



Assessment of Technological Feasibility of Converting Open Cycle to Combined Cycle Gas Power Plants

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Abstract: This study assessed the technological feasibility of converting open cycle to combined cycle gas power plants. The study was carried out on all the operational power plants in Nigeria, using both primary and secondary data sources. The data collected were analyzed using descriptive statistics. The results showed that out of the 72 open cycles and 5 combined cycle units considered, 60.0, 0, 33.3 and 6.7 % of the power plants had turbines that were installed between 1-5 years, 6-10 years, 11-15 years and 16 years and above, respectively. Similarly, 66.6 and 13.3 % of the plants had General Electric and Siemens machines installed in their plants. The power plants ran efficiently with a heat rate and thermal efficiency range between 9.33 to 14.44MJ/KWh, 25 to 39 % for open cycle plants and 6.63 to 11.97MJ/KWh, 30 to 54 % for combine plants. The result also showed that by using the average generation of each plant in the last 3 years as a baseline for conversion, an additional 1142.1MW would be obtained after conversion to the combined cycle without an increase in gas consumption. The study concluded that conversion of the gas turbine from open cycle to combined plants is technologically viable and an additional generation of 1142.1MW can be obtained.

Keywords: Technological Feasibility, Conversion, Open Cycle, Combined Cycle, Gas Turbine

I. Introduction

One of the major requirements meant for the existence of humans is energy, which is a driving force of development since our daily activities and productive processes involve energy in one form or another [1]. Due to population outburst, unavoidable industrial development, new agricultural production and improving living standards, the demand for energy in Nigeria is increasing. Nigeria has abundant primary energy resources which are enough to meet its present and future development requirements [2]. The objective of

the electric energy system is to provide the needed energy services [3]. Energy services are the desired and useful products, processes or indeed services that result from the use of electricity, such as for lighting, provision of air-conditioned indoor climate, refrigerated storage, and appropriate temperatures for cooking [4, 5]. With regards to this, power plants play a key role in producing electricity. Among different kinds of power plants, gas turbine power plants have gained a lot of attention because they are attractive in power generation field due to low capital cost to power ratio, high flexibility, high reliability without complexity, compactness, early commissioning and commercial operation, fast starting-accelerating and quick shut down. The gas turbine is further recognized for its good environmental performance, manifested in the low environmental pollution [5, 6, 7, 8]. A daily suitable measure can be taken by monitoring the operation status in order to

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reasonably maintain facility performance in gas turbine power plants [9, 10]. [11] stated that the most used source of fuel for electricity generation in Nigeria is natural gas through the use of gas turbines and steam turbines due to the abundance of gas reserves in the country. In a steam turbine, natural gas is fired to produce heat which converts water into steam. The steam turns the turbine blades for the generation of electricity. Likewise, in the gas turbine, natural gas is burnt in a combustion chamber with compressed air to produce hot gas which turns the turbine blades to generate electricity [11]. Above all, higher efficiency can be attained through the combination of a gas turbine with a steam turbine in combined cycle mode using a heat recovery steam generator (HRSG). A combined cycle power plant is a power plant that generates electricity from the combination of both gas and steam turbines by making use of the same quantity of natural gas. Combined cycle power generation using natural gas is the cleanest source of power available using fossil fuels. This technology is widely used anywhere gas can be obtained. The hot exhaust gas from the gas turbine plant is vented to the atmosphere. This is common to all open cycle gas turbines. Thus, a considerable amount of heat energy goes as waste with the exhaust of the gas turbine and contributes to environmental pollution. This heat can be utilized for other useful purposes using heat recovery steam generator rather than releasing it to the atmosphere. This fact prompted the need for converting all open cycle gas turbine power plants in Nigeria to a combined cycle system, such that the wasted heat from the hot exhaust gas is captured and channelled into the HRSG and used to generate steam to drive another generator (steam generator) to produce more electricity. Hence, this conversion process

results in improving the performance of the power plant (increased total output and efficiency) with less environmental pollution compared to the open cycle gas turbine plant. This is gaining increasing acceptance as an alternative to stand alone gas or steam cycle, due to high thermal efficiency of about 60 % and utilizing the same quantity of natural gas as fuel [12]. Therefore, a combined cycle power plant usually consists of a gas turbine plant, a HRSG and a steam turbine plant. The gas turbine plant operating on Brayton cycle and the steam turbine plant operating on Rankine cycle, they are often called topping and bottoming cycles respectively [13].

