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Comparison of Performance of Magneto Hydrodynamics Generator in Presence of Hall Effect

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Abstract

Magneto Hydrodynamics is studying of high-temperature plasmas exposed to strong electromagnetic field. Also, it is used to obtain an electrical power. This paper proposes a simple model of MHD generator. Moreover, efficiency of different configuration of this generator is obtained by this model. Also, this paper compares different configurations of Faraday generator with the Hall generator based on their isotropic efficiency. Moreover, this model considers the effect of Hall Effect (Ion slip) on the efficiency. This analysis proof that Hall Effect decrease the efficiency in Faraday generator but increase the efficiency in the Hall generator.

Keywords: *Hall Effect, Isotropic efficiency, Magneto Hydrodynamics*

Numinicalature:

V_e	*Electron Drift Velocity*
v_x	*x-Direction of electron drift velocity*
v_y	*y-Direction of electron drift velocity*
v_z	*z-Direction of electron drift velocity*
u	*Fluid velocity*

μ	*Mobility*
β_e	*Hall Number*
J	*Current*
E	*Electrical Field*
B	*Magnetic field strength*
σ_0	*Electrical conductivity*
K	*Load Factor*

1 Introduction

Magneto Hydrodynamics (MHD) is a study of high-temperature plasmas exposed to strong electromagnetic fields to obtain an electrical power generation. The MHD governing power generation deals specifically with the flow of combustion plasmas in the presence of magnetic fields. The combustion plasmas are generated by burning a fuel in a high-pressure combustor and the introduction of an easily ionizable substance.

The generation of electric power using MHD schemes with an ionized gas as the working fluid has been considered in considerable detail [1], [2] and a number of small-scale, experimental studies have been reported [3], [4]. Gas-dynamic MHD machines are appropriate for open-cycle systems where seeded combustion gases serve as the moving conductor; the objective is to gain a significant performance improvement over that of presently available steam power plants.

For closed-cycle systems in which the source of thermal energy is likely to be a nuclear reactor, both ionized gases and liquid metals may be considered as possible working fluids for the MHD generator duct. The temperature limitations imposed by current reactor technology are such that adequate gas conductivity only can be obtained by some scheme such as nonequilibrium ionization, but the conductivity of liquid metals is sufficiently high to enable them to be utilized directly. The liquid-metal MHD generator may be arranged to deliver either alternating or direct current.

Various pulsed MHD generators have been constructed and operated to produce electrical power pulse generation. This was a combustion-driven MHD pulse power system. This MHD power system type is fired by an independent high-pressure high-temperature combustor to produce high-velocity plasma. The new development on MHD power generation is used for aerospace applications [5], [6].

At very high magnetic fields relative to then gas pressure the positive ions deflected like as electrons. But because of larger mass of positive ion, they migrate in larger curve lateral path. This phenomenon (Hall Effect) affect on the efficiency of MHD generator.

MHD generator can be categorized in different configuration. This paper uses the isotropic efficiency as an index to compare these configurations in presence of Hall Effect.

You will be found the electrodynamics of MHD generator in the second segment. The efficiency of different configuration will be discussed in the third segment. Moreover, final segment analyze the equation of third part and will be shown their results.

2 Electrodynamics of MHD Generator

The basic MHD generator duct and the coordinate system are shown in Fig.1. The gas flow is in the x direction in a magnetic field which is in the z direction. The walls of the duct that the induced electrical fields set up are electrodes and the remaining of it is electrically insulating materials.

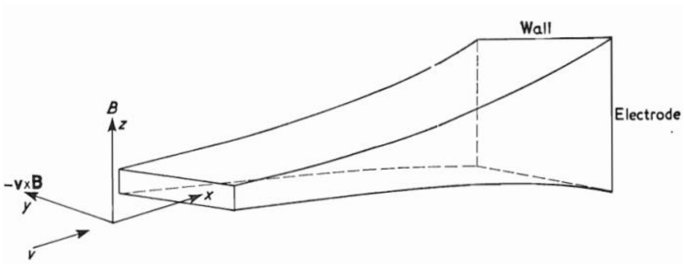

Figure 1: Basic MHD duct

To specify the manner of system in which the external load is connected to the electrodes it is necessary to consider the electrodynamics of the MHD generating duct. At first, the velocity of an electron in the electrical field is considering:

$$V_e = -\mu E_f \tag{1}$$

When both electrical field and magnetic field are present, the electrons drift velocity is now

$$V_e = -\mu_e (E + v_e \times B) \tag{2}$$

By this assumption that the magnetic field is only in the direction z, so the electron velocity split into component the parallel and perpendicular to the magnetic field. Now, the component of electron velocity is

$$\begin{aligned} v_x &= \frac{-\mu_e}{\left(1+\beta_e^2\right)}(E_x - \beta_e E_y) \\ v_y &= \frac{-\mu_e}{\left(1+\beta_e^2\right)}(E_x \beta_e + E_y) \\ v_z &= -\mu_e E_z \end{aligned} \tag{3}$$

