FEASIBLE DEVELOPMENT OF MAGNETOHYDRODYNAMIC (MHD) POWER PLANT IN NIGERIA

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ABSTRACT
This paper examines the feasible development of magneto-hydrodynamic (MHD) power plant in Nigeria. It proffers the possibility of harnessing magneto-hydrodynamic technology as dependable energy mix for ameliorating epileptic and incessant electric power failures due to inadequate power supply, and minimizes the excessive depletion of fossil fuel in the country. The methodology used in this study entails application of basic conservation laws of mass, momentum and energy, and induction equation. Findings reveal that in spite of abundant conductive fluids in the third world countries like Nigeria, India, etc., the benefits derivable from the MHD power plant were ignored due to dearth of technological know-how required to carry out the installation and operation of the MHD plant. Implementation of this study will eliminate gas flaring in Nigeria, enhance adequate supply of electricity to the rural communities in the country; drastically reduce depletion of fossil oil that causes global warming, environmental pollution and degradation, as well as increasing the socio-economic development of Nigeria.

Keywords: Magneto-hydrodynamic, Techno-economic, Lorentz Force, Power Plant.

1.0 INTRODUCTION

The excessive depletion of fossil fuels used for electric power generation in Nigeria and huge losses of energy gases through gas-flaring have been major challenges confronting the utility industries and stake holders in the electric power generation, transmission and distribution in the country [1]. The consequential global warming and contamination of both atmosphere and environment have become a worldwide concern [2]. Ever-increasing demand for electricity due to worldwide urbanization and rapid industrialization are putting utilities under increasing pressure. Electricity is a form of energy that has occupied the top grade in the energy hierarchy. It finds innumerable use in all facets of human activities [3] [4] [5]. The generation of electric energy involves the conversion of energy available in different sources into electric energy. The fast growing demand for electricity jeopardizes reliable and high quality power supply. Hence, a large proportion of the society has felt the debilitating effects of emission and contamination of environment and atmosphere by hydrocarbon operated generating plants.

Today, it is widely recognized that fossil fuels and other conventional resources are rapidly depleted in such manner that they are no longer sufficient to meet the requirements of the world demand for electricity which is increasing at alarming rate. It has been discovered that the fossil fuels and other conventional resources, presently being used for generation of electric energy, may not be either sufficient or suitable to keep pace with ever increasing demand of the electric energy requirement of the world. Moreover, generation of electrical power by thermal plants causes pollution and increase the global warming. The recent severe energy crisis has propelled the world to develop novel and alternative methods of electric power generation. The entire world is confronted with the problem of devising a solution to this excessive depletion of resources.

Therefore, this study examine the feasibility of introducing magneto-hydrodynamic power generator as an alternative energy mix in the Nigerian power system, and proffers strategies for reducing CO_2 emission (which increases the global warming), ensures generation of clean, efficient, reliable, safe and affordable electricity [5] [6].

Specifically, this research work attempts to:

1. Provide dependable alternative electric power generation in the country.
2. Harness the potentials of gas flare in Nigeria, especially in the Niger Delta areas of the country.
3. Survey the economic potentialities of MHD plant and the possibilities of establishing MHD electric power plant in Nigeria.
4. Provide possible technology for the establishment of MHD electric power plant in Nigeria.

2.0 OPERATION PRINCIPLE OF MHD POWER GENERATION

Anumaka (2014) stated that the principle of operation of MHD generators is based on Faraday's Law of Electromotive induction, which states that energy is generated due to the movement of conductor inside the magnetic field. As the conducting gases move through the magnetic field, electromotive force is generated in accordance with Faraday's law of induction, and the plasma experiences retarding force (or Lorentz Force) as well as Faraday's current (induced current), which flows into the electrodes. The Faraday's current that flows into the load react with the applied magnetic field, creating a Hall Effect current perpendicular to the Faraday's current and resulting lost of energy. In an electrically conducting fluid, moving at velocity V in a magnetic field B, an electromotive force E = (V x B) is induced. When a conductor moves through the magnetic field it creates an electrical field that acts in a direction perpendicular to both the gas flow and the magnetic field, in accordance with Fleming's Right Hand Rule [10],[11].