According to the Nigerian electricity system operator's daily broadcast of the 30th of April, 2016, there was a total installed capacity of 8,232 MW out of which an average of 3,746.91 MW was generated, while 3,662.20 MW was transmitted representing 45.52 % and 44.49 % of the available capacity respectively. A closer look at the daily broadcast reveals that 15.46 % of the daily available generation was hydro turbine, 16.28% was steam turbine, 54.90% was gas turbine and 13.36% was from combined cycle plants respectively. Similarly, by considering the relationship between the available capacities to the energy generated, it reveals that 48.17 % of total hydro plants availability was generated, 51.80 % of total steam turbine availability was generated, 35.14 % of total gas turbine availability was generated, while 77.41 % of total combined cycle plant availability was generated. It is clear that though gas turbine plants have the highest available capacity of 4,519.5 MW representing 54.90 % of the total availability, its ratio of energy generated remains the lowest at 35.14 %. It is therefore necessary to evaluate ways of improving the utilization and increasing the power generation

without increasing gas consumption. This can be done by converting the open cycle gas turbine units to combined cycle plants. Thus, there is a need to establish the technological feasibility of the project. Hence, this study.

II. Materials and Methods

A. Research Design

The study employed a descriptive survey method to identify and evaluate the performance of the types of gas turbines available in electric power generating systems in Nigeria; and assessed the technological feasibility of converting open cycle to combined cycle gas power plants.

B. Coverage of the Study and Sampling

The research study covered the current operating open cycle and combined cycle power plants in Nigeria. Specifically, for gas turbines, Transcorp power (Delta), Forte Oil (Kogi), Pacific Energy (Ogun and Ondo), Afam VI (Rivers), Okpai (Delta) and all National Integrated Power Project (NIPP) plants that were operational were considered.

C. Study Variables

The following variables were used to capture the identification and evaluation of the performance of the types of gas turbines;

- i. Original equipment manufacturer (OEM): General Electric / Siemens / Alstom / Hitachi / Stal Laval
- ii. Year of installation
- iii. Capacity of gas turbine: measured in MW
- iv. Plants current available capacity: measured in MW
- v. Current status of turbines: available / not available
- vi. Capacity factor: measured in percentage (%)

- vii. Fixed operations and maintenance cost (FOM): measured in Naira per MWh
- viii. Variable operations and maintenance cost (VOM): measured in Naira per MWh
- ix. Station heat rate: measured in MJ/KWh

Equations (i) to (iii) outline the key performance indicators (KPI) models used to assess the technological feasibility of converting open cycle to combined cycle gas power plants.

i. Station heat rate

This is the ratio of fuel energy input as heat per unit of work output [14].

$$Q_c = \frac{V_g \times C_g}{E_G} \quad (1)$$

where;

Q_c is the station heat rate (MJ/KWh)

V_g is the volume of fuel (gas) consumed (SCF)

C_g is the calorific value of fuel (MJ/Ft³)

E_G is the energy generated (MWh)

ii. Load factor

This describes the total energy generation of a station in relation to the available capacity of the station [14].

$$L_f = \frac{E_G}{A_I \times RH} \quad (2)$$

where;

L_f is the load factor

E_G is the energy generated (MWh)

A_I is the installed station availability (MW)

RH is the rated hours (Hrs)

iii. Thermal efficiency

This is the ratio of the energy generated in kilowatt seconds (output) to the heat input to the turbine [14].

$$\eta_T = \frac{E_G}{Q_T} \quad (3)$$

where

η_T is the thermal efficiency

E_G is the electrical energy generated (MWh)

