Performance Evaluation and Analysis of Operating Margin of Emission Factor of Ibom Power Plant

By

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Abstract

This study evaluates and analyses the performance of Ibom Power Plant from 2014 to 2016 based on performance indices such as capacity factor, load factor, plant capacity, utilization factor, overall efficiency, and thermal efficiency. The operating margin which is the emission factor (CO_2 emission factor) that refers to the group of existing power plants whose current electricity generation would be affected by the proposed clean development mechanism (CDM) project activity was also determined. Data obtained from the Power Plant inventory records and fault logbook includes monthly energy generation and number of failures for the period under study. Results obtained from the analysis showed that the average capacity factor was 28.89%, the typical load factor as calculated was 88.23%; plant capacity was estimated to be 1,673,160MWH and the average generating capacity from plant records was 483,333.84MWH. The averages of the overall and thermal efficiencies were 27.37% and 27.92% respectively. Using the CO2 emission factor of 56 KgCO2/GJ, the weighted operating margin emission factor ($EF_{OM,y1-y3}$) was determined to be 26.17 $KgCO_2$/MWH and this was attributed to increase in economic activities in Akwa Ibom State. Low plant availability as a result of breakdown or failures, disruption of gas supply and other such factors were identified among other reasons as key issues responsible for the power plant's low performance.

Keywords: Capacity factor, load factor, overall efficiency, thermal efficiency, CO^2 emission factor

Introduction

Electric power system operation is complex but lends itself readily to simulation modelling and performance analysis. Electric systems are among the largest "machines" operating on the planet, often with many dozens (or even hundreds) of electric generators operating synchronously, interconnected by transmission wires that are operated to meet loads subject to a set of dynamic security constraints. Each generating unit has its own operating cost (typically dominated by the cost of fuel), its own physical constraints (e.g., ramp rates and minimum operating levels for fossil units, intermittency for certain renewables, equipment maintenance and forced outage rates). Units with storage capability, such as hydroelectric facilities with reservoirs, are dispatched subject to complex procedures typically designed to maximize the value of the output of the facilities subject to environmental and other constraints. System operation can be extraordinarily complicated but is generally determined by a set of known procedures that are in practice, implemented by a system operator who implements the procedures in real time determining generating unit commitment and dispatch.

With the growth in commercialization, industrialization, digitization and the added rapid growth of urban cities, the gap between electricity demand and supply continues to widen as the country is gradually becoming the industrial hub of Africa and its population is constantly increasing. There is an increasing need to provide affordable electricity to the population in the required quantity and quality to suit the demand for electrical energy in Nigeria. Electric power

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generation in Nigeria is mainly from three power plant types; hydro-power, steam and gas thermal power stations. Most of these facilities are being managed by the Power Holding Company of Nigeria (PHCN) previously known as National Electric Power Authority (NEPA). According to Sule and Anyanwu[1], growth in thermal plants in Nigeria started with the installation of steam thermal plants at Oji River (1956), 4 unit gas thermal plants in Ijara (1966/78), 20 units gas thermal plants in Delta (1966/90), 4 steam thermal plants at Sapele (1978/80), additionally 18 unit gas thermal plants were installed at Afam (1982) and 6 steam thermal plants at Egbin (1985/87). A total of 6 power stations in all consist of a total of 55 units capable of producing a total capacity of 5988MW of electricity [2].

Electricity generation in Nigeria has been in existence for more than 100 years with various reforms of the electricity sector but its development and constant availability to Nigerians has been more of a dilemma. The electricity sub-sectors in Nigeria comprises of 18 companies which include: six Generating Companies, eleven Distribution Companies and one Transmission Company (Transmission Company of Nigeria; TCN). The electricity generated is evacuated through transmission lines at remarkably high voltages which aids in the reduction of losses as observed by Emodi and Yusuf [3]. Several studies have observed that Nigeria is vastly endowed with both renewable energy resources (e.g. solar, hydro, wind, biomass and wood fuel) and non-renewable energy resources (e.g. crude oil, natural gas, lignite and coal). Regrettably, in spite of this abundance, the country is still unable to generate enough electricity to meet its domestic demand[4]. The country's energy access status as observed by the International Energy Agency (IEA) is a little above 50% leaving the rest of the population to rely on themselves for their energy needs power generation. Even among those connected to the grid, the frequent outages experienced in Nigeria has forced about 90% of the industrial sector and significant number of household customers to provide their own power through different forms of generating sets at huge cost to themselves and to the Nigerian economy. Table 1 depicts the available power plants in Nigeria and their capacities. As at 2010, the total installed capacity of combined hydro and thermal power stations was 8,000 MW, whereas the power generation capacity available was approximately 4,000 MW from both PHCN and IPPs, out of which only about 1500 MW was readily available to generate electricity[5].

