View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NASA Technical Reports Server

DOE/NASA/10769-22
NASA TM-82744

End Region and Current Consolidation Effects Upon the Performance of an MHD Channel for the ETF Conceptual Design

S. Y. Wang and J. Marlin Smith
National Aeronautics and Space Administration
Lewis Research Center

Work performed for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Magnetohydrodynamics

Prepared for
Twentieth Aerospace Sceince Conference
sponsored by American Institute of
Aeronautics and Astronautics
Orlando, Florida, January 11-14, 1982

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agent, the United States Department of Energy, nor any Federal employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights

DOE/NASA/10769-22
NASA TM-82744

End Region and Current Consolidation Effects Upon the Performance of an MHD Channel for the ETF Conceptual Design

S. Y. Wang and J. Marlin Smith
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Work performed for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
Office of Magnetohydrodynamics
Washington, D.C. 20545
Under Interagency Agreement DE-AI01-77ET10769

Twentieth Aerospace Science Conference
sponsored by American Institute of
Aeronautics and Astronautics
Orlando, Florida, January 11-14, 1982

END REGION AND CURRENT CONSOLIDATION EFFECTS UPON THE PERFORMANCE OF AN MHD CHANNEL FOR THE ETF CONCEPTUAL DESIGN

S. Y. Wang and J. Marlin Smith
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

E-1057

Abstract

Operating conditions which yielded the peak thermodynamic efficiency (41 percent) for an ETF-size MHD/steam plant were previously identified by considering only the active region (the primary portion for power production) of an MHD channel. In this paper, the efforts of the previous study are extended to include the investigation of the effects of the channel end regions on the overall power generation. Considering these effects the peak plant thermodynamic efficiency is found to be slightly lowered (40.7 percent) and the channel operating point for the peak efficiency is shifted to the supersonic mode (Mach No., $M_c \sim 1.1$) rather than the previous subsonic operation ($M_c \sim 0.9$). The sensitivity of the channel performance to the B-field, diffuser recovery coefficient, channel load parameter, Mach number, and combustor pressure is also discussed. In addition, methods for operating the channel in a constant-current mode are investigated. This mode of channel operation is highly desirable from the standpoint of simplifying the current and voltage consolidation for the inverter system. This simplification could result in significant savings in the cost of the equipment. The initial results of this study indicate that this simplification is possible, even under a strict Hall field constraint, with reasonable plant thermodynamic efficiency (40.5 percent).

I. Introduction

Previous studies[1,2] have identified MHD channel configurations and operating conditions which result in peak thermodynamic efficiency of the combined MHD/steam plant. A critical factor in these studies was that the MHD channel was cooled by low pressure, low temperature boiler feedwater. This results in a lowering of the steam plant efficiency with increasing MHD channel heat loss since it reduces the amount of regenerative boiler feedwater heating that can be done within the steam plant itself. In these initial studies, only the active (significantly power producing) region of the channel was considered. This region was taken to extend from a B-field low of 4 tesla at the front of the channel to a B-field low of approximately 3.5 tesla at the rear of the channel (see Fig. 1). However, even though the regions upstream and downstream of the active region do not produce significant amounts of power, they still produce significant voltage which requires voltage isolation. Therefore, these regions require MHD-channel-type construction and hence cooling with low-pressure, low-temperature boiler feedwater with the attendant possibility of a further reduction in overall plant efficiency.

The results presented in this paper apply only to plants of the size of the ETF conceptual design (200 MW_e) and to MHD channels whose design requirements specify cooling with low-pressure, low-temperature boiler feedwater. The sensitivity of various channel parameters (maximum B-field, diffuser recovery coefficient, generator load parameter, Mach number, and combustor pressure) are examined under the constraints of a maximum axial electric field (E_x) of 2.5 kV/m, a maximum transverse electric field (E_y) of 4 kV/m, and a maximum transverse current (J_y) of 10 kA/m^2. In addition, the channel performance is investigated using constant current output in various regions of the channel in order to take advantage of possible cost savings for the inverter system under these conditions.[3,4]

II. Background

The channel analysis is based on a quasi-one-dimensional code.[5] However, in this study the code has been modified to allow the calculation of the voltage drops through the integral boundary layer. This is necessary since the original model is inadequate for the channel end regions. In addition to the voltage-drop calculations, the channel code utilizes tabulated chemical equilibrium properties which are computed separately.[6] This allows a considerable reduction of the required computing time, especially in the region of the boundary layers. The channel code is then combined with an overall system calculation[2] to determine the performance of the MHD/steam plant.

