International Digital Organization for Scientific Research ISSN: 2550-7931
IDOSR JOURNAL OF APPLIED SCIENCES 3(2) 1-9, 2018.

Combined Cyle Power Plants (CCPPS): Prospects for Gas Turbine -Steam Turbine Power Plants in Nigeria's Electricity Production

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ABSTRACT

Nigeria's electricity industry has suffered a systemic failure over the years. In the early 70s spanning through to the early 90s electricity production and supply in the country was just sufficient and fairly stable, with power outages not significantly pronounced. Since the late 90s to date electricity supply in the country has experienced a gradual decline with PHCN (now unbundled into the GenCos, TransCos and DisCos) struggling annually to meet the ever-increasing demand of electricity resulting from the increase in population. Consequently, majority of Nigerians experience irregular electricity supply. It is on this backdrop that the federal government embarked on an aggressive power sector reforms with the objective of privatising PHCN to make electricity production more efficient, effective and stable for sustainable national development. Electrical energy production in Nigeria over the last 40years varied from gas-fired, oil-fired, hydroelectric power stations to coal-fired station with hydroelectric power system and oil and gas-fired system constituting about 90% of her power plants. This paper discusses the prospects of combined cycle power plants (CCPPs) for increased electricity production in Nigeria, the technology involved and the potentials in terms of energy to be exploited thereby meeting her growing energy needs for sustainable national development. The paper also proposes the possibilities of upgrading existing gas-fired power plants in the country into combined cycle power plants for improved electricity supply.

Keywords: PHCN, electricity, energy, CCPPs, oil, gas, coal.

INTRODUCTION

Nigeria is endowed with adequate energy resources to meet its present and future developmental needs. The country possesses the world's sixth largest reserve of crude oil and is increasingly an important gas province with proven reserves of nearly 5,000 billion cubic meters. Coal and lignite reserves are estimated to be 2.7 billion tons, while tar sand reserves represent 31 billion barrels of oil equivalent. Identified hydroelectricity sites have an estimated capacity of about 14, 250MW of electricity. Nigeria also has significant biomass resources to meet both traditional and modern energy uses, including electricity generation. The country is exposed to a high solar radiation level with an annual average of 3.5 – 7.0kWh/m^2/day. Wind resources in Nigeria are however poor and sometimes moderate, and efforts are yet to be made to test their commercial competitiveness [1]. Access to electricity services in the country has been quite low. About 60 percent of the population (over 80 million people) are not served with electricity. Under a business-as-usual scenario, the proportion of Nigerians without access to electricity services will continue to increase over time [1]. The chronic shortage of available generating capacity has negatively affected the industrial and manufacturing sectors. With self-generation prevalent in the industrial, commercial and domestic sub-sectors, the electrical energy demand in Nigeria is currently estimated at 10,000 MW (Federal Ministry of Power & Steel, 2006) [1]. However, there has been no new power plant built within the period 1990 and 1999 and the same period witnessed substantial government under-funding of the utility for both capital projects and routine maintenance operations. Generating plants availability was low and the demand – supply gap crippling. Poor electrical services have forced most industrial customers to install their own power generators at high costs to themselves or relocate to neighbouring countries where power supply is stable and regular, thereby affecting the Nigerian economy [1].

Nigeria's quest to produce stable electric supply to her citizens has met with many bottlenecks, thereby, her inability to meet with the rising demands. [2] stated in their findings that the demand for energy is rising rapidly with the growing population and industrialization. The demand for power in Nigeria grew at an average annual rate estimated at 15 to 20 percent after the start of the 1973-74 oil boom. According to [3], less than half of Nigeria's population presently have access to grid-connected electricity. They observed that power supply in Nigeria averaged 3.1 GW in 2015, which is estimated to be only a third of the country's minimum demand. Nigeria has a per capita power consumption of only 151 kWh per year, which is amongst the lower end of the spectrum in Africa. Nigeria's population is three times that of South Africa's, but it only has less than a third of South Africa's installed power generation capacity. It is not only Nigerian consumers who are suffering, but their businesses as well, as power cuts in Nigeria have an adverse impact on the overall economy [3]. [4] explained that the Nigerian public electricity generating company, National Electric Power Authority (NEPA) was formed 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); the 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 has 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 [4]. 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- Shiroro Hydropower Station, Shiroro, Minna, Niger State (1990).
8) 600 MW- Delta V1 Thermal Power Station Ughelli, Delta State (1991) (Oluwatoyin *et al.*, 2015).