Q_T is the heat input (MJ/MWh)

Technological feasibility of the conversion involves the following;

D. Conversion Process

The conversion process of an open cycle to a combined cycle power plant consists of the open cycle plant and additional three major components namely: heat recovery steam generator (HRSG), turbine, condenser and pump. The waste exhaust gas from the gas turbine flows into the HRSG. This heat is used to convert water flowing through the HRSG to steam. The HRSG supplies steam for the steam turbine in producing electricity. The process of conversion involves the use of steam tailing; steam tail is the steam cycle placed on the exhaust of the gas turbine to form a combined cycle. It includes the heat recovery steam generator, the steam turbine and the generator. It can be designed and installed with the gas turbine cycle, making a comprehensive combined cycle project. It can also be designed and installed later, after the gas turbine has been operated for a while, as part of a phased contract or indeed a separate contract.

E. Combined Cycle configuration

When a gas turbine / HRSG / steam turbine is optimized for maximum power production, the steam turbine produces an additional power equal to approximately 50% of the power produced by the gas turbine. In order to get a steam turbine output that is equal to the gas turbine output, manufacturers usually provide combined cycle power plants with two gas turbines, each with its own HRSG, feeding into one steam turbine [15]. This is referred to as the two by one (2 x 1) arrangement and it is the configuration that was adopted for this research (as shown in Figure 1). The feasibility of

converting open cycle to combined cycle was measured using the following variables:

- i. Number of open cycle generator available: measured in number
- ii. Number of units available for conversion: measured in number
- iii. Capacity from open cycle in MW
- iv. Annual average generation for 4 years in MW
- v. Number of units recommended for conversion based on the average generation for 4 years
- vi. Availability of space to carry out the conversion
- vii. Additional capacity after conversion process in MW
- viii. Total capacity for proposed plant in MW

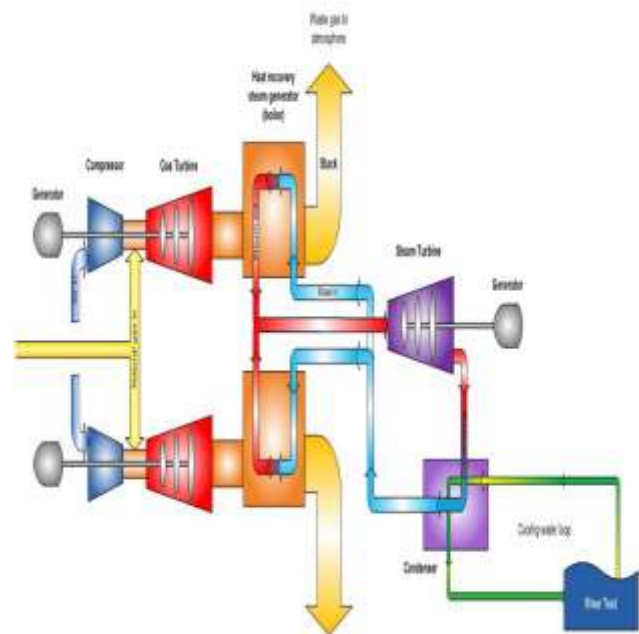


Figure 1: Combined Cycle configuration (2 x 1);
Source [16]

III. Results and Discussion

A. Technical Characteristics of the Power Plants

Table 1 shows the summary of the operational power plants considered for the study. It covers

14 power plants distributed across 9 states; Abia, Bayelsa, Cross River, Delta, Edo, Kogi, Ogun, Ondo and Rivers. Ihovbor NIPP, Sapele NIPP, Alaoji NIPP and Omotosho NIPP plants each have Four (4) units of General Electric open cycle turbines installed in their plants. Omotosho and Olorunshogo both of Pacific Energy have Eight (8) units, while Calabar NIPP has Five (5) units of General Electric open cycle turbines installed. Geregu NIPP and Geregu Forte oil each has Three (3) units of Siemens open cycles turbines installed. Afam VI, Olorunsogo NIPP and Okpai power plants are the only operational combined cycle plants under consideration. Alaoji NIPP plant has Four (4) units of General Electric open cycle turbines already installed and operational, and Two (2) additional units of combined cycle

