized combustor, 4 tons per hour of a slag through a tap in the boiler (non-pressurized), and the removal of particulates from the ESP.

Electrical

The electrical system delivers the electrical power generated by ETF to the utility grid; distributes power to the auxiliary systems for startup, shutdown, and normal operation; supplies emergency power to the ETF plant critical loads to allow an orderly emergency shutdown when normal power is lost; and provides a uninterruptible power supply for essential plant equipment (such as computer, instrumentation, and controls (I&C)). Unit synchronization is automatic with manual selects.

The primary load centers of ETF are connected through a ring bus. These 138 kV load centers are, in order:

1. The MHD power train, through the inverter bus step-up transformer.

2. First utility grid line.

3. Service transformer for topping cycle auxiliary loads, and the oxidant compressor motor transformer.

4. Service transformer for bottoming plant loads, including coal management.

5. Second utility grid line.

6. Steam turbogenerator, through its step-up transformer.

The electrical system configuration ensures that power will be available from off-site during startup, shutdown, or loss of one utility line. It provides a means of starting large motors which does not reflect the voltage drop through the entire distribution system. It furnishes a protective relay system, which isolates and interrupts faults at all voltage levels with a minimum disturbance. Bus interconnects provide sufficient station service transformer capacity to meet the total plant power requirements even if one of the transformers fails. If power from the ring bus is lost, the critical loads are maintained by automatic start, self-synchronizing gas turbine generator units. The most essential plant equipment is serviced through a bypass by a battery-powered uninterruptible supply.

Plant Services

A number of conventional plant services are required to support the ETF.

Closed Cycle Cooling Water

The closed cycle cooling water system circulates cooled, treated water through a closed loop system to equipment in the Turbine-generator and Compressor Buildings, the HR/SR Building, and the MHD Building. Main equipment serviced includes:

1. Turbogenerator hydrogen and oil coolers,
2. Condensate, BFW and booster pumps,
3. Pulverizer mills,
4. Magnet warm-bore liner,
5. Flue gas blowers and fan bearings,
6. ASU and compressors.

Plant Makeup Water

The cooling towers are the main users of plant makeup water, but other plant systems are also supplied. Sources for makeup are a combination of commercial supply and local ground water and streams. Storage tanks include a 400,000 gallon unit for filtered water and fire-protection-water backup, and a 300,000 gallon unit for raw water.

Sampling

The sampling system collects, conditions, and analyzes water and steam samples for their pertinent chemical characteristics. Selected samples are analyzed and their properties recorded on a continuous basis.

Industrial Gas

This system provides plant service air and instrument air from a single header. Dry, clean and oil-free gases at 140 psi are also available throughout the plant for miscellaneous purposes.

Fuel Oil

The fuel oil system provides storage and transport of fuel oil from the unloading area to the transfer tanks and supplies fuel oil to the

1. auxiliary and building boilers,
2. emergency power supply and fire pump, and
3. vitiation air heater (for startup only).

Oil is stored in a main 840 thousand gallon capacity tank, in individual below-ground emergency tanks, and in day tanks.

Plant Industrial Waste

The plant industrial waste system collects, stores, transfers, and processes, as needed, the liquid and sanitary wastes generated throughout the plant. Resultant effluent discharges comply with governmental and industrial standards. Major sources of waste are the

1. coal pile runoff,
2. chimney and air heater wash,
3. demineralizer regenerative wastes,
4. building drains,
5. wastewater treatment,
6. fuel oil area runoff,
7. plant yard drainage,
8. sanitary waste.

Oil contamination wastes pass through reclaimer tanks. Sanitary wastes are treated in the sewage treatment area before discharge.

Fire Service Water

Fire service water provides the means to detect and combat facility fires. In addition to water, stored in two separate tanks, specialized fire suppression fluids and techniques are provided.

Domestic Services

The supply and maintenance of potable water and the disposal of sanitary waste are specialized functions listed separately for emphasis. They are also included under the Plant-Industrial-Waste and Plant-Makeup-Water systems.

Heating, Ventilating and Air Conditioning

Services are provided for

1. protection against freezing of water supplies,
2. comfortable working environments,
3. dilution of odors,
4. controlled environments for temperature-humidity sensitive equipment.

Major load zones include the Administration, Compressor, MHD, and Inverter Buildings; the Consolidation Area; and the Main-Control and Relay Rooms.

