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Modernization Technologies of Existing Thermal Power Plants in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors KKO and AMO designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed literature searches. Authors KKO, AMO and AOA managed the analysis of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Since power generation is one of the key factor in developing the country's economy in Nigeria, the need to look at the way of reducing the negative impacts of these power plants are also required so as not to hinder the life of inhabitants of the country. In this paper, emphasis is majorly placed on thermal power plants, since it's the main generating method that is employed by Nigeria because the county is blessed with its materials such as natural gas and coal. But looking at this generating means, it has a lot of environmental impacts which can cause harms to the life of people in the country together with aquatic lives. These harmful effects include the release of greenhouse gases, water pollutions and so on.

Therefore, to reduce the harmful effects and improving the operation of these power stations, this paper suggested some modern technologies which can be employed by the power stations to reduce the harmful effects being caused by the power plants such as CO_2 emission, NO_x emission, particulate matter, SO_x and so on. Also, it tells us the ways by which electricity is generated from

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the raw materials being used, their environmental impacts, ways of reducing these impacts and some of the difficulties encountered by thermal power stations in Nigeria.

Keywords: Thermal power plant; gas turbine combined cycle (GTCC); integrated coal gasification combined cycle (IGCC); solid oxide fuel cell (SOFC); combined heat and power (CHP).

1. INTRODUCTION

Thermal power plant is a type of power plant in which the prime mover is steam driven. And in Nigeria there are mainly two types of thermal plants, which are coal-fired and natural gas-fired type.

Global warming is rising to the top environmental agenda and reduction of CO_2 emission attributed to thermal power generation by using of fossil fuels is particularly an important issue. Therefore, some of the modern technologies by which these emissions caused by thermal power station can be reduced are as follows:

1. Gas turbine combined cycle (GTCC).
2. Integrated coal gasification combined cycle (IGCC).
3. Solid oxide fuel cell (SOFC).
4. Combined heat and power (CHP).

2. OBJECTIVES OF STUDY

The main objective of writing this paper is to discuss or shed light on;

1. The ways by which electricity is being generated in thermal power stations.
2. The effects of electricity generation from thermal power plants and ways of minimizing the harmful effects.
3. Some of the difficulties encountered by thermal power stations in Nigeria.
4. Modern technologies by which thermal power stations can be improved.

3. EVOLUTION OF THERMAL POWER PLANT

Thermal power plant system was initially developed in the 18th century, it was known as the "reciprocating steam engine" which was being used to produce mechanical power, with notable improvements being made by James Watt. When the first commercially developed central electrical power stations were established in 1882 at Pearl Street Station in New York and Holborn Viaduct Power Station in London, reciprocating steam engines were used. The development of the steam turbine in 1884 provided larger and more efficient machine designs for the central generating stations. By 1892, the turbine was considered a better alternative to reciprocating engines [1]. Turbines offered higher speed, more compact machinery and stable speed regulation, allowing for parallel synchronous operation of generators on a common bus. The largest reciprocating engine-generator sets ever built were completed in 1901 for the Manhattan Elevated Railway. Each of the seventeen units weighed about 500 tons and was rated 600 kilowatts. A contemporary turbine set of similar rating would have weighed about 20% as much [2]. As at 1905, turbines entirely replaced reciprocating engines in large central power stations.

Nigeria's public electricity generating company, National Electric Power Authority (NEPA) was created by the government's decree No. 24 of 1972, from the merger of the previous Electricity Corporation of Nigeria (ECN) and Niger Dams Authority (NDA). That decree gave NEPA the mandate to "maintain and coordinate an efficient economic system of electricity supply for all parts of the federation." Later, it was renamed and it existed as the Power Holding Company of Nigeria (PHCN), with 18 business units. The country has total installed power generating capacity of 4000 MW, derived from both hydro and thermal power plants. The National Electric Power Authority (NEPA) had 8 electricity generating stations throughout the country. They are:

1) 1320 MW- Lagos Thermal Power Station, Egbin (1987).
2) 60 MW- Ijora Thermal Power Station, Ijora, Lagos. (1956)
3) 720 MW- Ogorode Thermal Power Station, Sapele, Delta State (1978).
4) Afam Thermal Power Station, Afam.
5) 760 MW- Kainji Hydropower Station, Kainji, Niger State (1968).
6) 540 MW- Jebba Hydropower Station, Jebba. (1985)
7) 600 MW- Jebba Hydropower Station, Shiroro, Minna, Niger State (1990).
8) 600 MW- Delta V1 Thermal Power Station Ughelli, Delta State (1991) [3].

