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Study and Analysis of Magneto Hydro Dynamic Power Generation Technology and its Temperature Sustainability

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Abstract-The MHD power generation processes is basically based on physic background of space plasma and its working is based on faradays law of electromagnetic induction. the electricity is directly extracted from thermal energy of plasma(ionized gas) which is passing through the strong magnetic field. this research paper reviews the different values of the power generation by the magneto hydrodynamic generator using the basic MHD equation by evaluating different values in the equation of different variables. It also determines the graphical representation of the variables involves in the determination of the power generated by the MHD generator which is the basic information in design analysis and graphing of power output by MHD generator. The research paper suggests the replacing of coal with nuclear reactor (Uranium) and its benefits and effect on environment. It also covers the temperature sustainability of the MHD generator working at high temperatures and the metals to be used to avoid any damages due to high temperatures and to sustain temperature at high levels. Moreover, potential use of nuclear energy means in place of conventional fuels has been presented.

Keywords-MHD (Magneto Hydrodynamic Generator, Magnetic Field, Hall Parameter, Temperature Sustainability.

I. Introduction

The magneto hydrodynamic phenomenon was first observed by Michael faraday in the year of 1832 during his work on the electromagnetic phenomena [i]. He observed that one could employ a fluid conductor as the working substance in a power generator. In the early 20th century an MHD pump was designed that later became the origin of the first MHD generator. in early 1940 the first experimental MHD generator was designed which did not achieved the expected power level due to the lack of knowledge of the properties of the ionized conducted fluids. After the studies of the properties of the ionized conducted fluid an MHD generator was designed in the late 1950s that produced about 12kw of power. The hybridization of the MHD generation was done in 1970's with the U-25 steam power plant which produced 75MW of electrical power out of which 25MW was produced by the MHD generator. For the first time in 1966 a joint team of scientist from 18 different countries was established known as “NEA/IAEA International liaison group on MHD power generation” to study the MHD generation and to hare technical information and solutions to technical difficulties related to MHD generation [ii]. At the end of the 20th century many MHD generators were reported working at a higher power levels.

A brief and comprehensive outline of the MHD phenomena along with various techniques as well as different parameters having potential influence has been presented. Also, a concise discussion regarding the replacement of use of coal for MHD fuel has been argued.

II. Methods of MHD Generation

The magneto hydrodynamic (MHD) phenomenon is the magnetic correlation with the electrical conducting fluids. It involves a high moving velocity conducting fluid under the effect of magnetic field. The MHD generation is a system that involves theconversion of kinetic energy of the conducting fluid directly into electrical energy without any mechanical energy losses as shown in figure 1. The MHD generator generates electrical power by the faradays law of electromagnetic induction phenomena [iii].

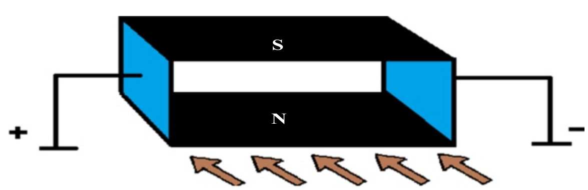


Fig. 1. M.H.D Generator

Generally, there are two methods are used for MHD powergeneration
(1) Open cycle MHD generation
(2) Close cycle MHD generation

A. Open Cycle MHD Generation

The type of generation that doesn't involve the reusage of the materials of the conducting fluid in an MHD plant. The temperature requirement for an open cycle generation is about 2300ºK which the lowest working temperature is [iv]. Normal working temperature used in open cycle MHD plant is up to 3000ºK

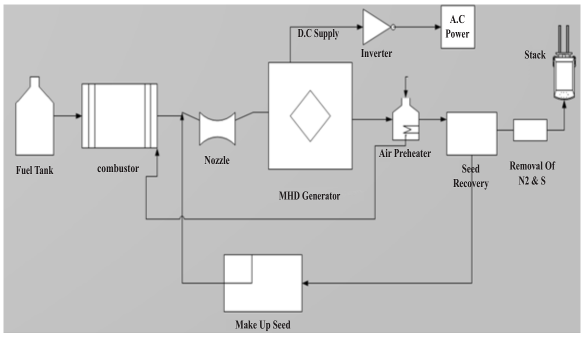


Fig. 2. open cycle MHD generator

B. Close Cycle MHD Generation

The generation in which the conducting fluid is recycled for generation is known as Close Cycle MHD generation [v]. The working temperature required for close cycle MHD is around 2000ºK. The reusage of the fuel and the working temperature gives the basic advantage of close cycle over the open cycle MHD generation.