plant proposed but construction for the actualization of these proposals has not yet begun. Transcorp power plant has Twenty (20) units of open cycle turbines installed. These include Two (2) units Stal-Laval, Twelve (12) units Hitachi and Six (6) units General Electric turbines. Gbarain NIPP plant has Two (2) units of open cycle installed but only One (1) is operational as the other unit is still being commissioned. Table 2 shows the year of installation and the original equipment manufacturer of the turbines available in the plants considered. It revealed that 60.0 % of the turbines were installed between 1-5 years ago followed by 33.3% that were installed between 11-15 years, while 6.7 % were installed over 15 years ago.

Table 1: Summary of Operational Plants Considered

S/ N	NAME OF POWER PLANTS	LOCATI ON	NUMBER OF UNITS (OC/CC)	OEM	STATUS
1	Ihovbor NIPP	Edo	4	General Electric	Station fully commissioned
2	Sapele NIPP	Delta	4	General Electric	Not being considered for conversion because of lack of space
3	Calabar NIPP	Cross River	5	General Electric	Station fully commissioned
4	Alaoji NIPP	Abia	4	General Electric	Station still under construction and its already intended to be a CC plant
5	Omotosho NIPP	Ondo	4	General Electric	Station fully commissioned
6	Olorunshogo NIPP	Ogun	4/2	General Electric	Station already a CC plant
7	Geregu NIPP	Kogi	3	Siemens	Station fully commissioned
8	Gbarain NIPP	Bayelsa	2	General Electric	Only one unit has been commissioned. Second unit is being commissioned so station is not considered
9	Geregu (Forte Oil)	Kogi	3	Siemens	Station fully commissioned
10	Omotosho (Pacific)	Ondo	8	General Electric	Station fully commissioned
11	Olorunshogo(Pacific)	Ogun	8	General Electric	Station fully commissioned
12	Transcorp	Delta	20	Stal Laval (2) General Electric (6) Hitachi (12)	Stal Laval turbines have been decommissioned
13	Okpai	Delta			Number data from Okpai
14	Afam VI	Rivers	3	Alstom	Combined cycle plant

Similarly, 66.6 % of turbines installed in the power plants were General Electric turbines, while 13.3 % installed Siemens turbines. Furthermore, 6.7 % of the turbines installed were Alstom, Hitachi and Stal-Laval.

Table 2: Year of Installation and the OEM Spread of Turbines in Selected Power Plants

Parameters		Power plants	
		Frequency (n=15)	Percentage (%)
Year of Installation	1-5	9	60.0
	6-10	-	-
	11-15	5	33.3
	15 and above	1	6.7
OEM	General electric	10	66.6
	Siemens	2	13.3
	Alstom	1	6.7
	Hitachi	1	6.7
	Stal Laval	1	6.7

Table 3: Heat Rate and Thermal Efficiency Benchmarks for Open and Combined Cycle

		Open Cycle	Combined Cycle
Heat Rate	Lower Range (MJ/KWh)	10.38	6.70
	Upper Range (MJ/KWh)	12.39	7.27
Efficiency (%)	Lower Range (%)	29.0	50
	Upper Range (%)	36.0	60

B. The Performance of the Types of Gas Turbines Available in Electric Power Generating System in Nigeria

Table 3 shows the benchmark values of heat rate and thermal efficiency for both open cycle and combined cycle power plant. Thus, plants which run within this benchmark are assumed to be efficient while those who run outside the benchmark needs to be re-examined to determine the cause of the deviation. Table 4