Where $\beta_e = \mu_e B = \omega_e \tau_e$

The current can be calculated by the equation (4)

$$J = -\sigma E_f = -\sigma \frac{V_E}{\mu_e} \tag{4}$$

By substituting the equation (3) in equation (4)

$$\begin{aligned} J_{sx} &= \frac{\sigma_0}{\left(1+\beta_e^2\right)}\left(E_{sx} - \beta_e E_{sy} + \beta_e uB\right) \\ J_{sy} &= \frac{\sigma_0}{\left(1+\beta_e^2\right)}\left(E_{sy} - uB + E_{sx}\beta_e\right) \\ J_{sz} &= \sigma_0 E_{sz} \end{aligned} \tag{5}$$

Where $\beta_e = w_e \tau_e$

The physical interpretation of the equation (5) can be expressed by these rules:

1) The current flowing parallel with the magnetic field are unaffected by B.

2) The projection of E on J_e has the magnitude J_e/σ_0 .

3 Basic MHD Generator Configuration

It is possible to specify three basic MHD generator configurations:

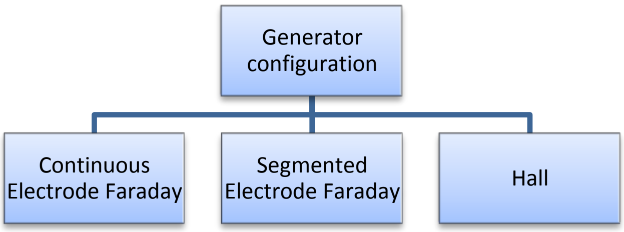

Figure 2: Categorize of MHD generator configuration

In this paper, efficiency of three configurations are calculated and compared with each other. Finally, indicated that which configuration is best one. Also, paper determines the variation of efficiency based on the Hall Effect.

3.1 Continuous Electrode Faraday (CEF) Generator Efficiency

This configuration is shown in Fig.3. CEF configuration is the simplest configuration and operates with a single load.

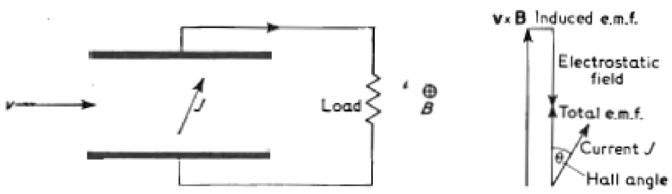

Figure 3 CEF generator

The boundary condition for this generator configuration is that the axial component of the electrical field is zero. So, bellow equation is reached

$$E_x = E_z = 0 \qquad J_z = 0$$
$$E_{sx} = E_{sz} = 0 \tag{6}$$

The open circuit voltage is uB and the short circuit voltage is E_{sy}. Consequently, the electrical efficiency K calculated by (7).

$$K = \frac{E_{sy}}{uB}$$
$$E_y = uB(K-1) \tag{7}$$

The x, y current component are given by (8)

$$J_x = \frac{\sigma_0}{1+\beta_e^2}\beta_e uB(1-K)$$
$$J_y = \frac{\sigma_0}{1+\beta_e^2}uB(1-K) \tag{8}$$

Finally, the power generated per unit volume is equal to $J_y E_{sy}$.

$$P_1 = \frac{\sigma_0}{1+\beta^2}U^2 B^2 K(1-K) \tag{9}$$

3.2 Segmented Electrode Faraday (SEF) Generator Efficiency

It is possible to eliminate the ohmic losses of continuous electrode Faraday generator by segmenting the electrode and connecting each pair through sub loads. It is shown in Fig.4. The generator loaded such that J_x is zero.

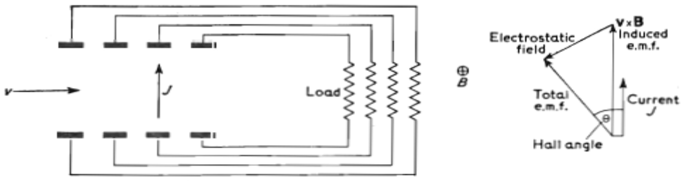

Figure 4 SEF generator

As before, open circuit voltage is uB and therefore, K, is given by

$$K = \frac{E_{sy}}{uB}$$
$$E_{sy} = KuB \tag{10}$$
$$E_y = uB(K-1)$$

Also we know that the transverse current is

$$J_y = \sigma_0 uB(1-k) \tag{11}$$

The power per unit volume is $J_y E_{sy}$.

$$p_2 = \sigma_0 u^2 B^2 k(1-k) \tag{12}$$

It is clear that the output power is independent of Hall Effect.

3.3 Hall Generator Efficiency

The Hall generator is one in which the segmented electrode pairs are short circuited and the external load is connected between the initial and final electrode pairs, as indicated in Fig.5.