4. OPERATION OF THE THERMAL PLANT

A thermal power station is a power plant in which the prime mover is steam driven. Water heated turns into steam and spins a steam turbine which drives an electrical generator. After the process of passing through the turbine, the steam is condensed in a condenser and recycled to where it was heated. This process is known as the Rankine cycle. The greatest variation in the design of the thermal power station is the different fossil fuel resources generally used to heat the water. Thermal plants convert heat energy into electrical energy [4]. In addition to generating electrical power, thermal plants are designed to produce heat for industrial purposes such as district heating and desalination of water. Globally, fossil-fuelled power plants contribute largely to the man-made emission of CO_2 into the atmosphere. Series of efforts are being made to reduce the emissions.

5. TYPES OF THERMAL PLANTS PRESENT IN NIGERIA

There are majorly two types of thermal power plants in Nigeria. They are:

i. The coal-fired thermal plant and
ii. The natural gas-fired thermal plant.

5.1 The Natural Gas Fired Thermal Plant

Natural gas is a combustible mixture of hydrocarbon gases. It typically consists of 70-90% methane. Before natural gas can be used as a fuel, it must undergo extensive natural gas processing to remove almost all its constituents other than methane. The by-products of the processing include; ethane, propane, butane, pentane and higher molecular weight hydrocarbons, elemental sulphur, carbon dioxide, water vapour and sometimes, helium and nitrogen. Natural gas is found associated with fossil fuels,

i. In coal beds (as methane clathrates)
ii. In porous sedimentary rocks such as shale and
iii. It is created by methanogenic organisms in marshes, bogs and landfills.

It is a widely used fuel source, a major feedstock for fertilizers and a potent green house gas [5]. Natural gas burns more cleanly than other fossil fuels such as oil and coal, and it produces less carbon dioxide per unit energy released. To produce an equivalent amount of heat, burning natural gas produces about 30% less carbon dioxide than burning petroleum and about 45% less than burning coal. Natural gas is a major source of electricity generation through the use of gas turbines and steam turbines. In the steam turbine, natural gas is fired to produce heat, which then converts water into steam. The steam turns the steam turbine for the generation of electricity. In the gas turbine, natural gas is burnt in a combustion turbine. The hot exhaust released heats the water to produce steam, which turns the steam turbine to generate more electricity. Most grid peaking power plants and some off-grid engine generators use natural gas. Particularly high efficiencies can be achieved through the combination of combined gas turbines with a steam turbine in combined cycle mode. Combined cycle power generation using natural gas is thus the cleanest source of power available using fossil fuels. This technology is widely used wherever gas can be obtained at a reasonable cost. Fuel cell technology may eventually provide cleaner options for converting natural gas into electricity, but it is not yet price competitive.

5.1.1 Environmental impacts of natural gas

Natural gas is often described as the cleanest fossil fuel, producing less carbon dioxide per joule delivered than either coal or oil, and far fewer pollutants than other fossil fuels. Compared to the average air emission from coal-fired generation, natural gas produces half as much carbon dioxide, less than a third as much as nitrogen oxides and one percent as much as sulphur oxides at the power plant [6]. Despite the fact that natural gas is described as the cleanest fossil fuel, it poses threat to the environment. The effects are as follows;

⇒ The drilling and extraction of natural gas from wells and its transportation in pipelines, results in the leakage of methane, which is a far more potent global warming gas than CO_2 [7].
⇒ The combustion of natural gas produces negligible amount of sulphur, mercury and particulates. Of course it does produce nitrogen oxide (NO_x), which is a precursor to smog, but at lower levels than gasoline and diesel used for motor vehicles [8]. NO_x causes asthma, bronchitis, lung cancer and heart disease, which is harmful to the human health and can reduce man's life-span.