III. Channel Characteristics

The operating conditions and electrical stress constraints used in this study are given in Table 1. In Ref. 1, the optimal channel had an active length of 12 m. In this study, the end regions of the channel are included by starting the calculations at the 0.5 tesla point and considering the entire length of the channel to be 16 m which results in a B-field of 0.5 tesla at the exit (Fig. 1). At these B-field levels, the Hall electric field at the channel entrance and exit is approximately 10 V/m and 40 V/m, respectively. At these electric field levels, voltage isolation is no longer a serious problem and the construction is that of the nozzle or diffuser which are cooled by intermediate or high-pressure boiler feedwater which does not seriously affect the overall system efficiency.

IV. Results

Table 2 lists the results for twelve cases all optimized for combustion pressure (P_c) and load coefficient (K_{min}). These cases are for the ETF conceptual design input power level of 540 MW_t, an air enrichment level of 30 percent O_2 by volume, and a length of 16 m, as discussed below.

Base Case

Case 1 is the result of adding the end regions to the initial ETF channel configuration in which only the active region (central 12 m) was considered.[1] In case 1, P_c and K_{min} have been readjusted to obtain the peak overall system efficiency for the total length of 16 m. An overall efficiency of 40.3 percent was obtained which compares to the 41 percent obtained previously. Axial profiles of E_x, E_y, J_y, K, MHD power (P_{MHD}), and Hall parameter (β) for this case are plotted in Fig. 2.

Variation of Mach Number and Maximum B-Field

The effect of varying the inlet Mach number on the plant overall thermodynamic efficiency is shown in Fig. 3 for peak B-fields of 6 tesla (cases 1-4) and 5 tesla (cases 5-8). It is seen that for the B_{max} = 6 telsa case a maximum efficiency of 40.7 percent is obtained at a supersonic Mach number of 1.1. This compares to a value of 41 percent at a Mach number of 0.9 obtained for the original 12-m channel calculation.^{1} The increase in optimum Mach number for the present calculation is primarily the result of the fact that a lower average B-field exists in this longer channel. As was shown in Ref. 1, the lowering of the B-field results in a higher optimum Mach number. This is again born out as can be seen from the results for the B_{max} = 5 tesla cases 5-8 where the maximum efficiency of approximately 40.4 percent occurs at a Mach number of 1.25.

In all of the above cases for B_{max} = 6 telsa, the diffuser pressure recovery coefficient, C_D, was held constant at 0.46. A sensitivity study was then conducted by considering $C_D = 0.4$ and 0.55. The result of this variation is shown in cases 9 and 10 of Table 2. It is seen that the sensitivity in the overall efficiency is about ±0.2 percent over this range of recovery coefficients.

Constant Faraday Current Operation

ETF conceptual design studies have shown that considerable simplification of the consolidation and inverter circuitry can be obtained by operating the generator at constant Faraday current, $I_y = J_y A_e$, where A_e is the effective electrode area. Cases 11 and 12 of Table 2 show the effect upon performance of attempting to operate various regions of the channel in this constant current mode. Because of the direct relation of J_y to the axial electric field, i.e., $J_y \sim \sigma E_x/\beta$, the current level is in turn limited by the E_x constraint--especially at the downstream section of the channel where the electrical conductivity (σ) drops and the Hall parameter (β) is high. The results of case 11 in which an attempt was made to operate the entire channel at a constant current output of $I_{y,max} \sim 2.9$ kA/m (where $I_{y,max}$ is the maximum transverse current/unit length) are shown in Fig. 4. The axial variation of I_y, J_y, E and β are depicted on the figure. Nearly one half of the channel can be run at constant current but at $X \sim 8$ m the Hall field limit is reached.

In an attempt to further simplify the inverter system, i.e., to eliminate the continuously varying current output at the latter half of the channel, a two-level case ($I_{y,max} \sim 3.0$, 2.5 kA/m; case 12) was investigated. The results are shown in Fig. 5 and are not significantly different from those in Fig. 4. Using two levels of constant current does not extend the length of constant current appreciably and does not render significant simplification of the current consolidation system over case 11.

