Performance Evaluation of MHD Renewable Energy Source for Electric Power Generation in Nigeria

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Abstract— Electrical energy is very vital in recent times and modern living. In the day-to-day running of businesses and homes, we need energy at least to power our appliances. In south-eastern geopolitical zone of Nigeria, we have coal, oil and gas in abundance. MHD electrical power generation technology is one the technologies many developing countries apply to alleviate electrical power problems. This work therefore studied some MHD configurations that will perform optimally best with reference to the available coal and gas in southern Nigeria. These naturally available resources can be harnessed towards boosting electrical power generation. The study investigated the performance of different plant configurations based on open-cycle MHD generators fed with coal and gas. The power plants analysis has been performed by developing an integrated model required to characterize mass and energy balances of each system component and the electro-magnetic equations needed to solve the energy balance in the MHD generator. System efficiency was achieved by considering the IG-MHCC, B plant configuration where a high temperature heat recovery level has been introduced.

Keywords— Magneto Hydrodynamics (MHD), plasma.

I. INTRODUCTION

Magneto Hydrodynamics (MHD) is one of the numerous renewable electrical energy sources in research nowadays. Electrical energy is very vital in recent times and modern living. In the day to day running of business, we need energy to power our home, illumination is very important in order to avoid darkness throughout the day. Some crumbling of businesses is as result of electrical energy failure. Recently we heard that Nigeria mega watts had drop from 4000mw to 1000gmw which is not enough to power our homes and industries. This poses serious threat to our economy. In order to boost power supply, the present administration encourages research and development in other find out other electrical power generators to complement the present grid capacity. In southern part of Nigeria, we have coal, oil and gas in abundance. This work therefore studies how these naturally available resources can be harnessed towards boosting our electrical power stability. Magneto Hydrodynamics (MHD) electrical power generation has some promising features that encourages our desire. We therefore study it under the following:

1) Magneto Hydrodynamics (MHD) power generation principle.
2) Gas powered generation.
3) Coal powered generation.
4) Combine cycled.
5) HRSG.

II. PRINCIPLES & CONFIGURATIONS

MHD is a method of extracting electrical energy from heat energy. The heat energy is from conventional fuel combustion system. The principle of MHD is based on Faraday’s law of electromagnetic induction, which states that when a conductor and a magnetic field moves relative to each other then voltage is induced in the conductor, which results in flow of current across the terminals. As the name implies the magneto hydro dynamics generator is concerned with the flow of a conducting fluid (plasma) in the presence of magnetic and electric fields. In conventional generator or alternator, the conductor consists of copper windings or strips while in an MHD generator, the hot ionized gas or conducting fluid replaces the solid conductor. The pressurized electrically conducting fluid, “plasma” flows through a transverse magnetic field in a channel or duct (see figure 1.1).
Pairs of magnetic electrodes are located on the channel walls at right angle to the magnetic field and connected through an external circuit to deliver power to a load connected to it. Electrodes in the MHD generator perform the same function as brushes in a conventional DC generator. The MHD generator develops DC power and the conversion to AC is done using an inverter.

The power generated per unit length by MHD generator is approximately given by

\[ \frac{BUB^2}{P}; \]

Where:
- \( B \) is the fluid velocity.
- \( E \) is the electrical conductivity of conducting fluid.
- \( P \) is the density of fluid.

It is evident from the equation above, that for the higher power density of an MHD generator, there must be a strong magnetic field of 4-5 tesla and high flow velocity of conducting fluid besides adequate conductivity.

The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associated current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to Fleming’s Right Hand rule.

Lorentz law describing the effects of a charged particle moving in a constant magnetic field can be stated as

\[ F = Q V B \]

Where
- \( F \) = Force acting on the charged particle
- \( Q \) = Charge of particle
- \( V \) = Velocity of particle
- \( B \) = Magnetic field

**MHD CYCLES AND WORKING FLUIDS**

The MHD cycles can be of two types, namely: Open and closed cycle MHD.

The detailed account of the types of MHD cycles and the working fluids used is given below.