reveals some of the key performance indicators of the power plants under consideration. The energy generated, gas consumption, load factor, heat rate and thermal efficiency for the 2016, 2015 and 2014 are shown in Tables 4a, b and c respectively. For Ihovbor NIPP power plant, total energy generation for 2014, 2015 and 2016 was 1,556,857.03 MWh, 1,122,176.11 MWh and 735,961.54 MWh respectively, while gas consumption was 17,253.02 MMSCF, 12,443.96 MMSCF and 8,661.41 MMSCF respectively. In the same vein, the load factor, thermal heat rate and thermal efficiency were 44 %, 11.26 MJ/KWh and 32 % for 2014; 28 %, 11.26 MJ/KWh and 32 % for 2015; and 19 %, 11.95 MJ/KWh and 30 % for 2016 respectively. This shows that the plant has not been able to run up to 50 % of its plant capacity in the years under consideration and this was mainly due to the unavailability of gas and also the inadequacy of the transmission network used for evacuating the energy. Also, Sapele NIPP has a total energy generated and gas consumption of 845,715.40 MWh and 9,567.81 MMSCF in 2014; 919,647.20 MWh and 8,449.00 MMSCF in 2015; while the 2016 data were 799,487.90 MWh and 8,543.26 MMSCF, respectively. The heat rate and thermal efficiency of the plant were 11.49 MJ/KWh and 31 % in 2014; 9.33 MJ/KWh and 39 % in 2015; while in 2016, the plant had 10.85 MJ/KWh and 33 %, respectively.

The open cycle power plants considered have a range of heat rate between 11.20 MJ/KWh for Geregu (Forte oil) and 13.92 MJ/KWh (Transcorp) in 2014; 9.33 MJ/KWh (Sapele NIPP) and 14.44 MJ/KWh (Calabar NIPP) in 2015; while the range in 2016 was 9.94 MJ/KWh (Omotosho Pacific) and 12.61 MJ/KWh (Calabar NIPP). Similarly, the thermal efficiency range for 2014, 2015 and 2016 were

26 % (Transcorp) to 33 % (Omotosho NIPP), 25 % (Calabar NIPP) to 39 % (Sapele NIPP) and 29 % (Calabar NIPP) to 36 % (Alaoji NIPP).

In contrast, Olorunsogo NIPP, Okpai and Afam VI plants which are the combined cycle plants considered have heat rate range of 6.76 MJ/KWh (Okpai) to 11.97 MJ/KWh (Olorunsogo NIPP) in 2014, 7.57 MJ/KWh

(Okpai) to 10.47 MJ/KWh (Olorunsogo NIPP) in 2015 and 6.63 MJ/KWh (Okpai) to 8.17 MJ/KWh (Olorunsogo NIPP) in 2016. The thermal efficiency of these plants also varies between 30 % (Olorunsogo NIPP) and 53 % (Okpai) in 2014, 34 % (Olorunsogo NIPP) and 48 % (Okpai) in 2015, while in 2016 the range was between 44 % (Olorunsogo NIPP) and 54 % (Okpai).

Table 4a: Key Performance Indicators for Power Plants for the Year 2016

	Energy Generated (MWh)	Gas Consumed (MMSCF)	Load Factor (%)	Heat Rate (MJ/KWh)	Thermal Efficiency (%)
Ihovbor NIPP	735,961.54	8,661.41	19	11.95	30
Sapele NIPP	799,487.90	8,543.26		10.85	33
Calabar NIPP	488,697.70	6,066.52		12.61	29
Alaoji NIPP	843,909.55	8,304.25	19	9.99	36
Omotosho NIPP	883,441.00	10,101.24	20	11.61	31
Olorunshogo NIPP	164,364.30	1,321.37	2	8.17	44
Geregu NIPP	699,579.00	8,107.15	18	11.77	31
Gbarain NIPP	COMMISSIONING CONCLUDED AND COMMERCIAL OPERATIONS BEGAN IN JUNE 2016				
Geregu (Forte Oil)	690,459.00	7,832.09		11.52	31
Omotosho (Pacific)	1,062,900.00	10,397.73	36	9.94	36
Olorunshogo (Pacific)	860,842.8	9,933.03		11.72	31
Transcorp	2,386,975.69	26,647.40	27	11.34	32
Okpai	2,565,681.06	16,737.71		6.63	54
Afam VI	2,239,337.89	17,126.45		7.77	46