The Nigerian government has maintained that she is committed to improving the performance of the power sector by providing an enabling environment for private investors. This includes; upwards revision of the power tariff within the multi-year tariff order to a cost reflective upper limit to the end user tariffs. Irrevocably speaking, the slow pace at which the Nigerian economy grows is as a result of the slow pace of growth in the Nigerian power sector; from projections made, it was estimated that Nigeria will need about 28GW in demand by year 2015 at a GDP of 7% and 30GW at GDP of 10% respectively[6]. Also, it was projected that these figures will almost double by the year 2020. Unfortunately, not much progress has been made in this direction. At the moment, Nigeria with a population of over 200 million people has a peak

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[1] Sule, E. I. K. and Anyanwu, C. M. (1994). *"An Appraisal of Electricity Supply in Nigeria and the Privatization Option"*, Research Department Occasional Paper No. 9.

[2] A.O. Adelaya, O.Y. Ogunmola and E.O. Williams, *"Performance Evaluation of Egbin Thermal Plant"*, 2011.

[3] Emodi, N. V., Yusuf, S. D. (2015). "Improving Electricity Access in Nigeria: Obstacles and the Way Forward". International Journal of Energy Economics and Policy, 5(1), 335-351.

[4] Akpan, G.E., Akpan, U.F. (2012). *"Electricity consumption, carbon emissions and economic growth in Nigeria"*. International Journal of Energy Economics and Policy, 2(4), 292-306.

[5] Idigbe KI, Igbinovia SO. Assessing the sustainability of electric power in Nigeria: a case study of the IPPs. J Econ Eng 2010: 70-7. ISSN: 2078-0346.

[6] Sambo, A.S. (2008). Matching Electricity Demand and Supply in Nigeria. 32-36 International Association for Energy Economics, Fourth Quarter, Available at <www.iaeee.org/en/> Accessed 7 December 2011.

generation of about 5,074.7MW and a generation capacity of 6707.3MW [7]. Nigeria ranks abysmally low compared to other countries in Africa, as indicated in the CIA Factbook. In order to achieve notable power generation capability, compulsory availability data documentation is crucial. The traditional measures used in reliability evaluation are probabilistic and, consequently they do not provide exact predictions [8].

Table 1. Power Plants in Nigeria, Capacities and Types [9].

On-Grid Generation Stations	Type	Installed Capacity (MW)	Available Generation Capacity (MW)
KAINJI	HYDRO	760	342
JEBBA	HYDRO	570	380
SHIRORO	HYDRO	600	450
EGBIN	GAS/STEAM	1320	1100
SAPELE	GAS/STEAM	1020	240
UGHELLI	GAS	972	600
AFAM IV-V	GAS	987	0
GEREGU	GAS	414	276
OMOTOSHO	GAS	336	336
OLORUNSOGO	GAS	335	294
GEREGU NIPP	GAS	434	290
SAPELE NIPP	GAS	450	337
ALAOJI NIPP	GAS/STEAM	1074	250
OLORUNSOGO NIPP	GAS/STEAM	750	625
OMOTOSHO NIPP	GAS	500	375
IHOVBOR NIPP	GAS	450	337.5
OKPAI (AGIP IPP)	GAS/STEAM	480	480
AFAM VI (SHELL IPP)	GAS/STEAM	642	450
OMOKU (RIVERS IPP)	GAS	150	0
IBOM POWER	GAS	191	114
AES LAGOS	GAS	270	0
TRANS-AMADI (RIVERS IPP)	GAS	136	0
RIVERS IPP	GAS	95	0
CALABAR NIPP	GAS	632	250
OMOKU NIPP	GAS	250	0
EGBEMA NIPP	GAS	338	0
GBARAIN NIPP	GAS	225	0
TOTAL		**14, 381**	**7,526.50**

[7] Central Intelligence Agency. “Botswana.”cia.gov.Central Intelligence Agency, n.d. Web. 26 August, 2011. <https://www.cia.gov/library/publications/the-world-factbook/geos/bc.html>

[8] Richwine, R. R. (2011). *“Using Reliability Data to Improve Power Plant Performance”*. NERC-GADS Workshop presented by Richwine Reliability Management Consultant, Richwine Consulting Group, LLC Oct. 27, 2011.