Plant Costs

Costing Procedure

The cost estimate was prepared in the ETF code-of-account structure. It is basically the Federal Energy Regulatory Commission (FERC) account structure used by the Utility industry, modified to provide accounts for the MHD equipment (No. 317). In addition to the principal accounts, cost categories of "Engineering" and "Other Costs" are included using factors specified by DOE/MHD.

Total cost is for overnight construction; i.e. escalation and allowance for funds during construction are not included. Costs are in first quarter, 1981 dollars.

Costing Bases

Conversion for costs from one time period to another was based on the Handy Whitman Index, which is the Electric Utility Construction Index, for the Plateau Region. Because the subsystems of Account No. 317 are not included in the index, escalation data is for Account No. 314, Turbogenerator Units. Over the last ten years, equipment costs in that category have escalated at a compounded rate of 9.5 percent a year.

The cost of components and materials was developed from the following:

1. Vendor data - most accurate.

2. Reference cost - primarily for high technology items. For the major cost items, the magnet, ASU, oxidant supply and HR/SR checks were made and close comparisons with vendor estimates were observed.

3. Analogous costs - comparison with existing powerplant subsystems after scaling and normalizing to present dollars.

4. Judgment - confined to minor effects such as building construction differences, piping and electrical complexity and electrical and I&C quantities.

Principal Account Values

Total direct costs for the ETF are $316 million. Individual subsystems of major impact are:

Acct.#	Description	Cost, $ 10^6
312.1	Coal Handling & Processing	13.7
312.41	HR/SR	35.5
312.51	ESP	8.1
314.1	Steam Turbine Generator	14.7
315.3	Plant Control Equipment	11.0
315.4	Bulk Commodities	12.3
317.1	Combustion Equipment	13.3
317.2	MHD Generator	9.4
317.3	Magnet System	53.5
317.4	Consolidation and Inversion	11.1
317.5	Oxidant Supply	11.4
317.6	Seed System	9.3
317.7	ASU	21.1

With assigned factors for "Engineering" and "Other Costs", total plant cost for overnight construction is $350 million.

Construction in Montana, rather than selection of an average ("Middletown") U.S. site, would reduce direct costs by 8 percent. For completion in 1991, using an illustrative 9 percent for interest and escalation, the multiplier would be 2.4.

Confidence Levels

Tolerance on costs were assumed to be a percentage of assigned contingency factors. All tolerances, for a worst case assessment, were taken as positive. Estimated correlations were:

Contingency %	Tolerance %	Cost Value, $ 10
15	+ 10	152.4
20	+ 30	40.8
30	+ 50	122.8

Total maximum system tolerance then would be 28 percent with an expected range of error between 10 and 18 percent. This equates to an additional $89 million plant capital cost for a maximum total capital cost of $404.9 million and a maximum total plant cost of $438.5 million.

Schedules

Construction profiles were prepared in the form of bar charts to specifically include the phases of:

1. Preliminary design (DOE Title I)
2. Definitive design (DOE Title II)
3. Procurement, Fabrication, and Construction
4. Testing (checkout)
5. Operations
   a. Test facility
   b. Commercial facility.

The schedule includes all tasks from inception of design to operation as a commercial facility. Consistent with standard powerplant procedures, a (minus) year of site activities and environmental impact analysis is shown preceding the first stage of design. Preliminary design occurs for 2 1/2 years with magnet subsystem design being the long-term subsystem activity.

Definitive design extends to month 50, but its early stages proceeds in parallel with preliminary design. Coal-management, boiler-flue-gas, and circulating-water systems are among those requiring the longest design periods.

Major items for procurement, fabrication, and construction are the boiler assembly, turbine generator, combustor, channel, magnet, and inverter transformers. The boiler requires extensive on-site construction; the turbine generator has a long manufacturing (factory) schedule. Scheduling of these major systems is well defined for powerplants. On the topping side, the combustor system will be the first equipment activated. The magnet will require field fabrication and assembly. This may require sequenced construction of the adjacent structures to allow for handling equipment and laydown. The channel, the inverters, and auxiliary electrical equipment will require long-lead design and manufacturing times.