**OPEN CYCLE MHD SYSTEM**

In open cycle MHD system, atmospheric air at very high temperature and pressure in passed through the strong magnetic field. Coal is first processed and burnt in the combustor at a high temperature of about 2700°C and pressure about 12 at p with pre-heated air from the plasma. Then a seeding material such as potassium carbonate is injected to increase the electrical conductivity. The resulting mixture having an electrical conductivity of about 10 Siemens/m is expanded through a nozzle, so as to have a high velocity and then passed through the magnetic field of MHD generator. During the expansion of the gas at high temperature, the positive and negative ions move to the electrodes and thus constitute an electric current. The gas is then made to exhaust through the generator. Since the same air cannot be reused again hence it forms an open cycle and this is named as OPEN CYCLE MHD.

**CLOSED CYCLE MHD SYSTEM**

As the name suggests, the working fluid in a closed cycle MHD is circulated in a closed loop. Hence, in this case inert gas or liquid metal is used as the working fluid to transfer the heat. The liquid metal has typically the advantage of high electrical conductivity hence the heat provided by the combustion material need not be too high. Contrary, to the open loop system there is no inlet and outlet for the atmospheric air. Hence the process in simplified to a great extent, as the same fluid is circulated time and again for effective heat transfer.

**MHD POWER PLANT CONFIGURATION.**

The conventional Coal Fired Magneto Hydrodynamic Combined Cycle, (CF-MHCC) based on a MHD generator integrated with a steam turbine power plant;

- The advanced Integrated Gasification Magneto Hydrodynamic Combined Cycle, (IG-MHCC) is based on a MHD generator integrated with a steam turbine power plant;

The coal is sent to the combustion chamber (CC) that is fed by air enriched with oxygen (generated in the Air Separation Unit) to reach the temperature for plasma generation. The combustion products, seeded with
potassium carbonate in order to increase the plasma conductivity, enter the MHD generator where electrical power is produced and leaves the system at high temperature and pressure close to the atmospheric one. The thermal power available from the MHD exhausts is used to generate steam and, in order to enhance the overall system efficiency, to preheat the combustion air in a heat exchange.

III. MHD PLANT SYSTEM MODELLING

The MHD generator model

The MHD generator for this work consists of a combustion chamber in which, in order to reach the temperature for plasma generation, the feeding fuel is oxidized by air and seeded to increase its conductivity, a nozzle where the plasma is accelerated up to the specified Mach number, the MHD duct (immersed in a magnetic field and equipped by electrodes placed on walls parallel to the magnetic field itself) where the plasma is expanded and the electric power is extracted, and a diffuser in which the kinetic energy of the plasma is converted to the energy pressure to achieve the required outlet conditions.

IV. RESULTS AND CONCLUSION

<table>
<thead>
<tr>
<th>Air Temp. (°C)</th>
<th>Power Balance PMHD PSPU EXP. (-------MW------)</th>
<th>System Efficiency (%)</th>
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</thead>
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<th>System Efficiency (%)</th>
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</tr>
<tr>
<td>1800</td>
<td>9.82 8.40 1.59</td>
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</table>

The power generated by the MHD generator increases with the air preheating temperature due to the greater plasma mass flow moving across the system. Moreover the power produced in the steam power plant decreases slightly with the increasing in the air combustion temperature because the input thermal power available is almost constant (the reduction of thermal gradient is covered by the greater mass flow rates of the MHD exhausts). The system efficiency ranges from 39.4% to 51% meaning that at higher air preheating temperature a better heat recovery is realized. With respect to the CFMHCC plant the efficiency penalty of IG-MHCC,A is very low resulting less than 2%.

An improvement of system efficiency is expected by considering the IG-MHCC, B plant configuration. In this case, a high temperature heat recovery level has been introduced. Results show that the system efficiencies are enhanced, in the whole air preheating temperature range, achieving a maximum value of 60%.

Conclusion

The aim of this paper was to investigate the performance of different plant configurations based on open-cycle MHD generators fed with coal and gas readily available in African communities. The power plants analysis has been performed by developing an integrated model required to characterize mass and energy balances of each system component and the electro-magnetic equations needed to solve the energy balance in the MHD generator.

Results show that the heat re-circulation to the combustion chamber (the thermal energy transferred to the air combustion by the cooling of MHD exhausts) has a significant impact on system efficiency.

In order to improve the system efficiency a high temperature heat recovery level has been introduced in the plant configuration by using a closed gas turbine cycle. Results show that the system efficiencies are enhanced,
achieving a maximum value of 60%. This means that higher system efficiencies could be further obtained by optimizing the working conditions.

REFERENCES