Table 4b: Key Performance Indicators for Power Plants for the Year 2015

	Energy Generated(MWh)	Gas Consumed (MMSCF)	Load Factor	Heat Rate (MJ/KWh)	Thermal Efficiency
Ihovbor NIPP	1,122,176.11	12,443.96	28	11.26	32
Sapele NIPP	919,674.20	8,449.00		9.33	39
Calabar NIPP	228,542.73	3,249.04		14.44	25
Alaoji NIPP					
Omotosho NIPP	1,316,719.80	15,160.51	30	11.69	31
Olorunshogo NIPP	1,171,961.68	12,075.53	18	10.47	34
Geregu NIPP	1,167,682.25	13,483.56	31	11.73	31
Gbarain NIPP	UNITS UNDERGOING COMMISSIONING IN 2015				
Geregu (Forte Oil)	1,092,459.30	11,748.63		10.92	33
Omotosho (Pacific)	1,466,772.00	14,548.67	50	10.07	36
Olorunshogo (Pacific)	1,544,110.53	17,706.12		11.65	31
Transcorp	2,783,682.28	38,686.67	32	14.12	26
Okpai	2,665,973.00	19,868.52		7.57	48
Afam VI	3,045,830.63	23,935.45		7.98	45

Table 4c: Key Performance Indicators for Power Plants for the Year 2014

	Energy Generated (MWh)	Gas Consumed (MMSCF)	Load Factor	Heat Rate (MJ/KWh)	Thermal Efficiency
Ihovbor NIPP	1,556,857.03	17,253.02	44	11.26	32
Sapele NIPP	845,715.40	9,567.81		11.49	31
Calabar NIPP		UNITS UNDERGOING COMMISSIONING IN 2014			
Alaoji NIPP		UNITS UNDERGOING COMMISSIONING IN 2014			
Omosho NIPP	1,104,656.80	11,832.34	25	10.88	33
Olorunshogo NIPP	879990.19	10,286.46	13	11.87	30
Geregu NIPP	1,201,450.50	14,157.89	32	11.97	30
Gbarain NIPP		UNITS UNDERGOING COMMISSIONING IN 2014			
Geregu (Forte Oil)	940,181.20	10,362.83		11.20	32
Omosho (Pacific)	978,645.00	11,127.18	33	11.55	31
Olorunshogo (Pacific)	1,082,988.28	12,533.87		11.76	31
Transcorp	2,353,365.57	32,256.02	27	13.92	26
Okpai	3,338,478.00	22,232.62		6.76	53
Afam VI	3,408,990.00	23,858.87		7.11	51

These clearly show that the combined cycle plants have a better performance as the heat rate and thermal efficiency have implied. Also, the combined cycle plants seemed to generate more power than the open cycle plants and this might be encouraging for intending investors and also a guide in making key business decisions.

C. Conversion of Power Plants from Open Cycle to Combined Cycle Gas Turbines

Tables 5a and b show the number of units of the power plants available for conversion from open cycle to combined cycle gas turbines. The decision for suitability for conversion of an open cycle plant into a combined cycle is hinged on three key assumptions;

- Plant must not have a current plan for conversion.
- Plants must have used less than half-life of its life cycle (30 years). This is to ensure that the converted plant would have the opportunity to run for a minimum of 15

years before an investment decision is made on replacing the open cycle component.

- Plant must have the space to accommodate the expansion from open cycle to combined cycle.