Coordinated checkout is estimated at 11 months before turnover of the plant to the Owner. The plant will go on stream at month 79. The test operational phase will then proceed for 2 1/2 years beginning with six months of short duration runs at loads progressing up to base load. During this period, I&C will be verified, subsystem "signature" data will be obtained, and in-service inspection techniques will be established. After the remaining two years of operational testing, including run durations of at least 2000 hours, commercial operation will be initiated and continue for 27 1/2 years.

Issues

Section 5.1 of the CDER outlines the areas (issues) which lack sufficient definition due to the developmental nature of the project and makes recommendations for their further study and resolution. Some ETF design features were presumptively defined to allow the rest of the design to proceed. In most of these cases, there was more than one reasonable approach which met the requirements, but no clear-cut overall advantage could be discerned for a given choice. These selections included:

1. Seed reprocessing is performed off-site, rather than by contructing a processing facility within the ETF.

2. The MHD channel is accessed for service and replacement, breaking flow train connections and rolling the magnet assembly aside as a single unit. The alternative is to remove the diffuser.

3. A high-efficiency subsonic channel was selected over the less-critical supersonic design.

4. The compressors and plant auxiliaries are driven by steam turbines. Preliminary studies by GAI indicate that the use of electric motors may simplify the design and increase efficiency somewhat.

5. The MHD channel is directly cooled by boiler feedwater. An isolated cooling loop for this system would simplify maintenance.

6. Power is not generated in the fringe magnetic fields at the entrance and exit of the channel.

7. Flue gas was selected over nitrogen for drying the coal.

Several design options were not incorporated because they required components that are not under active development by DOE or were not available during the preparation of the design. These include:

1. The design of the channel to provide a uniform electrode current distribution and thereby greatly simplify the current consolidation network and the inverters.

2. The use of regenerative cooling of the combustor by the incoming oxidant, thereby eliminating the oxidant heater in the HR/SR and generally simplifying the plant.

3. The use of a split magnet design whose halves could be rolled apart to expose the channel for inspection and maintenance. The design may also reduce costs by reducing the required size of the warm bore.

Conclusions

The ETF conceptual design integrates designs of the MHD Power Train, the superconducting magnet, and the HR/SR system with conventional power plant systems into a self-sufficient, coal-fired, 200 MWe, MHD/steam powerplant which has an efficiency of 38.0% and an overnight construction cost of $350 million. Although these are extremely attractive values for a sub-scale, first-of-a-kind plant, further improvement can be expected from the investigation of a number of design options which were identified during the preparation of the design. There were no difficulties encountered in conforming to the ground rule of using only component designs currently under development by DOE. Thus, the ETF conceptual design verifies that the MHD technology, currently under engineering development, is the potential basis of an attractive next generation of electric powerplants.

Acknowledgement

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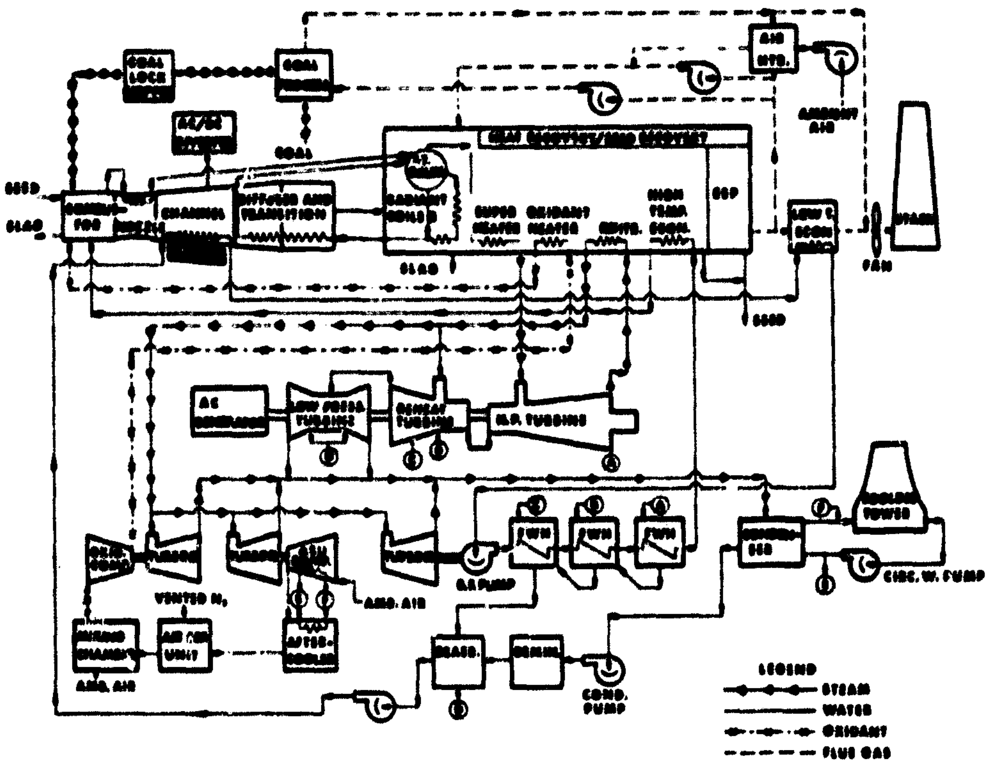