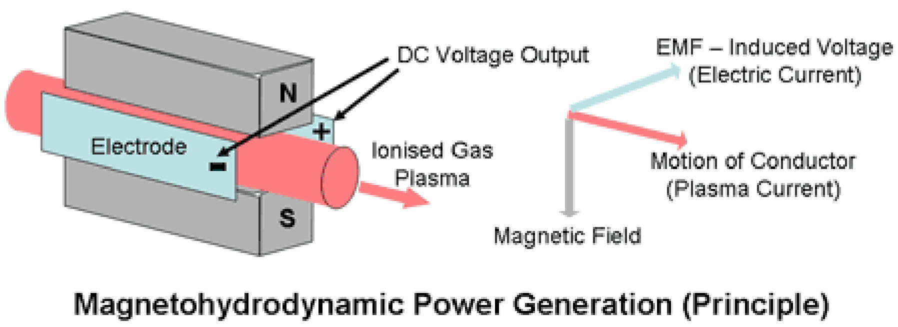

Figure 1: Principle of MHD Power Generation

The walls of the channel parallel to the magnetic field serve as electrodes and enable the generator to produce direct electric current to an external circuit. Inverter is used to convert DC power produced by the

MHD into AC power. For adequate operation of the MHD plant, the conducting gas is produced at high temperature and pressure by combustion of a fossil fuel. The speed of the plasma is then accelerated by a nozzle and injected into the magnetic field. The expansion nozzle reduces the gas pressure and consequently increases the speed of the plasma (as noted in the Bernoulli's Law) through the generator duct, thereby increasing the generator output. However, Gay-Lussac's Law is also applied at the same time the pressure drops, causes the temperature to reduce, thereby increasing the plasma resistance. For MHD generators to operate competitively with good performance and reasonable physical dimensions, the electrical conductivity of the plasma temperature is expected to be at the range between 1,500^{0}C to 2,500^{0}C. High value of fluid conductivity ranging from 10 to 50 Siemens per meter can be achieved through injection (seeding) of readily ionizable alkali material like potassium carbonate (sodium), cesium and rubidium, typically about 1 percent by mass into the hot gas. Even though the amount of seed material is small, economic operation requires that a system be provided to recover as much of it as possible. MHD generator offers the potential of an ultimate efficiency in the range of 60 to 65 percent. This is much better than the 35 to 40 percent efficiency that can be achieved in a modern conventional plant. In addition, MHD generators produce fewer pollutants than conventional plants [11].

3.0 DESIGN AND MODELING FEASIBLE MHD GENRATOR

When electrical conductor is moved so as to cut lines of magnetic induction, the charged particles in the conductor experience a force in a direction mutually perpendicular to the magnetic field (B) and to the velocity of the conductor (V). The negative charges tend to move in one direction, and the positive charges in the opposite direction. This induced electric field, or motional emf, provides the basis for converting mechanical energy into electrical energy
The Lorentz Force Law describes the effects of a charged particle moving in a constant magnetic field. The Lorentz force is given by the vector equation [12] [13].

$$F = Q \cdot (v \times B) \qquad (1)$$

Where:
F = Force acting on the particles (vector).
Q =Charge on the particle (scalar).
V = Velocity of the particle (vector).
B = Magnetic field (vector).
X = the cross product.
The vector F is perpendicular to both V and B in accordance with the Fleming's Right hand rule. When electrodes connected to an external circuit are arranged to be flowed over by the fluid, electrical current of density J is produced by the electromotive force, the magnitude of the current density for the conductive gas is given by the generalized Ohm's law as:

$$J = \sigma. (E + V \times B) \qquad (2)$$

The electrical power delivered to the load per unit volume of a MHD generator gas is:

$$P = - J. E. \qquad (3)$$

$$P = \sigma v^2 B^2 K (1 – K) \text{ W/m}^3 \qquad (4)$$

P = generated power (MW)
σ = specific electrical conductivity (siemn/m^3)
B = magnetic field (Tesla)
V = velocity of gas (m/s)

K = ratio of external load voltage to open-circuit voltage

This power density has a maximum value

$$P_{max} = \frac{\sigma v^2 B^2}{4} \quad (5)$$

For K = 1/2. The rare at which directed energy is extracted from the gas by the electromagnetic field per unit volume is - u. (J x B). We therefore define the electrical efficiency of a MHD generator as:

$$n_e = \frac{J.E}{v. (J. x} \quad (6)$$

The Faraday generator therefore tends to have higher efficiency near open circuit operation.