[9] Olaoye, Tunde, et al. (2016) *"Energy Crisis in Nigeria: Need for Renewable Energy Mix."* American Journal of Electrical and Electronic Engineering 4.1 1-8.

According to Prasad et al[10], about 30-40 per cent of power supplied is never billed. The power sector incurs a cash loss of around US$2billion per month. Over US$400 million annually is spent by the Federal Government of Nigeria as an annual subsidy to cover losses and investment, an amount that is higher than the Federal budget for health.

For electrical energy to be received by consumers in the required quantity and quality, the performance of these power plants that generate this electrical energy need be taken into consideration [11]. Additionally, with the global call for the decrease in activities that contribute to global warming caused by greenhouse gas emission, the evaluation of operation margin of emission factor of power plants becomes inevitable, hence one of the focus of this study.

Literature Review

Several studies have been carried out on the performance evaluation of various power plants across the country. All of such studies aim to determine the plants' efficiency and as well as suggest measures to optimize the plant usage. For instance, Adelaya et al[2] evaluated the performance of Egbin Thermal Plant and observed that reasons such as; low plant availability, unstable grid system, erratic natural gas supply among others were identified as the key factors responsible for the poor performance of the plant. Obodeh and Isaac[11] investigated the performance of Sapele thermal power station and the results of the study indicated that the load factor was between 39.9% and 60% as against 80% best practice; plant availability was measured as 21% against over 95% best practice, capacity factor was 5.49% in 2006 indicating excessive plant failure. Also, while studying the effect of inlet cooling system and components irreversibility on the performance of an active 25MW gas turbine power plant[12], observed that the use of a spray cooler on the existing gas turbine cycle gave a better thermal efficiency and less irreversibility rate in the components system and the entire plant and retrofitting the existing gas turbine plant with an inlet cooling system gives a better system performance and may prove to be an attractive investment opportunity. Adegboyega and Famorijoi[13] employed the basic factors such as; Plant Capacity, Plant Use Factor, Load Factor and Utilization Factor to estimate the performance of a Central Gas Turbine Power Station. Using inventory records of monthly energy generation between 2002 and 2012 and operational statistics; results showed that Edgeba gas turbine power station has a Capacity Factor of 20.4% as against the 40-65% ISO standard, Plant Use Factor of 29.14546% as against the target of 50-70% ISO standard, Load Factor of 81.76% as against 80% ISO standard, and Utilization Factor of 49.1-58.9% as against 85% ISO standard. An investigation of generator availability and performance on four gas and six steam turbine unit generators at Sapele power station in Nigeria was carried out by Ogieva et al[14]. IEEE std 762 generator performance indices were used to evaluate the data for the six (6) out of the ten (10) generating units available as the remaining four were out of service. Using a MATLAB developed program, the availability and performances results generated for the period were ST01=89%, ST02=89.99%; ST03=85.24%; ST04=87.45%;

[10] Prasad V.S.N. Tallapragada and B. S.Adebusuyi (2008). *"Nigeria's Power Sector: Opportunities and Challenges"*. Paul Collier, Chukuma Soludo and the International Monetary Fund, Economic Options for a Prosperous Nigeria.
[11] O. Obodeh and F.O. Isaac (2011). *"Performance Analysis for Sapele Thermal Power Station: Case Study of Nigeria"*. Journal of Emerging Trends in Engineering and Applied Sciences, 2(1), 166-171.
[12] Fidelis Ibiang Abam, Ikpi U. Ugot and Dodeye Ina Igbong (2012). *"Performance Analysis and Components Irreversibilities of a (25MW) Gas Turbine Power Plant Modeled with a Spray Cooler"*. American Journal of Engineering and Applied Sciences 5(1), 34-41.
[13] Adegboyega Gabriel A. and Famorijoi John O. (2013). *"Determination of the Central Gas Turbine Efficiency and Reliability, Edjeba, Delta, Nigeria"*. International Journal of Science and Research, 2(4), 482-490.
[14] Engr. Ogieva F. E., Engr. Dr. Ike S.A. and Engr. Dr. Anyaeji C.A. (2015). *"Sapele Thermal Power Station Generator Availability and Units Performance Studies"*. International Refereed Journal of Engineering and Science, 4(6), 01-17.