Fig. 1   Schematic Drawing of Basic ETF Configuration

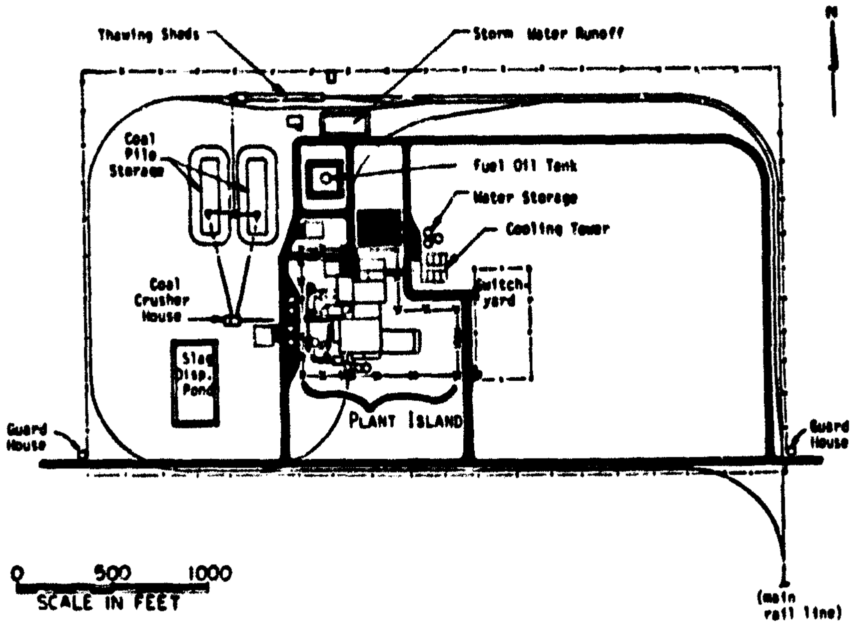

Fig. 2   Engineering Test Facility Site Plan