- ⇒ The oil and gas drilling process can alter land use and harm local eco systems by causing erosion and fragmenting the wildlife habitat. When oil and gas operators clear a site to build a well pad, pipelines and access roads, the construction process can cause erosion of dirt, minerals and other harmful pollutants into nearby streams [9].
- ⇒ Unconventional drilling of oil and gas may pose health risks to nearby communities through the contamination of their drinking water sources with the hazardous chemicals used in drilling the well bore, hydraulically fracturing the well, processing and refining the oil and gas or disposing of waste water [10].
- ⇒ Improper management of flow back or produced waste water can cause leaks and spills of drilling mud, diesel, and other fluids. This, however, is a risk to the surface water.
- ⇒ The disposal of fracking waste water by injecting it at high pressure into deep class II injection wells has been linked to larger occurrences of earthquakes in the United States [11].
- ⇒ Natural gas plant that uses a combustion turbine uses little water. The water cycled through the plant to cool becomes warmer in the process. When this warm water is released into the environment, it alters the temperature of local water ways, thereby harming or killing much aquatic life. This is known as thermal discharge [12].

5.1.2 Ways of reducing the harmful Impacts of natural gas plant

1. By mandating the strongest well siting, design, construction, standard of operation and best drilling practice.
2. Funding robust inspection and enforcement programs, enforcing clean water and safe drinking water laws, reducing toxic wastes and holding toxic oil & gas waste to the same standard as other types of hazardous wastes [13].

5.2 The Coal-fired Thermal Plant

The coal fired thermal plant makes use of the raw material called coal. The conversion from coal to electricity takes place by burning of coal in the boiler furnace to produce heat. The coal is first pulverized into very fine powdery form; it is then air-blown into the furnace through burners located at its four corners. It is then ignited to burn rapidly, forming a large fireball at the centre. Carbon in the coal and oxygen in the air combine to produce carbon dioxide and heat. Then the thermodynamic process begins, as the heat from combustion of the coal boils water in the boiler to produce steam. In modern power plant, boilers produce steam at a high pressure and temperature. The steam is then piped to a turbine; the high pressure steam impinges and expands across a number of sets of blades in the turbine. The impulse and the thrust created rotate the turbine. The steam is then condensed and pumped back into the boiler to repeat the cycle. Then the rotation of the turbine rotates the generator rotor to produce electricity based on faradays principle of electromagnetic induction.

5.3 Problems Encountered when Using Coal Fired Thermal Plants

1. Combustion of coal contributes the most to acid rain and air pollution and has been connected with global warming. Due to the chemical composition of coal there are difficulties in removing impurities from the solid fuel prior to its combustion.
2. Another problem related to coal combustion is the emission of particulates that have serious impacts on public health. The exposure to particulate matter is related to an increase of respiratory and cardiac mortality, particulate matter can also initiate small airways in the lungs, which can lead to problem with asthma, chronic bronchitis, airway obstruction and gas exchange. The dominant form of particulate matter from coal-fired plants is coal fly-ash. It is the remains that are left after the coal has been combusted. It consists of the incombustible materials that are found in the coal [14].
3. Coal ash produced by coal fired power plants dumps at sites across 21 states in the U.S. has contaminated ground water with toxic elements. The contaminants include the poisonous arsenic and lead [15]. Arsenic has shown to cause skin cancer, bladder cancer and lung cancer and lead also damages the nervous system [16].
4. In coal power plants with once-through cooling system, once the 70 to 180 billion gallons of water have cycled through the power plant(for a typical 600megawatts plant), they are released back into the lake, river or ocean. This water is hotter (by up to 20-25°F) than the water that receives it,

creating thermal pollution that can decrease fertility and increase heart rates in fish [17].