ST05=86.50%; ST06=29.71%; and the overall station units' availability was 88.35%. The total power generation availability of Sapele power station was 7% where ST-1=36.7%; ST-2=20.03%; ST-3=0.77%; ST-4=0.00%; ST-5=0.0%, and ST-6=14.54% respectively. Results indicated that reduction in plant availability is caused by increased number and duration of forced outages. The performance analysis and evaluation of Omotosho Power Plant for the period 2008-2012 based on data obtained from the outage log books was performed by Adeoye and Bamisaye[15]. Results showed that the average values of the thermal efficiency and overall efficiency of the generating plant was calculated to be 28.39% and 29.12% respectively due to different factors such as: breakdown or failures, obsolete technology, instability of the national grid system, ageing of plant components and disruption of gas supply. Without doubt, power plant performance evaluation is critical and of necessity especially in a country like Nigeria where the electricity access rate is worrisome and has continued to be a topic for national and international discuss. This work therefore seeks to evaluate the performance of Ibom power plant with a view to also determine the associated emission factor. It is anticipated that the result of the study will give a better understanding of the plant operation and fill the missing knowledge gap.

Methodology

Case Study- Ibom Gas Turbine Power Plant

Ibom power plant is a gas turbine plant owned by the Federal Government of Nigeria. The plant site is located at Ikot Abasi Local Government Area (LGA) while the company has its corporate office in Uyo, the Akwa Ibom State capital with a liaison office at Abuja. The power plant has a total planned capacity of 685 Megawatt (MW) to be implemented in two phases - Phase 1 has an installed capacity of 191MW from two GE Frame 6B and one Frame 9E turbine generators. The plant also has ancillary systems for compressed air, DC power, raw water, potable water, drainage and effluent. Phase 2 has a planned capacity of 494MW for a total of 685MW. At the moment, the installed capacity is 191MW and available capacity is 114MW with 2 out of the 3 units currently in operation. Gas supply to Ibom Power plant is from Seven Energy/Accu gas facility at Uquo in Esit Eket LGA. Ibom power output is evacuated to the rest of the national grid through the Ikot Abasi – Eket 132KV transmission line. Regrettably, the transmission line from Eket through Uyo to Itu can only carry 50-60MW. The upgrade of the line from Eket through Uyo to Itu has been under development since 2004. It was taken over by the NIPP projects and it is expected that this work would be completed in 2017.

The power generated by the power plant is sold to the Nigerian Bulk Electricity Trading Company (NBET) while NBET sells to the distribution companies. In this case, PHEDC (Port Harcourt Electricity Distribution Company) becomes the buyer and distributor, while TCN takes charge of transmitting the electric power to the Nigerian public [16]. IPC is a registered participant in the Nigerian Electricity Supply Industry (NESI). IPC implements good corporate governance and performance management in compliance with the Companies and Allied Matters Act 1990 (CAMA).

In power generation, the turbine and the generator are the most crucial equipment required for the generation of electricity; the other equipment in the station are termed auxiliaries and are needed for the smooth running of the plant and monitoring of the operating conditions of the plant component. The turbine is a type of internal combustion engine. It has an upstream

[15] Adeoye O.S. and Bamisaye A.J. (2016). *"Performance Evaluation and Analysis of Omotosho Power 2016 in Nigeria".* Innovative Energy and Research, 5 (1) 1000134.