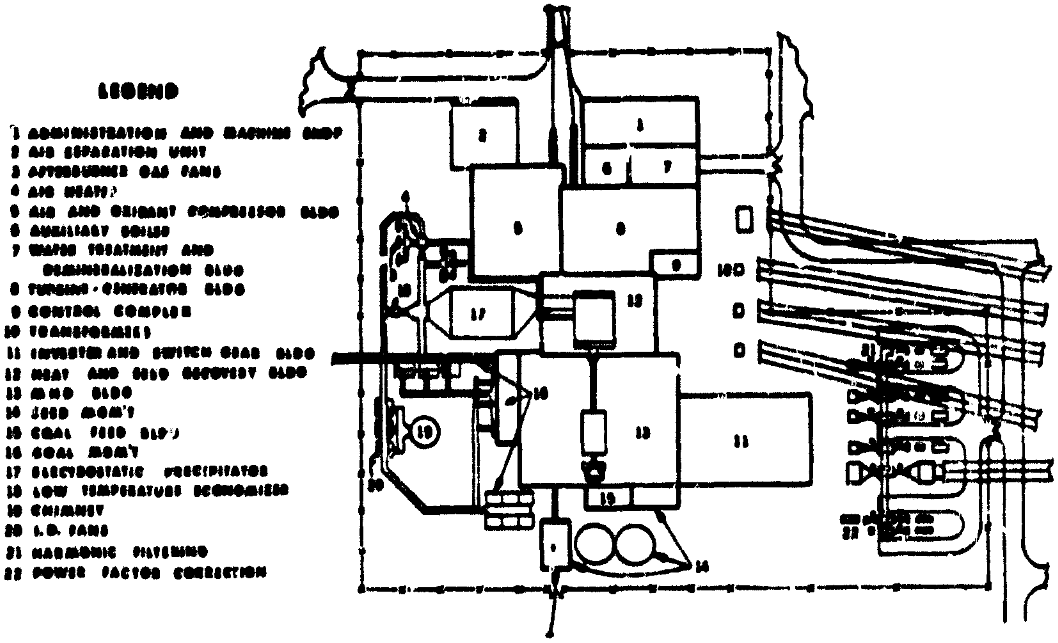

Fig. 3 Plant Island

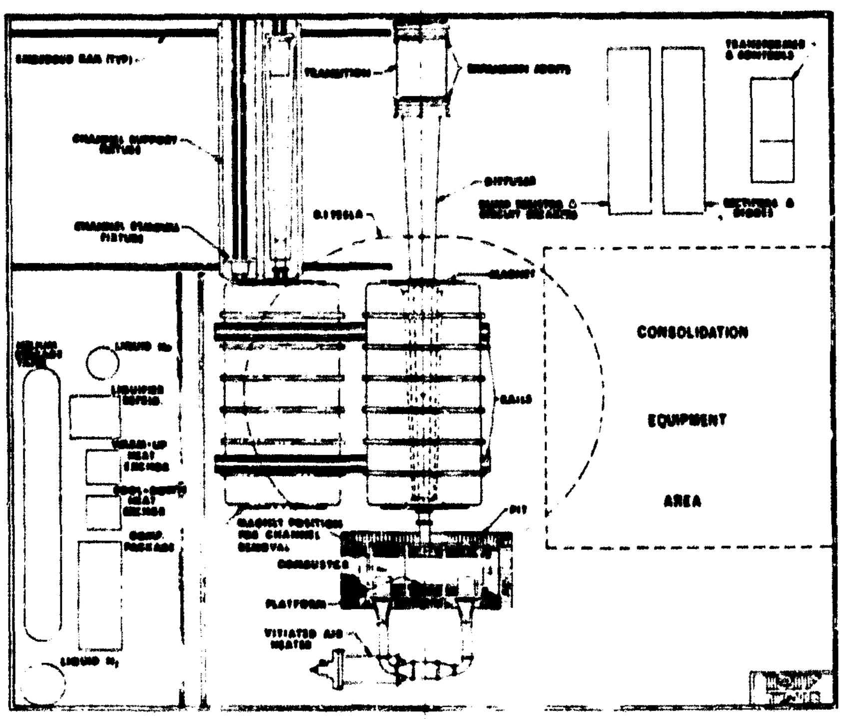

Fig. 4 MHD Building Plan