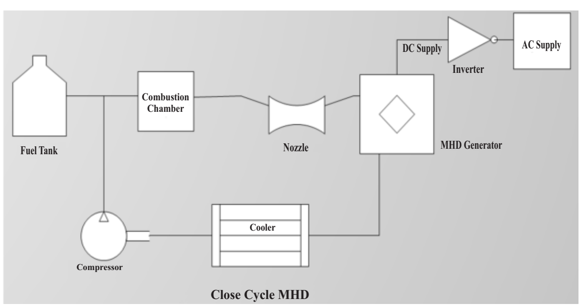


Fig. 3. Close cycle MHD System

III. Power Equation with Graphical Presentation

A. Derivationsof Power Equation

J = Current density

σ = *Electrical conductivity*

B = Magnetic field

$\vec{E}$ = *Electric field*

m = Mass of electron

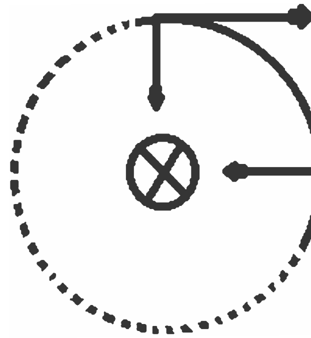
μ_e = *Mean electron velocity*

λ = *Mean free path*

T = *Mean time between collision*

Solving for the motion analysis

$$Acceleration = \frac{{v_\perp}^2}{R} \tag{1}$$



Circular motion of Electron

Fig. 4. Circular motion of electron

According to Newton's law

$$m\frac{{v_\perp}^2}{R} = \mathrm{Ze}V_\perp\beta \tag{2}$$

$$\frac{v_\perp}{R} = \omega = \frac{\mathrm{Z}e\beta}{\mathrm{m}} \tag{3}$$

Relating mean free path

$\frac{\lambda}{\mathrm{T}} = v_\perp$, $v_\perp = \omega\mathrm{R}$

$\omega_T = \frac{\lambda}{R}$

["ω_T" quantifies the HALL EFFECT]

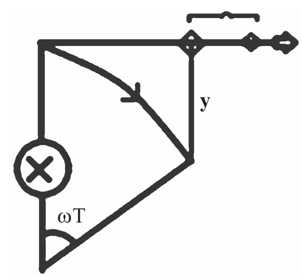


Fig. 5. Hall Effect

Using Faraday's interpretation

$J = \sigma(\vec{V} \times \vec{B})$, $V = -\mu\vec{E}$,

$J = -nZe\vec{V}$, $J = nze\mu\vec{E}$

$\sigma_0 = nZe\mu$, $J = \sigma_0 E$,

$E_f = \vec{E} + \vec{V} + \vec{B}$, $v_e = -\mu_e(\overrightarrow{E} + v_e + \vec{B})$

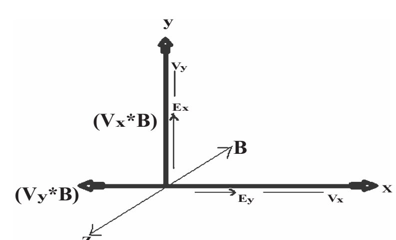


Fig. 6. Graphical Vectors

$$v_x = -\mu_e(E_x - v_y B)$$

$v_y = -\mu_e(E_y + v_x B)\,, v_z = -\mu_e E_z$

$v_x = -\dfrac{\mu}{1+\beta^2}[E_x + \beta E_y]$

$v_y = -\dfrac{\mu}{1+\beta^2}[E_y - \beta E_x]$

$v_z = -\mu E_z$

$\beta = BU = \omega\mathrm{T}$ (4)