[16] Akpabio EM, Akpan NS. *"Power supply and environmental sustainability in the University of Uyo: an agenda for full-blown research in Nigeria".* J Afr Dev 2010; 2(6): 132-43.

rotating compressor coupled to a downstream turbine and a combustion chamber in between, with maximum continuous rating of 42MW, speed 3000rpm, with 18 stages ring exhaust thermocouples. The generator is the radiant type, 3-phase, hydrogen-cooled and air cooled with output voltage of 10.7KV, Power 33.47MVA (40.6MW), speed 3000rpm, 0.38 power factor, exciting current 6.1A, exciting voltage 48.9V, 50Hz frequency, and field current of 2781A, ambient temperature of 45ºC. Figure 1 shows the overview of the turbine and the generator as well as the auxiliary components making up the electricity generation process.

Figure 1. Gas Generator-Alternator assembly.

Performance analyses were carried out on the plant as a whole. Several trips were made to the plant during which empirical data were collected from plant records from 2014 to 2016 as prepared by the Efficiency Department of the utility. The associated parameters used in this work include:

i. Energy Generated (MWH).
ii. Rated Capacity of Power Plant (MW).
iii. Expected Running Hours (H).
iv. Average Load (MW).
v. Maximum Load (MW).
vi. CO_2 emission factor of power unit m in year y (2014-2016) (Kg CO_2/MWH).
vii. Amount of fuel type i consumed by power unit m in year y (Mass or volume unit).
viii. Net calorific value (energy content) of fuel type i in year y (MJ/mass or volume unit).
ix. Emission factor of fuel type i in year y (Kg CO_2/GJ).
x. Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWH).
xi. Calorific Value of Gas (MJ/M^3)
xii. Volume of fuel consumed (MMSCF)
xiii. Total Energy Generated (MWH)

Table 2 shows some of the data vintages that are used for the calculations of the performance indices of Ibom Power Plant.

Table 2. Data obtained from Inventory Records.

Year	Total Energy Generated (MWH)	Volume of Fuel Consumed (MMSCF)	Calorific Value of Gas (MJ/M^3)
2014	479,453.88	5,187.09	38.54
2015	490,497.04	6,194.74	38.54
2016	480,050.61	6,250.36	38.29

Data presentation

The scope of the study is to determine certain parameters and factors for a period of three (3) years (2014-2016), as key performance indices of the power plant. Data were obtained from Ibom Power Plant inventory records for monthly energy generation records between 2014 and 2016 and additionally, the number of failures that occurred during the period under consideration was obtained from the station fault logbook which was translated into percentages in order to ascertain the actual running periods for the study period.

Plant performance indices

The performance indices were determined by numerical calculations. According to Raja et al[17], power plant performance depends on several indices. For this work, the performance of Ibom Power Plant was evaluated based on the following performance indices:

i. Capacity factor.

ii. Load factor.

iii. Plant capacity.

iv. Utilization factor.

v. Thermal (and overall) efficiency.

vi. CO_2 emission factor for the displacement of electricity generated by power plant in an electricity system.

It should be noted that for the load factor and utilization factor, the average of the parameters (used for their evaluation) from the power plant inventory records were used for the three years needed for the calculations.

The plant performance indices used in this work are outlined as follows:

Capacity Factor (CF)

The extent of use of the generating plant is measured by the plant capacity factor (CF) which is the ratio of the actual energy produced to the maximum possible energy output of the plant for a given period of time. From the data set acquired, the percentage plant capacity factor for the period under review was calculated using equation (1);

[17] Raja AK, Srivastava AP, Dwivedi M (2006) Power plants engineering. New Age International Private Ltd, New Delhi, India, 1-40.

$$CF = \frac{EG}{R_C \times H} \times 100\% \tag{1}$$

Where:

CF = Capacity Factor

EG = Energy Generated (MWH)

R_C = Rated Capacity of Power Plant (MW)

H = Expected Running Hours (In a year.)

Load Factor (LF)

The load factor which is the ratio of average load to maximum demand during a given period is calculated in percentage using equation (2); it is an indication of the utilization of the power plant capacity.

$$LF = \frac{AV_{LOAD}}{MAX_{LOAD}} \times 100\% \tag{2}$$

Where:

LF = Load Factor

AV_{LOAD} = Average Load (MW)

MAX_{LOAD} = Maximum Load (MW)

Plant Capacity (PC)

This is a measure of energy the plant is capable of generating and this is dependent on power generation of the plant and the corresponding running hours. For this study, total plant capacity for each year is calculated using equation (3); it measures the extent of use of the power plant and additionally indicates the degree of the power plant failure.

$$PC = R_c \times H \tag{3}$$

Where:

PC = Plant Capacity

R_C = Rated Capacity of Power Plant (MW)

H = Expected Running Hours (In a year.)