The worldwide demand for Combined Cycle Power Plants (CCPP) is growing dramatically, with the expectations of an explosive growth over the next decades (Nag, 2001). CCPPs operate by superposing a high temperature power plant as a topping unit to the steam plant resulting to a higher energy conversion efficiency from fuel to electricity. The following types of CCPPs exist: 1) Gas Turbine – Steam Turbine plant, 2) Magneto-hydrodynamic (MHD) – Steam plant, 3) Thermionic-Steam plant and 4) Thermoelectric-Steam plant (Nag, 2001).

The total capacity of power self-generation units in Nigeria is estimated at about 2,500MW. Continuous power supply at the required quality remains a critical challenge for Nigeria despite her abundant energy resources. Installed capacity is 8,000MW, but only about 7,000MW is available to generate electricity. At 125 kWh per capita electricity consumption Nigeria is one of the lowest in the world. This paper focuses on the application of the Gas Turbine (GT) – Steam Turbine (ST) type of CCPP for improved electricity production in Nigeria.

Electricity Generating Plants in Nigeria

The call for power sector reform in Nigeria is primarily as a result of inadequate electricity supply, incessant power outages, low generating plant availability and high technical and non-technical losses that characterized the Nigerian electricity industry. The federal government in 2000 adopted a complete approach of restructuring the power sector and privatizing of business units unbundled from NEPA [5]. By this development, NEPA would be unbundled into seven generation companies (GenCos), one transmission company (TransCo) and eleven distribution companies (DisCos). This arrangement would be expected to encourage private sector investment particularly in generation and distribution.

In 2009, the installed and available electrical capacities in the Nigerian generating stations are shown in Table 1. The Table 1 showed that despite a total grid capacity of 6037.3MW, only 4732.4MW was available. Thus about 22% of the installed capacity was unavailable. This may be due to operational inadequacies and inability of units to operate at full capacities of the generating stations and their respective percentage contributions to the total energy products [6].

Table 1: Generating plants - grid stations as at 2009

Site	Type	Installed capacity [MW]	Available capacity [MW]	No. of units
Afam	Thermal	776	488	20
Delta	Thermal	812	540	20
Egbin	Thermal	1320	1100	6
Ijora*	Thermal	66.7	40	3
Sapele	Thermal	1020	972	10
Jebba	Hydro	570	450	6
Kainji	Hydro	760	560	12
Shiroro	Hydro	600	600	6
Calabar*	Thermal	6.6	4.4	3
Orji River*	Thermal	60	Nil	4
Others	Diesel	46	18	Nil
Total		6037.3	4732.4	

***Non-Operating Assets**

Source: [6]. Power Sector Reforms in Nigeria: Opportunities and Challenges.

However, with the recent drive of the federal government through its power plan road map, an upgrade has been made on the generation input as indicated in Table 2. The table depicts that Nigeria currently has twenty-three (23) thermal power plants which are mostly gas-fired and three hydropower plants in operation; with additional three planned hydropower plants under construction.

Table 2: Current and Planned Power Plants in Nigeria and their Locations

Power station	Location	Type	Installed capacity (MW)	Year completed
AES Barge	Egbin	SCGT	270	2001
Aba	Aba, Abia State	SCGT	140	2012
Afam IV–V	Afam, Rivers State	SCGT	726	1982
Afam VI	Afam, Rivers State	CCGT	624	2009
Alaoji (NIPP)	Abia State	CCGT	1074	2013
Calabar (NIPP)	Cross River State	SCGT	561	2014
Egbema (NIPP)	Imo State	SCGT	338	2013
Egbin	Egbin	Gas-fired steam Turbine	1320	1986
Geregu I	Geregu, Kogi State	SCGT	414	2007
Geregu II (NIPP)	Geregu, Kogi State	SCGT	434	2013
Ibom (IPP)	Ikot Abasi	SCGT	190	2009
Ihorbor (NIPP)	Benin City	SCGT	450	2013
Okpai	Okpai	CCGT	480	2005
Olorunsogo I	Olorunsogo	CCGT	336	2007
Olorunsogo II	Olorunsogo	CCGT	675	2012
Omoku I	Omoku	SCGT	150	2005
Omoku II (NIPP)	Omoku	SCGT	225	2013
Omotosho I	Omotosho	SCGT	336	2005
Omotosho II (NIPP)	Omotosho	SCGT	450	2012
Sapele	Sapele	Gas-fired steam Turbine	1020	1981
Sapele (NIPP)	Sapele	SCGT	450	2012
Ughelli	Delta State	SCGT	900	1990
Itobe	Kogi State	CFB Technology	1200	2015–2018
Kainji	Niger State	Hydro	800	1968
Jebba	Niger State	Hydro	540	1985
Shiroro	Kaduna State	Hydro	600	1990
Zamfara (Planned)	Zamfara State	Hydro	100	2012
Kano (Planned)	Kano State	Hydro	100	2015
Kiri (Planned)	Benue State	Hydro	35	2016
Mambilla (Planned)	Taraba State	Hydro	3050	2018