$J_x = \frac{\sigma_0}{1+\beta^2}[E_x + \beta E_y]$, $J_y = \frac{\sigma_0}{1+\beta^2}[E_y - \beta E_x], J_z = -\mu E_{z)}$

$E_x = -E_{sx}\,, E_y = \overrightarrow{UB} - E_{sy} = \overrightarrow{UB} - E_{sy} = -E_{sz}$ where $k = \frac{E_{cc}}{E_{oc}}$ *(Loading factor)*

Boundry conditions are:

$E_x = 0,\quad E_z = 0,\quad J_z = 0$

$So \quad K = \frac{E_{sy}}{UB}, K = \frac{E_{sy}.J_y}{UB.J_y}$

$E_{sy} = KUB$

$E_y = UB(1-K)$ (5)

$J_x = \frac{\sigma_0}{1+\beta^2} UB(1-K)\beta -$ (6)

$J_y = \frac{\sigma_0}{1+\beta^2} UB(1-K) -$ (7)

$P = \frac{\sigma_0}{1+\beta^2} UB(1-K)KUB$ (8)

$$\boldsymbol{P = \frac{\sigma_0}{1+\beta^2} U^2 B^2 K(1-K)} \quad (9)$$

(basic power equation for an MHD generator in order to maximize power)

$Also \quad \frac{d_p}{d_k} = 0, \& \quad 1 - 2K = 0$

$K = 0.5$ (*the optimum value of loading factor*)

IV. Design Analysis of MHD Generator in Terms of Power

The main variables effecting the power of an MHD generator as seen from power equation are velocity (u), magnetic field (B), conductivity (σ_0)), hall parameter(wT) and loading factor (K). in order to maximize the power output of an MHD generator the loading factor K is kept constant at 0.5. Now we will analyse the output power of an MHD generator with varying one factor and keeping the other constant as given in the Figures 9~11.

A. Varying velocity

An MHD generator designed for maximum power output of 31MW for varying velocity while keeping all the other variables constant is shown in Fig. 7.

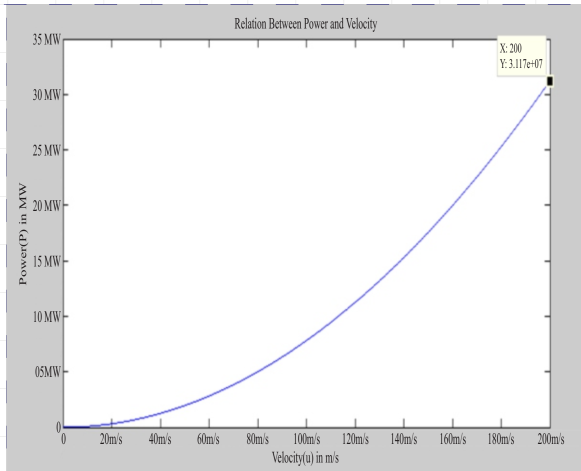


Fig. 7. Relation between power and velocity.

TABLE I
VARYING VELOCITY SCENARIO

Max. Generation capacity	31MW	Hall parameters	0.05
Conductivity	125 S/m	Loading factor	0.5
Magnetic field	5T	Velocity	0-200m/s

B. Varying Conductivity

The capacity of MHD generator is increased from 31MW to 37MW by varying the conductivity from 125-150 S/m while keeping velocity constant at 150m/s.

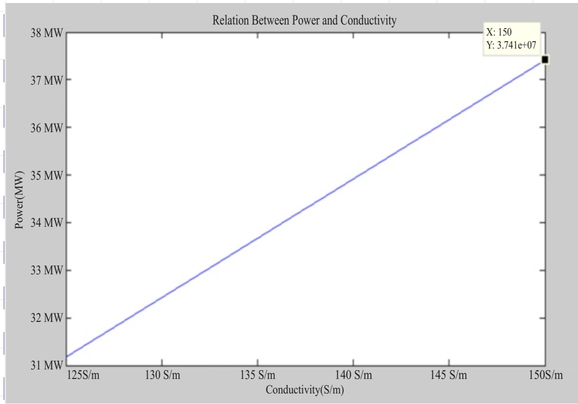


Fig. 8. Relation between power and conductivity.