Utilization Factor (UF)

This is a measure of the use made on the total installed capacity of the plant; the percentage utilization factor is calculated using equation (4); it reflects how effectively managed the power plant is in terms of down time.

$$UF = \frac{MAX_{LOAD}}{R_C} \times 100\% \quad (4)$$

Where UF = Utilization Factor and the rest of the parameters in equation (4) have their same meaning in equation (1) and equation (2). The overall efficiency and the thermal efficiency of the power plant was calculated using equation (5) to (10).

Overall Efficiency

The overall efficiency of the power plant was calculated using equation (5) to (7).

$$\text{Overall Efficiency} = \frac{\text{Heat equivalent of electrical plant}}{\text{Heat of combustion of coal}} \times 100\% \quad (5)$$

$$\text{Overall Efficiency} = \frac{(\text{Energy generated (MWH)} \times 1000 \times 3600)\text{KJ}}{\left(\frac{\text{Gas consumed} \times 10^6}{35.3147}\right)(m^3) \times \text{net CV}\left(\frac{\text{KJ}}{m^3}\right)} \times 100\% \quad (6)$$

Where
$$\text{volume }(m^3) = \frac{\text{Volume (SCF)}}{35.3147} \quad (7)$$

SCF is Standard Cubic Feet, net CV is net Calorific value of the gas.

Thermal Efficiency

The thermal efficiency of the power plant was evaluated using equation (8) to (10)

$$\text{Thermal Efficiency} = \frac{\text{Heat equivalent of mechanical energy transmitted to turbines shaft}}{\text{Heat of coal combustion}} \times 100\% \quad (8)$$

$$\text{Thermal Efficiency} = \frac{\text{Overall Efficiency}}{\text{Electrical (generator) efficiency}} \times 100\% \quad (9)$$

$$\text{Thermal Efficiency} = \frac{\text{Overall Efficiency}}{0.98} \quad (10)$$

Where electrical/generator efficiency is constant at 98%

CO_2 Emission Factor

For the determination of the CO_2 emission factor for the displacement of the electricity generated by power plants in an electricity system is done by calculating the operating margin (OM). The operating margin is the emission factor that refers to the group of existing power plants whose current electricity generation would be affected by the proposed clean development mechanism (CDM) project activity. Using the steps of the United Nations Framework Convention on Climate Change; TOOL07 Methodological tool (Methodological Tool, 2017): Tool to calculate the emission factor for an electricity system Version 05.0; to calculate the operating margin of the emission factor for Ibom Power Plant. The baseline methodology procedure required applying the following six steps.

i. Identify the relevant electric power system.

ii. Select an operating margin (OM) method.

iii. Calculate the operating margin emission factor according to the selected method.

iv. Identify the cohort of the power units to be included in the build margin (BM).

v. Calculate the build margin factor.

vi. Calculate the combined margin (CM) emission factor.

From the above steps, step (i) to step (iii) alone are used for the determination of the operating margin CO_2 emission factor because, the build margin and the combined margin are outside the associated scope of this study. Following the steps, the relevant electricity system was identified in the scope of the study as Ibom Power Plant and the operating margin method which was chosen was the simple operating margin. The simple OM emission factor was calculated as the generation-weighted average CO_2 emissions per unit net electricity generation ($KgCO_2/KWh$) of all generating power plants serving the system, not including low cost/must-run power plants/units. It was calculated using equation (11):

$$EF_{\text{grid, OMsimple, y}} = \frac{\sum_i FC_{i,\text{m,y}} \times NCV_{i,y} \times EF_{CO_2,i,\text{y}}}{EG_{m,y}} \tag{11}$$

Where

$EF_{\text{grid, OMsimple, y}}$ = CO_2 emission factor of power unit *m* in year *y* (2014-2016) (Kg CO_2/MWH)

$FC_{i,m,y}$ = Amount of fuel type *i* consumed by power unit *m* in year *y* (Mass or volume unit)

$NCV_{i,y}$ = Net calorific value (energy content) of fuel type *i* in year *y* (MJ/mass or volume unit)

$EF_{CO_2,i,y}$ = CO_2 emission factor of fuel type *i* in year *y* (Kg CO_2/GJ)

$EG_{m,y}$ = Net quantity of electricity generated and delivered to the grid by power unit *m* in year *y* (MWH)

m = All power units serving the grid in year y except low-cost/must-run power units

i = All fuel types combusted in power unit *m* in year y.

y = Either the applicable year during monitoring for the ex-post option or the three most recent years for which data is available at the time for the ex-ante option.