Preliminary calculations show that if $E_{x,max}$ is relaxed to about 3.5 kV/m, almost the whole channel can be controlled at one level of constant current but the plant thermodynamic efficiency drops about one point relative to case 11. Nevertheless, both cases 11 and 12 show reasonable performance for partial constant-current control with a plant thermodynamic efficiency (η_{th}) of about 40.5 percent.

Concluding Remarks

This study of the MHD channel for a 540 MW_{th}, ETF-size plant, 16 m long, including the end sections suggests:

1. The best performance is obtained in the supersonic mode, even for B_{max} = 6 tesla ($\eta \sim 40.7$ percent, $M_c \sim 1.1$).
2. Lowering B_{max} to approximately 5 tesla does not severely lower the performance ($\eta_{th} = 40.4$ percent at $M_c \sim 1.25$) and could result in a reduction of the magnet size of up to 40 percent.
3. The overall performance is not too sensitive to diffuser pressure recovery coefficient. For a C_D range of 0.4 - 0.55, the overall efficiency changes by ±0.2 percent.
4. A simplification of the inverter system is possible. Good channel performance ($\eta_{th} \sim 40.5$ percent) can be obtained using a partial constant-current mode, even under a strict electrical constraint on the Hall field ($E_{x,max} \sim 2.5$ kV/m). If this constraint could be relaxed to about 3.5 kV/m, the entire channel could be controlled by a constant-current operation; however, the penalty in plant efficiency might not be negligible.

References

1. Wang, S. Y., Staiger, P. J., and Smith, J. Marlin, "An MHD Channel Study for the ETF Conceptual Design," DOE/NASA/10769-14, NASA TM-81764, 1981.
2. Staiger, Peter J., "Performance Calculations for 200-1000 MWe MHD/Steam Plants," DOE/NASA/10769-16, NASA TM-81775, 1981.
3. Demirjian, A. M. and Pian, C. C. P., "Performance of MHD Generators with Electrode Current Control," AIAA-81-0249, Jan. 1981.
4. Demirjian, A. M. and Quijano, I. M., "Power Conditioning and Control Requirements of Coal-Fired MHD Generators," AIAA 81-0246, Jan. 1981.
5. Pian, C. C. P., Seikel, G. R., and Smith, J. M., "Performance Optimization of an MHD Generator with Physical Constraints," Proceedings of the 14th Intersociety Energy Conversion Engineering Conference, August 1979, Vol. 2, pp. 1939-1944.
6. McBride, B. J. and Gordon, S., "Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks and Chapman-Jouguet Detonations," NASA SP-273, 1976, Rev.

TABLE 1. - THE OPERATING CONDITIONS AND ELECTRIC STRESS CONSTRAINTS

Thermal input, MW	540
Coal type	Montana Rosebud
Moisture content in coal, percent	5
Oxidizer (O_2 enriched air), vol. percent	30
Oxidizer preheat temperature, °F	1100
Seed, 1 percent-mass, K	K_2CO_3
Total flow rate, kg/sec	133
Combustor heat loss, percent	5
Combustor slag rejection, percent	65
Oxygen stoichiometry, percent	90
Poly. eff. of cycle compressor, percent	89.8
Specific power of ASU, kW-hr/eq. ton O_2	204
Ambient pressure (atm) and temperature (°F)	0.89; 42
B-field	National Magnet Laboratory (NML) preliminary design (Fig. 1)
Axial electric field limit, kV/m	2.5
Transverse electric field limit, kV/m	4.0
Transverse electric current limit, kA/m^2	10

TABLE 2 - PERFORMANCE OF THE 16-m CHANNEL FOR ETF WITH END REGIONS

(O_2 ~ 30 percent, B_{max} ~ 5,6 tesla, M_c ~ 0 9 ~ 1 35, C_D ~ 0 4 - 0 55)