Source: Emodi and Yusuf (2015) [6]
NIPP- National Integrated Power Project, *SCGT*- Single Combined Gas Turbine, *CCGT*- Combined Cycle Gas Turbine, *CFB* - Circulating Fluidized Bed

Combined Cycle Power Plants (CCPPs)

Combined Cycle Power Plants (CCPPs) could provide leading solutions to tackle new challenges in the fossil fuel industry by improving efficiency and reducing emissions. Today the CCPP is the most used power plants. [8] related that combined cycle power plants constitute the millennium part of fossil fuel power plant with its centrepiece being the gas turbine. According to [9], CCPPs use a combination of two thermodynamic cycles that are combined for maximum efficiency, the Brayton combustion turbine topping cycle and the Rankine steam turbine bottoming cycle. The gas turbine cycle (Brayton cycle) operating in a high-temperature and the steam turbine cycle (Rankine cycle) in a low-temperature range by using steam production in a heat recovery steam generator (HRSG).

Figure 1 explains the basic principle of operation of a CCPP; where Natural gas or liquid fuel is burnt in the combustion turbine (1) creating a constant pressure which spins a generator (2) producing electricity; the combustion turbine exhaust waste heat and mass flow is captured in a Heat Recovery Steam Generator (HRSG) (3) that creates superheated steam to drive a steam turbine (4) that spins another generator (5) (IMIA Working Group, 2015).

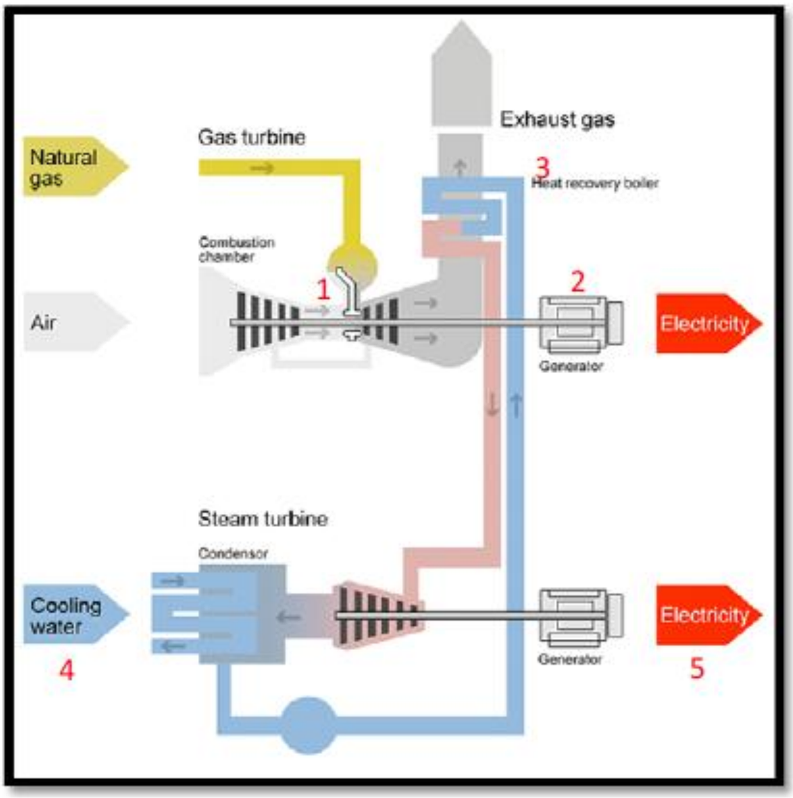

Figure 1: The basic principles of operation of a typical CCPP.
Source: IMIA Working Group (2015)