TABLE II
VARYING CONDUCTIVITY SCENARIO

Maximum Generation capacity	37MW	Hall parameters	0.05
Conductivity	125-150 s/m	Loading factor	0.5
Magnetic field	5T	Velocity	150 m/s

C. Varying Magnetic Field

Maximum power generating Capacity is increased from 31MW to 124 MW by increasing the magnetic intensity from 5T to 10T while keeping the conductivity at 125S/m is shown in Fig. 9.

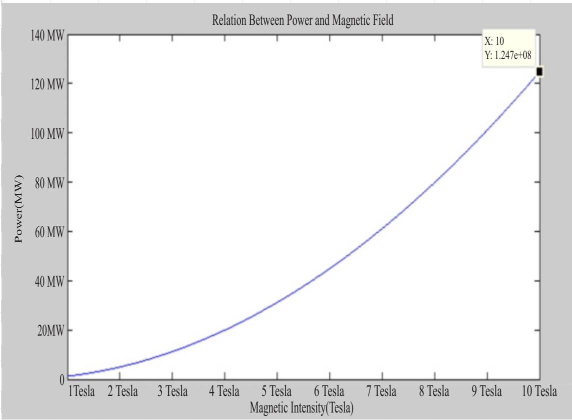


Fig. 9. Relation between power and Magnetic Field

TABLE III
VARYING MAGNETIC FIELD SCENARIO

Maximum Generation capacity	124MW	Hall parameters	0.05
Conductivity	125 s/m	Loading factor	0.5
Magnetic field	0-10T	Velocity	150 m/s

D. Varying Hall Effect

Increasing Hall Effect decreases the power generating capacity of MHD generator as given Fig. 10.

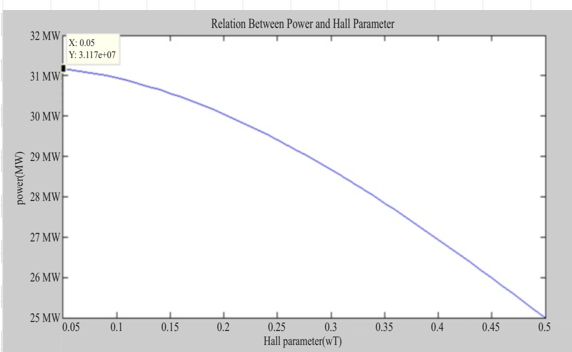


Fig. 10. Relation between power and Hall Effect

TABLE IV
VARYING HALL EFFECT SCENARIO

Maximum Generation capacity	31MW	Hall parameters	0.05-0.5
Conductivity	125 s/m	Loading factor	0.5
Magnetic field	5T	Velocity	150 m/s

E. Comparing Effect of Conductivity and Velocity

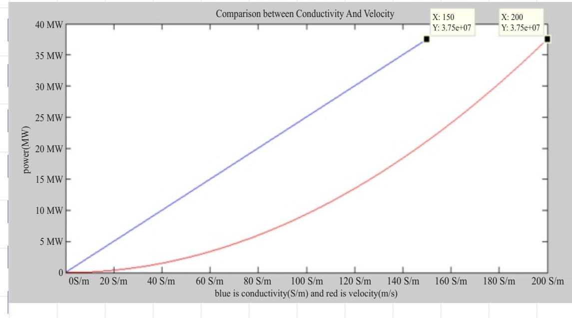


Fig. 11. Comparing the overall effect of conductivity and velocity on power generation.

It has been concluded that economically increasing conductivity of the fluid is more appropriable than increasing the velocity in open-cycle MHD. While increasing velocity is more appropriate in close cycle MHD. From the design analysis we concluded that changing the different parameters effect the power output of an MHD generator in its own way. Here the MHD generator designed at first for varying velocity has maximum power output of 31MW which is increased up to 37MW due to increase in the conductivity of the conducting fuel. And the same generator maximum generating power is improved to 124MW due to increase in the magnetic intensity from 5Teslas to 10Teslas. Thus, we can assume that magnetic intensity can affect the generating power up to wide range of minimum and maximum variations than any other parameter but the only problem here is that increasing the magnetic intensity has high initial cost.

