Part-Load Performance And Voltage-Current Characteristics Of A Base Load MHD Generator

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PART-LOAD PERFORMANCE AND VOLTAGE-CURRENT CHARACTERISTICS OF A BASE LOAD MHD GENERATOR

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Abstract

A knowledge of the electrical and aerodynamic response of an MHD generator to load changes is important for the design of the ducting, control system, and inverter of an MHD power plant. It is also of interest to know how the efficiency of a plant will vary with loading. This paper explores the characteristics that are to be expected in a subsonic Faraday generator designed for base-load service. It is shown that a Faraday hookup will tend to act as a constant current source under some important conditions. The performance of a subsonic channel in terms of percent enthalpy extraction drops relatively slowly as load is reduced. A ten to fifteen percent drop is predicted at a mass flow rate one-half of the design point value.

I. Boundary Conditions

For the purpose of predicting the output voltage-current (V-I) characteristics of an MHD generator, four different possible limiting boundary conditions are of interest. These are:

1. Constant velocity
2. Constant inlet stagnation pressure.
3. Constant mass flow rate
4. Constant loading parameter,

$$K = \frac{E_y}{uB}.$$

In general, the time scale of interest determines which is the most appropriate condition to apply.

The first condition, constant velocity is the boundary condition appropriate when studying response to a rapid load change which occurs in a time so short, that the inertia of the gas inhibits any appreciable change in velocity. Typically this means a time less than about one millisecond.

The second condition, constant inlet stagnation pressure, is expected to apply for time scales on the order of seconds. The length of time during which essentially constant stagnation pressure prevails depends upon the characteristics, in particular the volume of the equipment upstream of the generator. Typically, in a base-load plant the volume in the combustion chamber, ducting, and air preheaters, is sufficiently large so that even for quite drastic changes in mass flow rate through the generator, it will be several seconds before the stagnation pressure at the inlet to the generator changes significantly.

In all cases it will be assumed that the resistance to flow in the exhaust ducting is sufficiently low and the losses in the diffuser sufficiently invariant or small or both so that the stagnation pressure at the exit of the generator channel is always a constant, i.e. about one atmosphere. This simplification is allowable for the purpose of making qualitative statements about channel behavior as long as the flow is subsonic.

Condition three, constant mass flow rate, is approximately the condition that a compressor will attempt to impose. Therefore, an increase in load current, which first causes the mass flow rate through the generator to fall will, after a few seconds during which the upstream equipment fills, result in a rise in stagnation pressure to a new equilibrium value and the restoration of the mass flow rate through the generator to its original value. This assumes that the compressor does not stall or that nothing has been done in the meantime to reduce the compressor rpm or to bleed off excess air. A bleed system capable of reacting on a time scale of about one second probably should be a feature of any power plant if the compressor and its drive system are not capable of reacting this fast, hence the condition of constant mass flow rate during a rise in load current may not be encountered in practice. However, it is still of interest to see what the V-I characteristic would be under this condition.

Condition four, constant loading parameter, is approximately the condition that one would expect to impose during deliberate load changes of extended duration, i.e. operation at part load for several minutes, hours, or longer; that is to say, times long enough so that one would seek to maintain the highest possible plant efficiency. While it may turn out that best part-load performance of the plant as a whole is obtained at a loading parameter somewhat different from that used at full load, it is not likely that it would differ greatly, and so the assumption of constant K should be sufficient to reveal the general trend of the voltage, current, and generator performance changes that will occur at part load.

There is yet a fifth condition during which everything is constant but a localized fault occurs in the circuitry connected to a single electrode pair of a multielectrode Faraday channel. It is, of course, a condition of considerable importance for inverter design and one expects that a very flat V-I characteristic, i.e. large change in current with a small change in voltage, will result. However, it does not involve changes in the overall aerodynamics of the flow through the generator, and is not considered in this paper. Possibly, however, some of the overall response characteristics to be described below could be utilized for the purpose of minimizing the current surge due to a localized fault. This will be discussed a bit more later.