5. Coal is a sedimentary rock formed primarily plant matter, and it includes many inorganic materials and elements which were deposited along with organic material during its formation, as the rest of the earth crust. Coal contains low level of uranium, thorium and other naturally occurring radioactive isotopes whose release into the environment leads to radioactive contamination. As for a 1000 MW coal burning power plant, uranium release will be as much as 5.2 metric tons per year (containing 74 pounds (34 kg) of uranium - 235) and 12.8 metric tons per year of thorium [18].

5.4 Methods of Reducing the Emission of Particulate Matter in Coal-fired Power Plants

1. Roughly 80% of the ash falls into an ash hopper, but the rest of the ash is released into the atmosphere as coal fly-ash. Therefore, to reduce the emission of particulate matters, the following measures are employed;

   i. The use of a bag house,
   ii. An electrostatic precipitator and
   iii. A cyclone collector

   The bag house has a fine filter that collects the ash particulates. Electrostatic precipitators use an electric field to trap ash particulates on high voltage plates. Cyclone collectors use centrifugal force to trap particulates to the walls [19].

2. The use of clean coal technology: this method can be employed to reduce the emission of poisonous gases when using the coal-fired thermal plant. It is the process by which coal is chemically washed of minerals and impurities. It is sometimes gasified and burned and the resulting flue gases are treated with steam in order to remove sulphur dioxide. It is then re-burned so as to make the carbon dioxide in the flue gas economically recoverable. Coal industries use the term clean coal to describe the technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use [20].

3. In relation to clean coal technology, a terminology “carbon coal capture and storage” (CCS) is also used. It is a method of capturing the carbon dioxide, preventing the greenhouse gases from entering the atmosphere, and storing it deep underground as follows:

   - CO_2 pumped into disused coal fields displaces methane, which can e used as fuel.
   - CO_2 may be pumped into and stored safely in saline aquifers.
   - CO_2 pumped into oil fields help to maintain pressure, making extraction easier [20].

4. The use of polish solution based on electron beam application method is also a promising method of controlling air pollution [21].
5. To prevent the emissions of coal from affecting the environment, the use of refined coal is advisable. Refined coal is the product of coal-upgrading technology which removes moisture and certain pollutants from lower rank coals such as sub-bituminous and lignite (brown) coals. It is a form of several pre-combustion treatments and process for coals, which alter the coal’s characteristics before it is burnt.

6. MORDERN TECHNOLOGIES FOR IMPROVING THE THERMAL POWER PLANTS

The thermal plants used in Nigeria have various environmental impacts, which affect the living organisms negatively. These power plants need to be improved in order to ensure effective operation. Modernizing it to a standard that will limit the problems being caused by the power plants will be profitable. Therefore, the technologies methods are suggested:

i. Gas Turbine Combined Cycle (GTCC)
ii. Integrated Coal Gasification Combined Cycle (IGCC)
iii. Solid Oxide Fuel Cell (SOFC)
iv. Combined Heat and Power (CHP)

6.1 Gas Turbine Combined Cycle (GTCC)

Thermal power plants have been the principal source of power long before now because it is able to respond stably to changes in demand for

power between day and night, summer and winter, etc. and it is also cost effective. Of all the fossil fuels used for thermal power generation, the increase in demand for natural gas worldwide has been especially notable. The CO_2 emission from natural gas fired thermal plants is about 40% less than that from an equivalent coal-fired plant. Increasing its efficiency is very effective in terms of both resource conservation and prevention of global warming. GTCC technology is widely viewed as one way forward. In this GTCC technology, both the gas turbine and the steam turbine are able to generate electricity. The gas turbine generates electricity through natural gas combustion, while the steam turbine generates electricity using high temperature steam recovered from the heat in the exhaust gas emitted by the gas turbine. GTCC is to recycle the heat that is discarded in the case of a conventional system. The combined cycle means that more electricity can be generated from the same amount of natural gas. Therefore, the GTCC offers higher thermal efficiency compared with electricity generated by a gas turbine or a steam turbine alone.