In order that a MHD generator have an acceptable size, it is necessary that the generator deliver a minimum of about 10 MW per cubic meter of gas. Using the preceding characteristic values for V and B, this requirement means that the electrical conductivity must be such that:

$$\sigma \geq \frac{4 P_{max}}{v^2 B^2} \sim 10 \text{ mhos m}^{-1}. \quad (7)$$

4.0 CONSTRUCTION STRUCTURES OF MHD POWER PLANT

The construction of MHD generator resembles a rocket engines, consists of intense magnetic fields placed side by side and electrodes lying parallel to each other. The duct is made of non- conducting materials and heat- resistance materials like zirconium dioxide or yttrium oxide that can withstand high temperature ranging from 1000^0C to 3000^0C. Electrodes also must of course be conducting as well as heat resistant. The entire MHD generating plant consists of vital elements such as fuel processor, combustion chamber, expansion nuzzle, heat exchanger, seed recovery or pre-heater, purifier, compressor, inverter, and stalk.

4.1 FEASIBLE POWER PLANT FOR NIGERIAN POWER SYSTEM.

The researcher modeled two feasible MHD power plants for the Nigerian power system, viz:

1.OPEN CYCLE MHD GENERATING PLANT

Open cycle MHD generating plant is illustrated in figure 2. In open-cycle system of MHD power generation, the working fluid after the generation of electrical energy is discharged into the atmosphere [6].

In this generator, the fossil fuel is admitted into the combustion chamber that operates at temperature ranging from $2,000^0$C to $2,800^0$ C. The hot gases are mixed with ionized alkali metals such as cesium and potassium to increase the

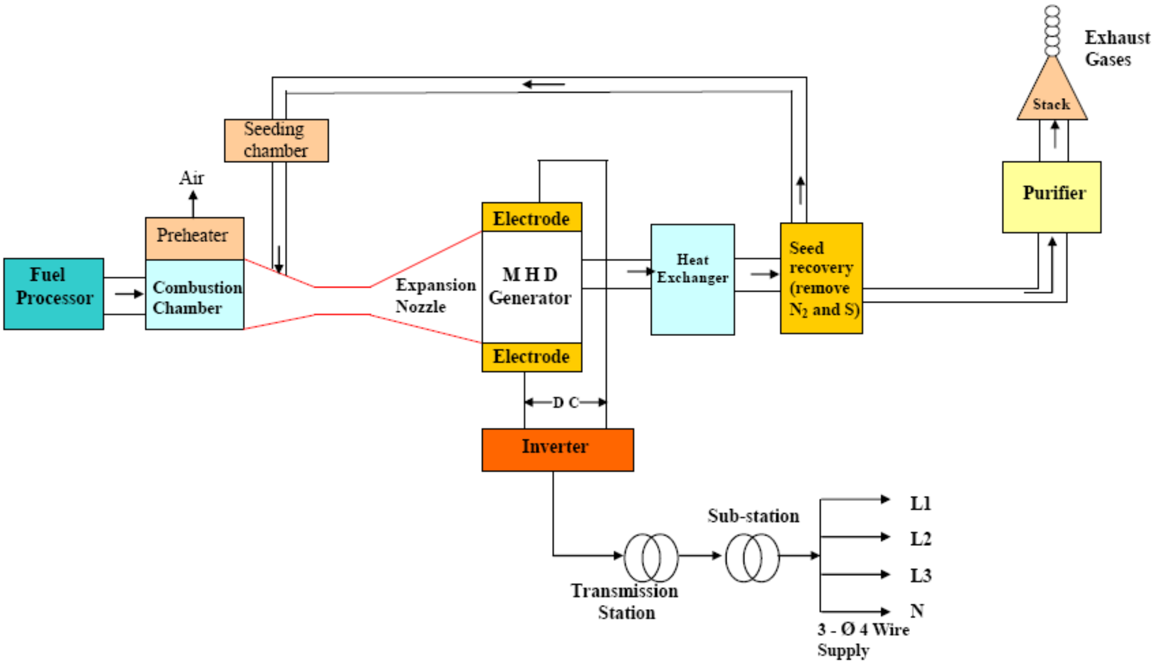

Figure 2: Open Cycle MHD Generating Plant

electrical conductivity of the hot gas [10]. The seeded material, potassium, is ionized by the hot combustion gas. The expansion nozzle causes the hot gases to pass through the intense magnetic field at high pressure. During the movement of the gases, the positive and the negative ions flow to the electrodes and constitute direct current electricity, which is converted into alternating current electricity by means of an inverter [9]. The gases from the MHD are channeled into the heat exchanger. The seed material is recovered for successive use at the seed recovery apparatus. The pollutants (nitrogen and sulphur) are removed from the gases at the purifier chamber, while the clean and unharmful gases are released to the atmosphere through the stack.