V. MHD GENERATION USING NUCLEAR REACTOR INSTEAD OF COAL

Generally, in MHD generating plant coal is used as a fuel to produce heat up to 2000K. But it cost a lot due to travelling expenses and refining process and requires more area. And it's not friendly for environment, birds and human beings. As study shows that to produce 1000MW power using coal as a fuel for burner it approximately requires 9000tons of coal [vi]. While on the other hand the same power can be generated by just using 3Kgs of Uranium. It costs a lot to transfer 9000tons of coal from the mine to the plant as compared to transfer 3Kgs of uranium. 3kgs of uranium surrounds a small area as compared to 9000tons of coal. Coal combustion is the main source of carbon dioxide (CO_2) production which is the major cause of global warming. The usage of Uranium burner with MHD generator can reduces the size of MHD generator up to compatible size. Due to which it can be used for generating power at space technology, at submarines and space craft's. Due to size compactness and low weight to power ratio MHD system with uranium burner provides more reliability than any other power generating system. The use of the MHD system reduces the risk of problems at space station due to no vibrations because of any moving parts like turbine etc. As MHD plant operates at temperatures above 2000K so it is easy to achieve that much high temperature using uranium burner instead of coal burner [vii-viii]. The use of uranium as a burning fuel in an MHD plant can increase the efficiency of the MHD plant because it's easy to achieve high temperature ranges with Uranium which results in the sufficient ionization of gases. The usage of MHD plant with nuclear reactor has more promising outputs than MHD plant with a coal burner.

VI. Temperature Sustainability

Since the working temperature of MHD plant is above 2000K so it's a major problem of an MHD plant to sustain against such high temperatures. For an MHD plant to sustain against such high temperatures it is required to use high quality of metal or metal alloys. Metal alloys can provide promising sustainability against high temperatures. Since the overall property of a metal can be improved by making its alloys. Here we will discuss some metals and metal alloys that can provide good temperature sustainability for an MHD plant [ix-x]

TABLE V
Metals Physical Characteristics'

Metal or Metal Alloy	Melting point	Temperature Sustainability
Tungsten	3695K	3500K
Tantalum	3290K	3000K
Titanium Alloys	Greater than 2000K	2000K
Ceramics (AL_2O_3)	2345K	2150K
Technetium	2430K	2300K
Zirconium	2128K	2000K

In pure metals like tungsten and tantalum they have high costs while alloys in some cases provides the best properties and thermal resistance in low costs. Because the usage and cost of these metals depend on the usage and production per year and abundance in earth's crust. According to a research on the production of metals it is stated that 65 x 10^6 of titanium is produced in the year of 2012 while765 tons of tantalum, 73000 73 x 10^3 tons of tungsten and 14.2 x 10^5 tons of zirconium in the same year [xi-xii]. So, the more abundant metal among those which can sustain against temperatures above than 2 x $10^3 K$ is titanium. And titanium alloys can provide better sustainability against higher temperatures with lower costs.

VII. Conclusion

As a direct energy conversion power device, it is observed that we can produce sufficient amount of power through MHD generator combined with nuclear reactor. It is most efficient, effective and economical. MHD power plant with nuclear reactor reduces the fast depletion of fossil fuels and it is also environmental friendly since coal combustion is the major cause of carbon dioxide, which is responsible for global warming and depletion of Ozone layer. MHD generator with nuclear reactor is also providing promising results in the field of space technology, submarines and military applications. Due to no moving parts there are minimum chances of wear and tear, which results in an increase life span of plant. Due to fast depletion of fossil fuels petrol and coal in the earth crust the world is facing energy crisis and an increase in prices. MHD plant with a nuclear reactor can be effective in such situations. The suggestion for using nuclear energy means instead of coal can contribute to curtail the global warming related issues of the present day.

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