Case no.	B_{max}, tesla	Mach no	Diffuser coefficient	Combustor pressure, atm	MHD power, MWe	Channel heat loss, MWt	Cycle compressor power, MW	O_2 compressor power, MW	Bottom cycle input, MWt	Steam cycle efficiency, percent	Steam cycle output, MWe	Cycle coal input, MWt	Gross ac power, MWe	Thermal cycle efficiency, percent
1	6	0.9	0.46	4.4	85 06	28 48	21.98	11 62	430 47	38 76	133 25	539 81	217.5	40.29
2		0.95		4 4	86 10	27.79	21 98	11 62	429 13	38 80	133 03	539 21	218 3	40 43
3		1.07		4 4	87 39	25 42	21 98	11 62	428 14	38 96	133.19	539 81	219 7	40 70
4		1.15		4 3	86.29	23 99	21 60	11 62	428 86	39 05	134 23	539 81	219 7	40 69
5	5	1 05	0 55	4.4	81.18	26 18	21 98	11 62	434 35	38 91	135 39	539 81	215 9	39.97
6		1 15		4 2	82 95	24 10	21 31	11 62	431 91	39 05	135 79	539 81	217 9	40 37
7		1.25		4 0	81 39	21.67	20 42	11.62	432 57	39 20	137 20	539 81	218.1	40 40
8		1.35		3 7	77 52	19 56	19 17	11 62	435 20	39 51	140 27	539 81	217.0	40 20
9	6	0 9	0.40	4.5	83.90	28 96	22 36	11 62	432 10	38 71	133 40	539 81	216.4	40 08
10			0.55	4 5	87.08	27 90	22 36	11 62	428 82	39.79	132 39	539.81	218 6	40 49
11				4 2	86.26	28 22	21 21	11 62	428 50	38 77	133 30	539 81	218.7	40 51
12				4 2	86 51	27 95	21 21	11 62	428 25	38 79	133 27	539 81	218 9	40.56

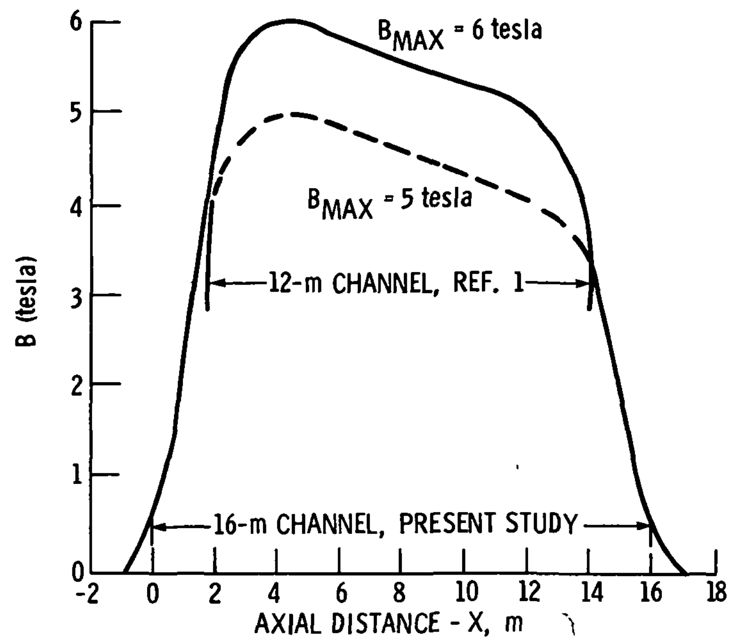

Figure 1. - Axial profile of B-field from National Magnet Laboratory preliminary design for the ETF.