2. HYBRID OPEN CYCLE MHD GENERATING PLANT

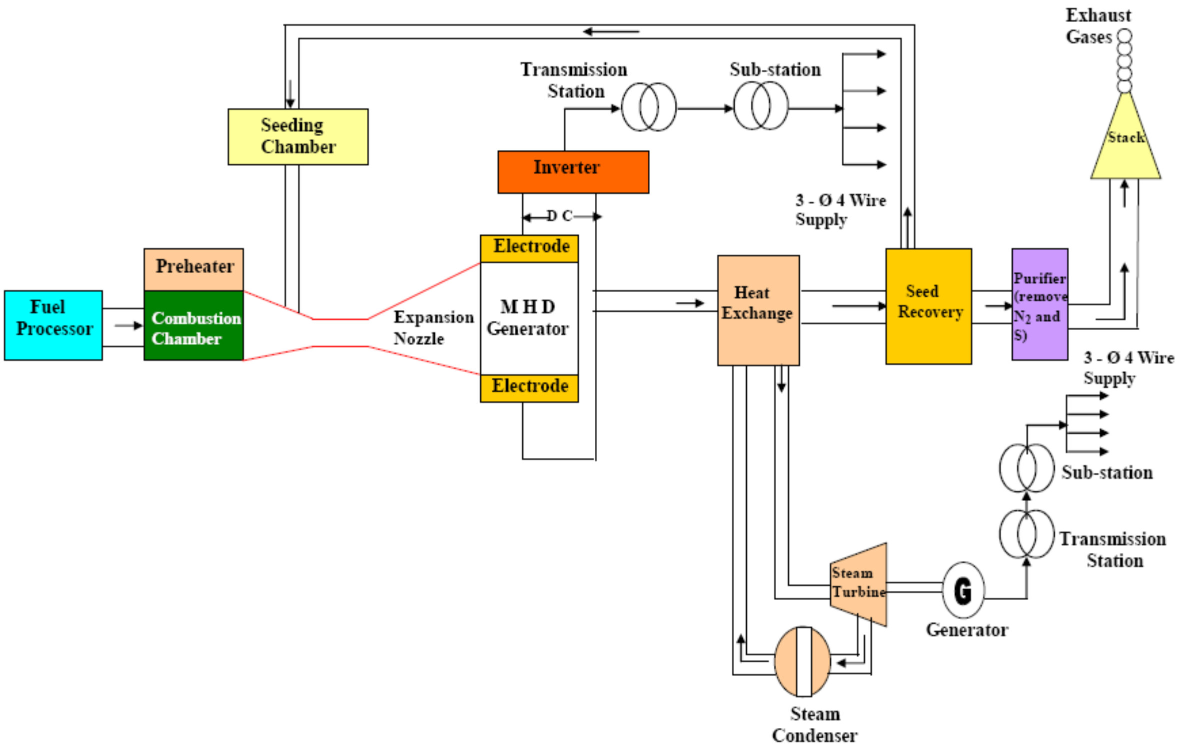

Figure 3: Hybrid Open Cycle MHD Generating Plant

Due to shortcomings of open cycle MHD generators, there is need to improve the operation of the generator so that it can be suitablefor commercial use and ensure efficient opration. This can be achievedby embeding a relatively complex yccle to the open cycle MHD, which is kown as hybrid or binary cycle MHD generator (figure 3).In this system, the exhaust gas from the MHD are channeled to steam turbine generator unit and steam turbine compressor for generation of additional electric power and efficient perfomance of the plant [7],[8].

CONCLUSION

Inadequate power supply, excessive depletion of fossil and greenhouse emission, which has resulted increase in global warming have posed serious concern to the global community. This research work found out that the solution to inadequate and unreliable power supply in Nigeria can be achieved through the introduction of dependable renewable and alternative energy mix like the magneto-hydrodynamic power plant, which this study has explored. Open cycle system and Hybrid open cycle MHD generating plants are suitable and feasible power plants for the Nigerian power system.

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