Table 5 reveals that Transcorp has the highest (13) number of units available for conversion from 18 available units. Similarly, Ihovbor NIPP and Omosho NIPP, have 4 units available for conversion, Geregu NIPP and Geregu Forte oil have 3 units available for conversion, Calabar NIPP has 5 units available for conversion, Olorunshogo Pacific and Omosho Pacific have 8 units available. Sapele NIPP have 4 units available but they do not have adequate land space to accommodate the conversion, while Gbarain only has 1 unit operational as the other unit is still being commissioned. Table 6 indicates that the combination of two (2) open cycle turbines can produce six (6) units of combined cycle gas turbines after conversion for Transcorp power plant, while eight (8) units of open cycle gas turbines for Omosho phase 1 and

Olorunsogo Pacific energy can be converted to four (4) units combined cycle gas turbines. Also, for Ihovbor power plant two (2) steam turbines can be produced from converting the available four (4) units of open cycle gas turbines in order to increase efficiency. According to the findings of [17] who studied the performance of the combined gas turbine-steam cycle for power generation, that thermal processes can be combined whether they operate with the same or with differing working media. He further noted that conversion to combined cycle increased the efficiency of power plant

Also, the report of [18] on analysis of gas turbine systems for sustainable energy conversion further corroborates the result of this study. The additional conversion for Omotosho phase 1 and Olorunsogo Pacific Energy show that their open cycle capacity (335

MW) could produce an additional conversion capacity of 167.5 MW for a combined cycle gas turbine. Similarly, Transcorp with more gas turbines had an additional conversion capacity of 142.8 MW from 925.6 MW open cycle

D. Technological Feasibility of Converting Open Cycle to Combine Cycle Gas Power Plants

Table 7 shows the feasibility of converting open cycle to combined cycle gas power plant by taking into consideration the number of units available for conversion and number of recommended units for conversion to be possible. It shows the average generation of each power plant in the last 3 to 5 years and uses these to get an average within which the recommendation for conversion was made..

Table 5a: Year of Installation and Plant Suitability for Conversion into Combined Cycle

Power plants	OEM	Year	Suitability for conversion (YES/NO)	Remarks
Ihovbor NIPP	GTG 1	General	2013	YES
	GTG 2	Electric	2013	YES
	GTG 3		2013	YES
	GTG 4		2014	YES
Omotosho NIPP	GTG 1	General	2012	YES
	GTG 2	Electric	2012	YES
	GTG 3		2012	YES
	GTG 4		2012	YES
Geregu NIPP	GTG 1	SIEMENS	2013	YES
	GTG 2		2013	YES
	GTG 3		2013	YES
Calabar NIPP	GTG 1	General	2015	YES
	GTG 2	Electric	2015	YES
	GTG 3		2015	YES
	GTG 4		2015	YES
	GTG 5		2015	YES
Sapele NIPP	GTG 1	General	2012	NO
	GTG 2	Electric	2012	NO
	GTG 3		2012	NO
	GTG 4		2012	NO
Gbarain NIPP	GTG 1		-	NO
	GTG 2		2016	NO

**GTG – Gas Turbine and Generator

Units are healthy and have not reached half-life of its life cycle.

Units are healthy and have not reached half-life of its life cycle, but the plants have no space for the conversion.

Only one unit has been commissioned. The second unit is still under construction.

Table 5b: Year of Installation and Plant Suitability for Conversion into Combined Cycle

Power plants		OEM	Year	Suitability for conversion (YES/NO)	Remarks
Transcorp	GT 1	Stal-Laval	1963	NO	Units too old and have been decommissioned.
	GT 2		1963	NO	
	GT 3		2002	YES	
	GT 4		2002	YES	
	GT 5		2002	YES	
	GT 6		2002	YES	
	GT 7		2002	YES	
	GT 8	Hitachi	2002	YES	Units are healthy and have not reached half-life of its life cycle.
	GT 9		2005	YES	
	GT 10		2005	YES	
	GT 11		2005	YES	
	GT 12		2005	YES	
	GT 13		2005	YES	
	GT 14		2005	YES	
	GT 15		2017	YES	
	GT 16	General Electric	1990	NO	Units are healthy but have passed half-life of its life cycle.
	GT 17		1990	NO	
	GT18		1990	NO	
	GT 19		1990	NO	
	GT 20		1990	NO	
Olorunsogo Pacific Energy	GT 1		2006	YES	
	GT 2		2006	YES	
	GT 3		2006	YES	
	GT 4		2006	YES	
	GT 5		2006	YES	
	GT 6		2006	YES	
	GT 7		2006	YES	
Omotosho Pacific Energy	GT 8		2006	YES	Units are healthy and have not reached half-life of its life cycle
	GT 1		2006	YES	
	GT 2		2006	YES	
	GT 3		2006	YES	
	GT 4		2006	YES	
	GT 5		2006	YES	
	GT 6		2006	YES	
Geregu Forte Oil	GT 7		2006	YES	
	GT 8		2006	YES	
	GTG 1	SIEMENS	2006	YES	
	GTG 2		2006	YES	
	GTG 3		2006	YES	