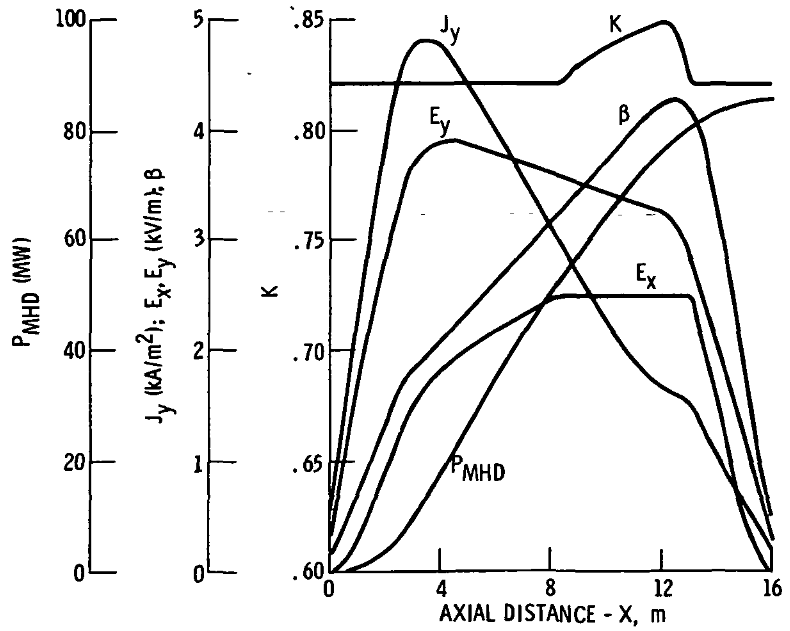

Figure 2. - Axial profiles of E_x, E_y, J_y, K, P_{MHD}, and β for case 1. (O_2 = 30%-vol., M_c = 0.9, 16-m channel.)

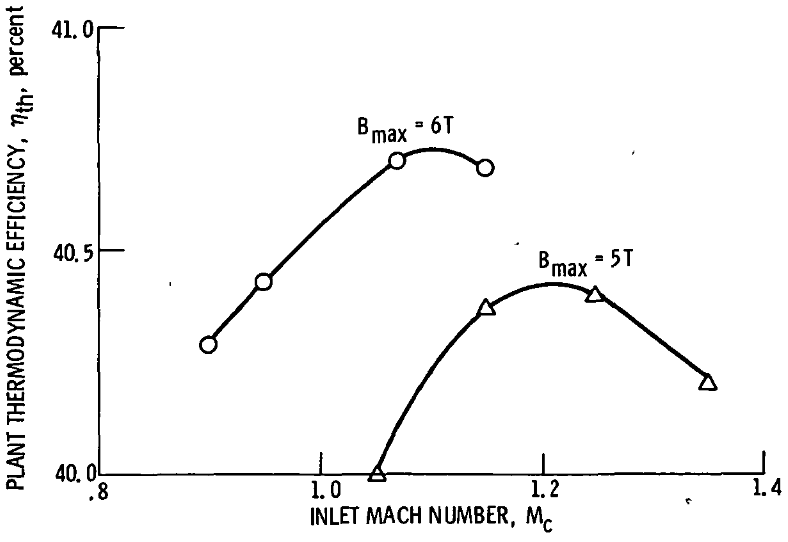

Figure 3. - Thermodynamic efficiency versus Mach number for maximum B-field of 6 tesla and 5 tesla.

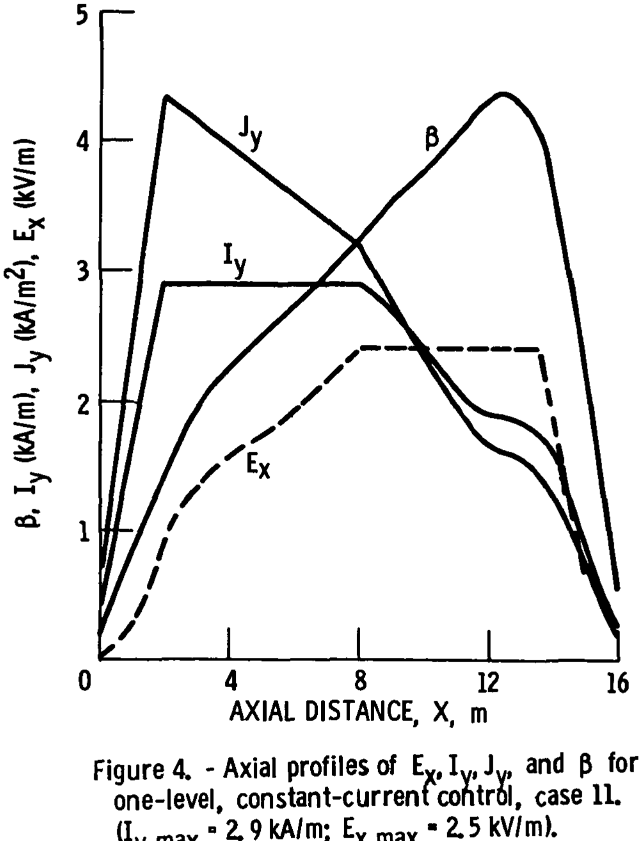

Figure 4. - Axial profiles of E_x, I_y, J_y, and β for one-level, constant-current control, case 11. ($I_{y,max}$ = 2.9 kA/m; $E_{x,max}$ = 2.5 kV/m).