Another matter of interest is of course the details of the internal behavior of the flow through the generator while it passes from one to the other of the quasi-steady conditions described above, in particular from condition one to condition two, which occurs on a time scale on the order of the time it takes a particle or a sound wave to travel the length of the channel. This also is not considered here, but has been considered by Oliver.[1]

II. Procedure

In order to find the response of a subsonic generator to various loads under the several conditions or constraints listed above, it is necessary to make a large number of flow calculations, the number being increased by the difficulty of matching the one atmosphere exit condition by any other method than iteration. However, since the objective of this study was to obtain only a qualitative description, a very simple method of calculation was employed in which the boundary layers are neglected and simple equations are employed to describe the geometry of the channel and the dependence of conductivity upon pressure and temperature. Thus a large number of iterations could be performed easily. It is believed that the results never-the-less represent reasonably well the character of the response that will be obtained from a subsonic channel. A small number of detailed calculations, using a large generator off-design program, were performed some time ago by Lowenstein at AVCO[2], and the results obtained here are qualitatively consistent with the earlier results. An important limitation here is, however, that conditions that would cause a transition to supersonic flow are excluded.

The calculations are based upon design-point conditions which approximately correspond to those used in Base Case I of the GE-AVCO part of the ECAS study.[3,4] The pertinent conditions are: coal firing, an air preheat temperature of 2500°F (1640 K), an inlet stagnation pressure of 9 atmospheres, a loading parameter of approximately 0.75 and an inlet Mach number of approximately 0.8. The channel configuration is such as to maintain, when operating at the design point, approximately constant Mach number throughout the length of the channel.

III. Results

The results of these calculations are summarized in Figure 1 which shows V-I characteristics for the four stated boundary conditions and three axial positions and in Figure 2 which shows the relative axial Mach number distributions. In the latter, it is of interest to note the tendency for the Mach number to remain relatively constant throughout the length of the channel except in the case of constant mass flow rate. Even in this case the distribution is quite flat except near the channel exit.

The most interesting feature of the V-I characteristics is the tendency under conditions 2 and 4, which are possibly the most important ones, for a very steep slope. In other words, the Faraday generator is acting much like a constant current source, the behavior that is commonly but probably erroneously attributed to a Hall or diagonal generator at high Hall parameter. Although this study is limited to subsonic conditions, it is evident that a transition to supersonic flow caused by anything that results in a decrease in Faraday current, will tend to continue or even accentuate the steep slope. Once supersonic flow is established, the slope will then become more gradual.

A possibility introduced by the steep slope is to use it to inhibit a high local current due to a localized fault, say a failure of an inverter to commutate. It could perhaps be prevented from doing so by momentarily causing the loading parameter to drop on all circuits on the theory that if all circuits try to draw a large current then none can.

Calculated part-load performance, obtained by varying the mass flow rate while keeping the loading parameter constant, is as follows:

Table 1.--Part-Load Performance

$\dot{m}/\dot{m}_D$	1	.75	.5	.3
P_o(atm)	9	8.7	7.7	6.5
$\Delta h/\Delta h_D$	1	.96	.92	.84

where $\dot{m}$ = mass flow rate
P_o = inlet stagnation pressure
Δh = percent enthalpy extraction per unit mass

and the subscript D denotes a design-point value.

The change in percent enthalpy extraction depends mainly upon the change in the product ($\sigma u/\rho$) as mass flow rate and Mach number are changed (here: σ = conductivity, u = velocity, and ρ = density). This product, over a moderate range of Mach numbers, does not change rapidly, hence the moderately slow drop-off in performance as flow rate is reduced.

In order to maintain the design-point enthalpy extraction at half-load an increase in conductivity by a factor of about 1.4 turns out to be required. Since the design-point seeding rate is 1%, which is near the optimum, an increased seeding rate is not likely to give a factor this large. However, it could be obtained with a 150 to 200 K increase in air preheat temperature if this was in other respects feasible.

IV. Summary

It has been shown that a subsonic segmented Faraday MHD generator will exhibit a variety of voltage-current characteristics depending upon conditions. It will tend to operate as or nearly as a constant current source under two conditions of interest. Part load performance, at least down to half-load will drop only moderately, and under most conditions the axial Mach number distribution will remain relatively flat. These conclusions are based upon relatively rough calculations, however, and more detailed calculations, including boundary layer effects, and variable diffuser performance, and extending into the supersonic range are desirable. Also desirable for coupling the generator to an inverter are further studies such as that of Ref. 1 on transient effects and a study of the voltage-current characteristic of a local fault.