Furthermore, the GTCC is beneficial in terms of more efficient use of natural gas, reduction in CO_2 emission, and reduction in emission of other harmful gases like nitrogen oxide (NO_x) and sulphur oxide (SO_x). Also, the amount of hot water discharged into the oceans or rivers will be reduced, thereby making the environment safer and more peaceful [22].

6.2 Integrated Coal Gasification Combined Cycle (IGCC)

Considering the global warming demand, coal satisfies approximately 25%. Coal reserves are estimated as being at least three (3) times greater than those of oil, and it is a low-cost fossil fuel. Coal has a major disadvantage; when it is being combusted, it produces much more CO_2, NO_x and SO_x than oil or natural gas. But, IGCC offers a solution to these disadvantages. IGCC is a combined cycle that is capable of converting coal into gas, which drives a gas turbine to generate electricity. The exhaust heat from the gas turbine is also used for generating electricity by a steam turbine. Comparing this with the conventional coal-fired thermal power plant which uses only a steam turbine, IGCC is more efficient and it also emits less CO_2 [14].

Furthermore, the IGCC can use low-grade coal which is unsuitable for conventional thermal plant. IGCC technology is therefore one way forward to the efficient use of fossil fuels. Even though environmental assessment for CO_2 storage is still in its infancy state, the eventual widespread application of IGCC combined with carbon capture and storage (CCS) has the ability to drastically reduce CO_2 emission [22].

6.3 Solid Oxide Fuel Cell (SOFC)

Fuel cells, which generate electricity and heat through chemical reaction between hydrogen and oxygen, are depended upon as means by which electricity can be generated without any harmful gaseous emission. The fuel cells offer high power generation efficiency because electricity is directly generated as a result of chemical reaction and their overall energy efficiency is also high because the generated heat can also be used. Fuel cells are classified according to the type of electrolyte used to capture the oxygen ions from the air. Solid oxide fuel cells SOFCs employ a ceramic electrolyte, and use hydrogen (H_2) and carbon monoxide (CO) as fuel. Therefore it offers the highest power efficiency with excellent durability. SOFCs can be used for power plants since its fuels (H_2 and CO) are obtained from natural gas. As SOFCs operate at high temperatures (ranging from 900 to 1000ºC), they can be combined with gas turbines easily. Therefore, there are high expectations for their combined use at large scale natural gas-fired and coal-fired thermal power plants. This ultimate combination of SOFC and GTCC will enable highly efficient use of fossil fuels. Power plants with the combination of SOFC and GTCC are expected to achieve power generation efficiency of 70% or higher when natural gas is used as fuel and 60% or higher when coal is made use of as fuel. Presently, their combination is considered to be the most efficient thermal power generation method for reducing CO_2 emission [22].

6.4 Combined Heat and Power (CHP)

A combined heat and power system is also called a cogeneration system. It generates heat and electricity from a single source such as fuel, oil or gas simultaneously.

The CHP system generates electricity by driving a gas engine, gas turbine, diesel engine, etc. and the exhaust heat being produced during power generation is used for hot water supplies, air conditioning and steam power. SOFC fuel cells can also be utilized in a CHP system.

Since this CHP system make use of exhaust heat, which is discarded in the case of conventional systems, its overall energy efficiency is extremely high (up to 70-80%). Therefore, it results in a great reduction in fossil fuel consumption and CO_2 emission [22].

7. CONCLUSION

Thermal power plants have a lot of environmental impacts which can cause harm to the life of people in the country together, with the aquatic lives. These harmful effects include the release of greenhouse gases, water pollutions, etc. This paper suggested some modern technologies which can be employed by the power stations to reduce the harmful effects being caused by the power plants such as CO_2 emission, NO_x emission, particulate matter, SO_x and so on. The modern technologies include: Gas Turbine Combined Cycle (GTCC), Integrated Coal Gasification Combined Cycle (IGCC), Solid Oxide Fuel Cell (SOFC) and Combined Heat and Power (CHP).

If the generating stations can employ these technologies, the power plants' hazardous emission will be minimized and life will be convenient for both aquatic and human lives. This will improve electricity generation in the country and the country's economy will then be improved.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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