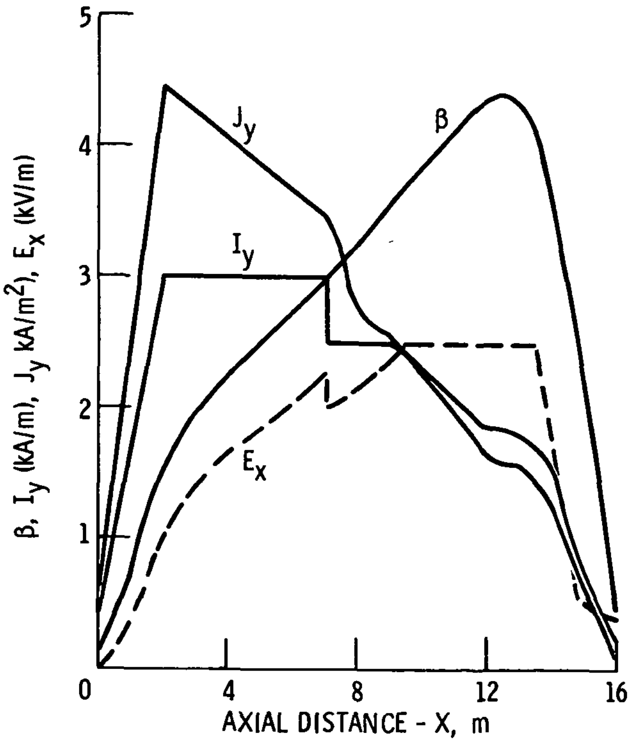

Figure 5. - Axial profiles of E_x, I_y, J_y, and β for two-level constant-current control, case 12. ($I_{y,max}$ = 3.0/2.5 kA/m; $E_{x,max}$ = 2.5 kV/m.)

1 Report No NASA TM-82744	2 Government Accession No	3 Recipient's Catalog No

4 Title and Subtitle END REGION AND CURRENT CONSOLIDATION EFFECTS UPON THE PERFORMANCE OF AN MHD CHANNEL FOR THE ETF CONCEPTUAL DESIGN	5 Report Date November 1981
	6 Performing Organization Code 778-11-05
7 Author(s) S. Y. Wang and J. Marlin Smith	8 Performing Organization Report No E-1057
	10 Work Unit No
9 Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135	11 Contract or Grant No
	13 Type of Report and Period Covered Technical Memorandum
12 Sponsoring Agency Name and Address U.S. Department of Energy Office of Magnetohydrodynamics Washington, D.C. 20545	14 Sponsoring Agency ~~Code~~ Report No. DOE/NASA/10769-22

15 Supplementary Notes

Prepared under Interagency Agreement DE-AI01-77ET10769. Prepared for Twentieth Aerospace Science Conference sponsored by the American Institute of Aeronautics and Astronautics, Orlando, Florida, January 11-14, 1982.

16 Abstract

Operating conditions which yielded the peak thermodynamic efficiency (41%) for an ETF-size MHD/steam plant were previously identified by considering only the active region (the primary portion for power production) of an MHD channel. In this paper, the efforts of the previous study are extended to include the investigation of the effects of the channel end regions on the overall power generation. Considering these effects the peak plant thermodynamic efficiency is found to be slightly lowered (40.7%) and the channel operating point for the peak efficiency is shifted to the supersonic mode (Mach No., $M_c \sim 1.1$) rather than the previous subsonic operation ($M_c \sim 0.9$). The sensitivity of the channel performance to the B-field, diffuser recovery coefficient, channel load parameter, Mach number, and combustor pressure is also discussed. In addition, methods for operating the channel in a constant-current mode are investigated. This mode of channel operation is highly desirable from the standpoint of simplifying the current and voltage consolidation for the inverter system. This simplification could result in significant savings in the cost of the equipment. The initial results of this study indicate that this simplification is possible, even under a strict Hall field constraint, with reasonable plant thermodynamic efficiency (40.5%).

17 Key Words (Suggested by Author(s)) Power generation MHD channel Combustion Fluid dynamics Coal	18 Distribution Statement Unclassified - unlimited STAR Category 75 DOE Category UC-90g

19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages	22 Price*

* For sale by the National Technical Information Service, Springfield Virginia 22161