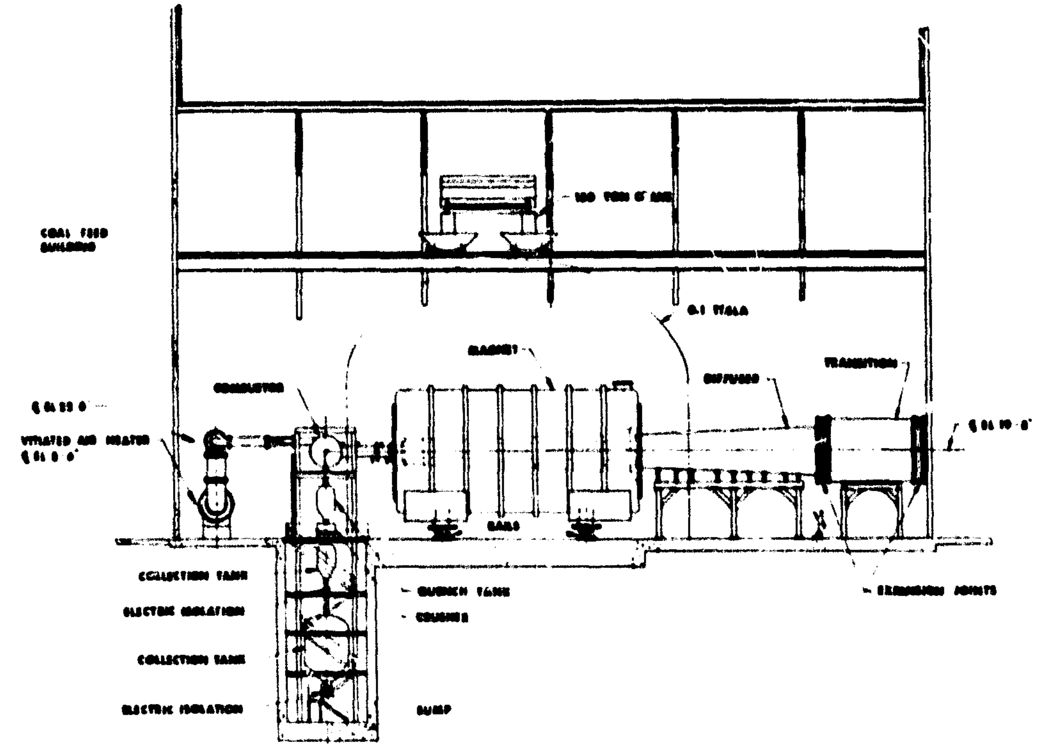

Fig. 5 MHD Building - Cross Section

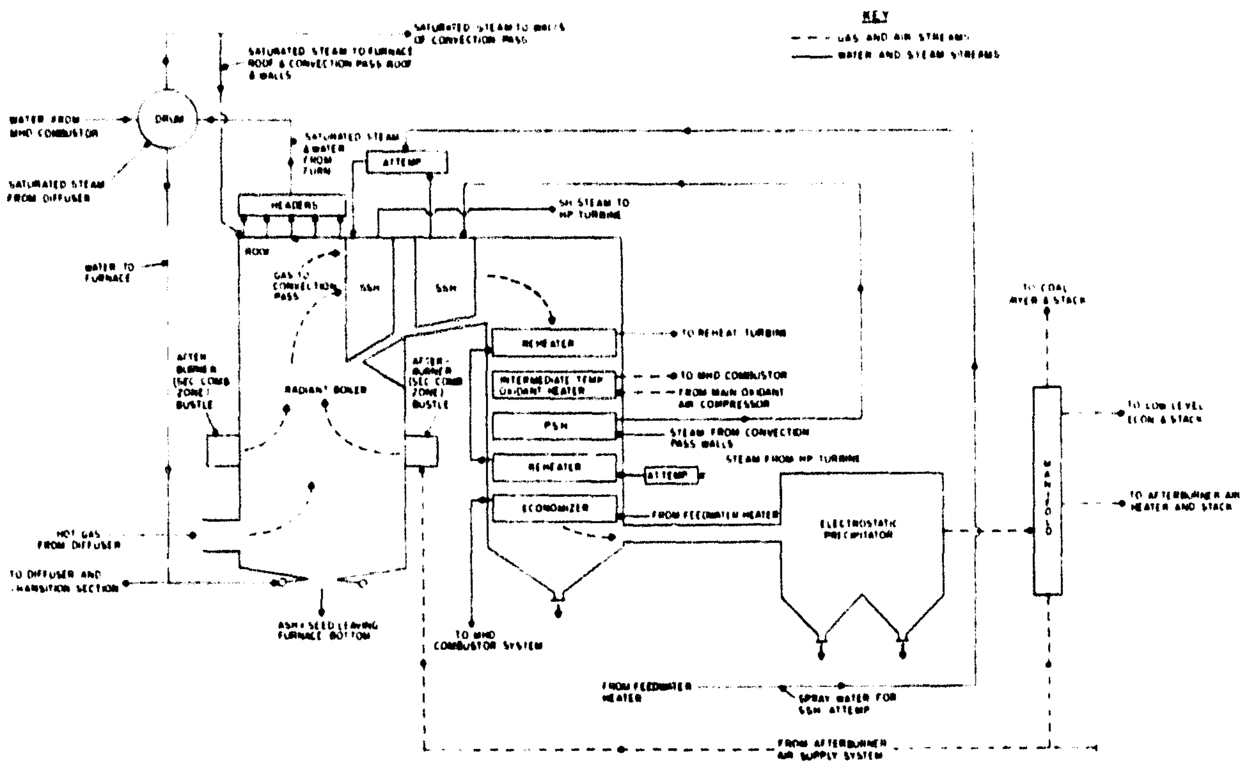

Fig. 6 Heat and Seed Recovery System