Most combined cycle power plants use a gas turbine and is called a Combined Cycle Gas Turbine (CCGT) plant. The low efficiency output of a gas turbine in a simple cycle operation, is improved since the steam turbine accounts for about half of the CCGT plant output [9]. CCGT power plants exist in many different configurations, however, each GT has its own associated HRSG, and multiple HRSGs supply steam to one or more steam turbines; for instance, at a plant in a 2 x 1 configuration, two GT/HRSG trains supply to one steam turbine; likewise there can be 1 x 1, 3 x 1 or 4 x 1 arrangements. The steam turbine is sized to the number and capacity of supplying GTs/HRSGs [9]. [10] reviewed that the exhaust gas of the gas turbine which is at a temperature of about 550 to 600°C is used as a source to generate steam in a heat recovery steam generator (HRSG) and the combined cycle shows higher thermal efficiency of about 55 to 60% compared to the thermal efficiency of about 35 to 40% produced from conventional thermal plants. Examining the capital cost and installation time, it is obvious that gas turbine is the best choice for peaking power. Steam power plants are 50% higher in initial costs of $800 – $1000/kW (₦289, 600 – ₦362, 000/kW) compared to combined cycle plants which are about $400 - $900/kW (₦144, 800 – ₦325, 800/kW) [8]. [11] related that the availability of gas turbine output of 100 – 350MW has made large combined cycle power plant a major factor in thermal power generation. Japan, because of its total dependence on imported fuel, was the first large-scale user of combined cycles building several 2000MW stations. Large scale combined cycle plants with ratings of up to 2000MW have been installed in many countries including Korea, Malaysia, Hong Kong, Singapore, Argentina and USA, with thermal efficiencies in excess of 55% [11]

The combined cycle power plant offers high thermal efficiency, low emissions, low installation cost, flexibility in fuel selection and low operation and maintenance cost. CCPPs are suitable for daily cycling operation due to short start-up times and for continuous base load operation. Part load efficiencies are also high due to the control of the gas turbine inlet mass flow using inlet adjustable vanes. The major disadvantage of CCPP is its complexity and advancement in turbine technologies could take care of this disadvantage.

Potentials of Combined Cycle Power Plants in Nigeria

Energy utilization can be maximized and plant efficiency increased with the use of Combined Cycle Power Plants. However, this technology is not fully employed in Nigeria among its generation options despite its potential of generating large megawatts (MW) of electricity.

In October 2008, the Afam VI power plant began generating electricity, fed by natural gas from the Okoloma gas plant. The power plant began producing over 400 MW to the grid via the open cycle phase and has attained a generation capacity of 624 MW through the full combined-cycle phase which has contributed 14% to 20% of Nigeria's current power supply (SPDC, 2013). The Afam VI power plant is an example of the integration of new technology in domestic power generation. By utilizing combined cycle technology, the plant uses 40% less gas than open cycle plants. The Afam VI plant delivers 10 trillion Watt-hour electricity into National Grid (SPDC, 2013). Also, in consideration of the Shell Petroleum Development Company (SPDC) Joint Venture's commitment to sustainable development, the plant has the potential to reduce greenhouse gas emissions from power generation, saving over 500,000 tonnes of CO_2 emissions per year. In the light of this, the power plant was registered as a Clean Development Mechanism (CDM) project in February 2013 by the United Nations Executive Board for Climate Change. As part of capacity development for the host and impacted communities, the power plant project has also undertaken the training of 30 graduate community youth in combined cycle power plant operation and maintenance (SPDC, 2013).

Other power plants in Nigeria employing combined cycle technology are the Alaoji Power station (partially operational), Okpai power station (operational) and Olorunsogo II power station (partially Operational) with installed capacities of 225MW, 480 MW and 675 MW respectively [12].

RECOMMENDATIONS

In order to secure a sustainable economy by the year 2025, this paper makes the following recommendations:

1. The Federal government should begin to build modern combined cycle power plants of large generating capacities as base load plants and encourage private partners to invest in this area of technology to increase our electricity generation.
2. Existing gas power plants which constitute majority of our thermal power plants should be upgraded, where possible, into Combined Cycle Power plants (CCPPs) to boost the current electricity produced.
3. Where Possible the government should also encourage the development of Integrated Gasified Combined Cycle (IGCC) power plants from coal to maximize the full potentials of her coal deposit in electricity generation.
4. There should be full monitoring of projects in the power sector to improve and strengthen the governance structure to enhance accountability and minimize corruption
5. .

CONCLUSION

About 45% of Nigeria's populations have access to electricity, with only about 30% of their demand for power being met. The power sector is plagued by recurrent power outages to the extent that some 90% of industrial customers and a significant number of residential and other non-residential customers provide their own power at a huge cost to themselves and to the Nigerian economy. Other multinational companies have resorted to relocating their manufacturing plants to neighboring African countries where stable electric power could be sourced. Though Nigeria is blessed with abundant energy resources she has not fully harnessed her energy potentials for electricity generation to meet national demand. Her generation sources are predominantly hydro and gas-fired power plants, but she must seek more modern methods of generating electric power through more efficient, less fuel consuming and affordable installation cost of which the combined cycle power plant present a viable option. This will result in production of large megawatts of electricity to the national grid within a specified period of time to meet the demand-supply gap. The production of sufficient amounts of electric power is the key to sustainable national development.

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