V. References

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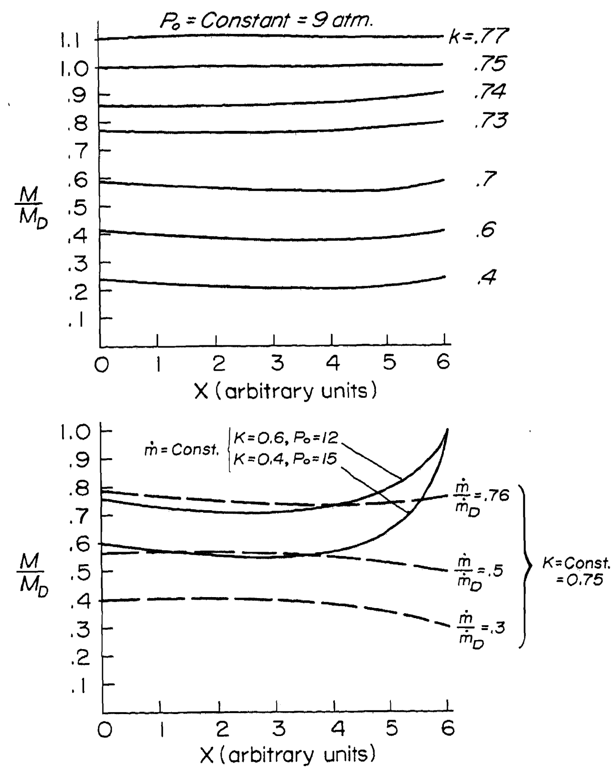

Figure 2 Mach No. Distribution

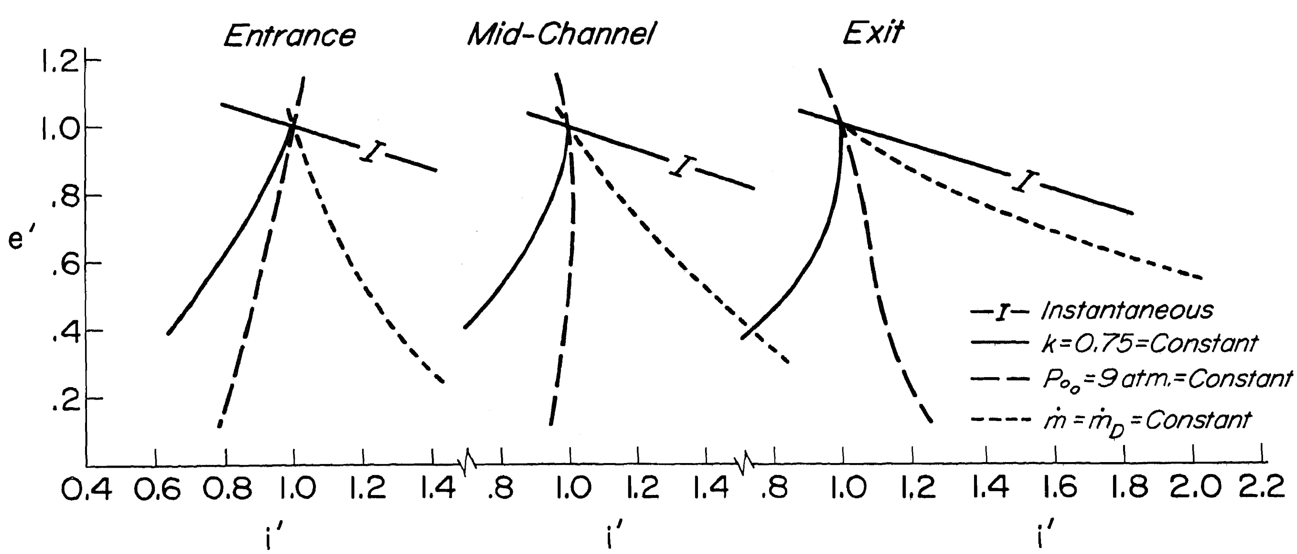

Figure 1 Voltage-Current Characteristics of a Subsonic, Faraday, Base-Load Channel. Approx. ECAS Case No. 1 Conditions (1640°K Preheat, 1 wt%K)