**GT – Gas Turbine

Table 6: Units Available for Conversion from Generating Power Plants

Name of plant	Number of units available	Number of units available for conversion	Number of steam turbine units from conversion	Capacity from open cycle (MW)	Additional capacity conversion process (MW)
IHOVBOR NIPP	4	4	2	450	225
OMOTOSHO NIPP	4	4	2	500	250
GEREGU NIPP	3	3	1	435	145
OMOTOSHO PACIFIC ENERGY	8	8	4	335	167.5
TRANSCORP	18	13	6	925.6	142.8
CALABAR NIPP	5	5	2	563	225.2
ALAOJI					
OLORUNSOGO PACIFIC ENERGY	8	8	4	335	167.5

Table 7: Feasibility of Converting Open Cycle to Combined Cycle Gas Turbine

Name of Plant	Number of Units Available	Number of Units Available for Conversion	Capacity from Open Cycle (MW)	Average Annual Generation for 4years	Number of Units Recommended for Conversion	Additional Capacity from Conversion Process (MW)	Total Capacity for Proposed Plant (MW)
Ihovbor	4	4	450	152.68	2	112.5	562.5
Omotosho NIPP	4	4	500	152.39	2	125	625
Geregu NIPP	3	3	435	140.58	2	145	580
Omotosho Pacific Energy	8	8	335	166.22	4	114	449
Olorunsogo Pacific Energy	8	8	335	166.58	4	114	449
Transcorp	18	13	925.6	377.32	6	161.4	1087
Calabar NIPP	5	5	563		4	225.2	788.2
Geregu Forte Oil	3	3	435	144.42	2	145	580
			3978.6			1142.1	5120.7

It also reveals the total capacity for the proposed power plant derived from the addition of the capacity from open cycle and conversion process. The number of units recommended for conversion based on the results as shown in the

Table for Ihovbor, Omotosho NIPP, Geregu NIPP and Geregu Forte Oil was 2. This is because the units available for conversion from its open cycle capacity for the gas turbines were four (4) and three (3). That is, the gas turbines

can be combined in twos to produce one (1) combined cycle gas turbine. Omotosho Pacific energy and Olorunsogo Pacific energy which had eight (8) units available for conversion when combined can give four (4) units as recommended. Table 6 further showed that the total capacity for the proposed plant for Transcorp and Calabar NIPP are 1087 MW and 788.2 MW. This could be attributed to their high additional capacity conversion process in megawatt and capacity from open cycle. The total capacity for proposed plant means that generating electricity from combined cycle gas turbines is sustainable and can serve the country better. Thus, generating electricity from combined cycle gas turbines produces optimum generation capacity as shown in the Table.

IV. Conclusion

The study concluded that most of the power plants have been installed for up to 5 years and operates efficiently. The open cycle plants considered in this work are efficient and their performances are adequate for them to undergo the conversion process. Also, the combined cycle plants are efficient when it operates fully as a combined cycle plant and not partially as open cycle. An additional power generation of 1142.1 MW can be generated after converting the open cycle plants to a combined cycle. This additional generation will not need an increment in the capacity of gas consumption of these plants. The conversion process for the power plants for each additional conversion unit shows that it is profitable to convert to a combined cycle gas turbine for the generation of electricity. The analysis shows that the plants have some fluctuations in operation on the required load factor and thermal efficiency. These are the key performance indicators used to determine the technological feasibility of the

conversion process, hence the need to convert gas.

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