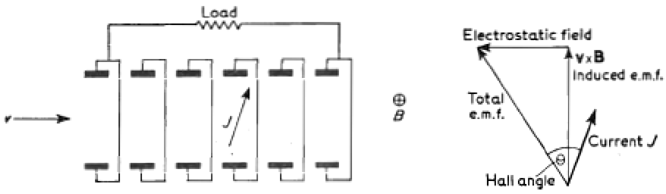

Figure 5 Hall generator

The loading factor no longer has the complete definition it had for CEF and SEF generators. But, it is still equal to the ratio of closed circuit voltage to open circuit voltage.

$$K = \frac{E_{sx}}{\beta_e uB} \qquad E_{sx} = \beta_e kuB \tag{13}$$

And the current components are:

$$J_x = \frac{\sigma_0}{\left(1+\beta_e^2\right)}\beta_e uB(k-1) \qquad J_y = \frac{\sigma_0}{\left(1+\beta_e^2\right)}uB(1+k\beta_e^2) \tag{14}$$

The power output per unit volume is

$$p_3 = \frac{\sigma_0}{(1+\beta_e^2)}\beta_e^2 u^2 B^2 k(1-k) \tag{15}$$

4 Simulation

There are many different indexes to compare application of these configurations. The power output varies with the MHD parameters. So, specific power output or isotropic efficiency is the best index to comparing applicants of these configurations.

Isotropic efficiency for continuous electrode Faraday generator is shown in the Fig.6. This figure indicates that Hull number is very important. If Hull number increases, so the specific power output decreases. The maximum isotropic efficiency reach in the Hull number equal zero.

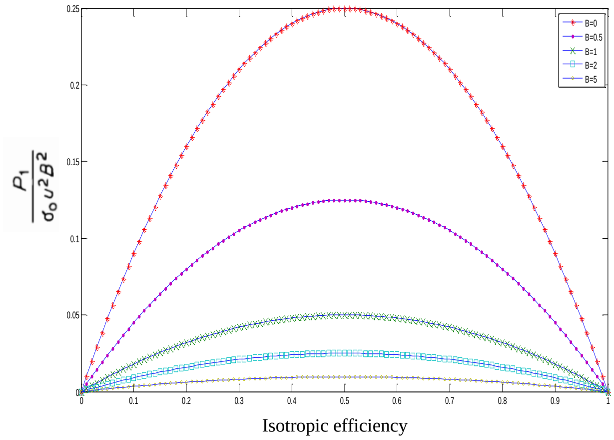

Figure 6 Isotropic Efficiency for CEF generator

In contrast to this, Fig.7 shows that the isotropic efficiency of the segmented electrode Faraday generator is independent of Hall number. One practical disadvantage of SEF generator is a multiplicity of external load circuits, which for a practical generator maybe several hundreds.

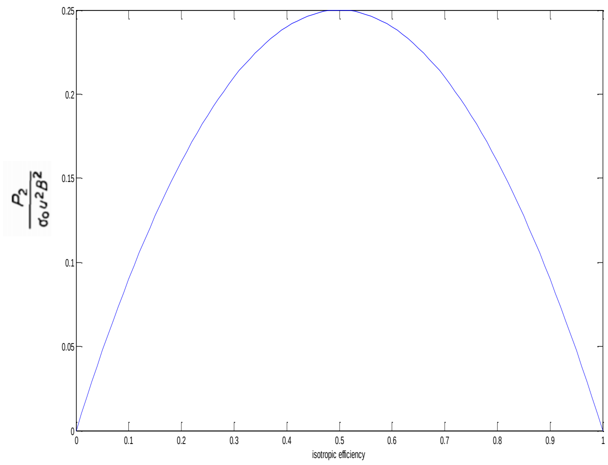

Figure 7 Isotropic Efficiency for SEF generator

Specific power output of Hall generator is shown in the Fig.8. High isotropic efficiency is practical for this generator configuration if the Hall number is high, greater than 10. Also, this configuration has advantage that it uses a single external load.

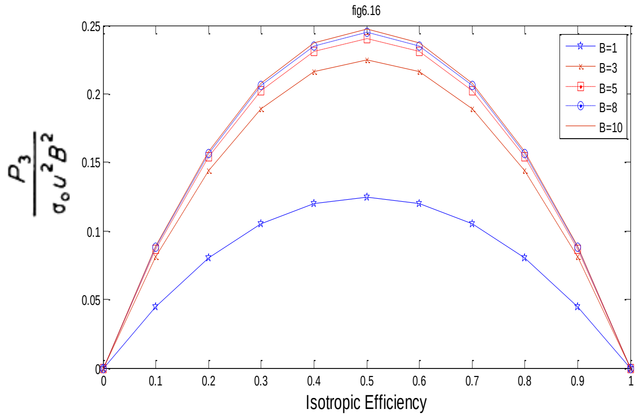

Figure 8 Isotropic Efficiency for Hall generator

5 Conclusion

One type of new generators is Magneto hydrodynamic (MHD) generator. This generator uses a plasma and magnetic field to produce electrical power. This plasma is produced in the combustion chamber and then flow through the magnetic field. This paper examines dynamic of fluid in the magnetic field.

Paper proposes a model for calculating of isotropic efficiency or loading factor. Also, paper compares different configuration of Faraday generators and Hall generator. This paper illustrates that Hall Effect decrease the electrical efficiency of Faraday generators but instead increase the electrical efficiency of Hall generator.

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