As the tool allows the use of the following two data vintages for calculation of the OM:

i. Ex-post option: the emission factor is determined for the year in which the project activity displaces grid electricity, requiring the emissions factor to be updated annually during monitoring.

ii. Ex-ante option: the emission factor is determined once at the validation stage, and thus no monitoring and recalculation of the emissions factor during the crediting period is required. For grid power plants like Ibom Power Plant, a 3-year generation weighted average is used.

For the determination of the operating margin (OM) for Ibom Power Plant, this is done based on the average operating margin using the net electricity generation of all power plants serving the system, the fuel types and total fuel consumption.

Results and Discussion

For the period under review, as captured in Table 3, the percentage capacity factor for the year, 2014 was determined to be 28.656 %, 29.316 % for 2015 and 28.613 % for 2016 respectively, with an average of 28.86 %. From the results, it is seen that the minimum value of the capacity factor was recorded in 2016 and the maximum value was recorded in 2015. For the period under consideration, the capacity factor of the power plant has been low as against the industry best practice of between 50 and 80 % [11]. It should be noted that a low capacity factor (such as 28.613 % in 2016) as presented in Table 3 signifies that the average energy generation is low accompanied with excessive plant failure and inclusively, most of the plant's capacity remains underutilized for a major part of the year and so operational cost would be high compared to revenue implying that for the three years, the Power Plant most probably was running at a loss. In Figure 2, the total energy generation for each year is represented in the chart. As expected, there is a trend associated between the total energy generated by the power plant and the capacity factor of the power plant as seen in Figure 3.

Table 3. Plant Capacity and Capacity Factor.

Year	**Total Energy Generated (MWh)**	**Total Plant Capacity (MWh)**	**Capacity Factor (%)**
2014	479,453.88	1,673,160	28.66
2015	490,497.04	1,673,160	29.32
2016	480,050.61	1,673,160	28.69
Average	**483,333.84**	**1,673,160**	**28.89**

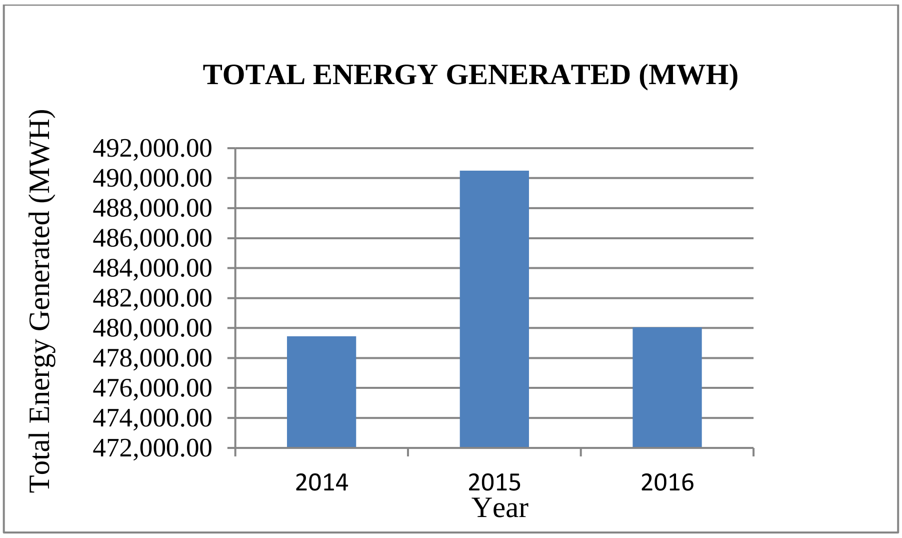

Figure 2. Total Electrical Energy Generated by Ibom Power Plant.

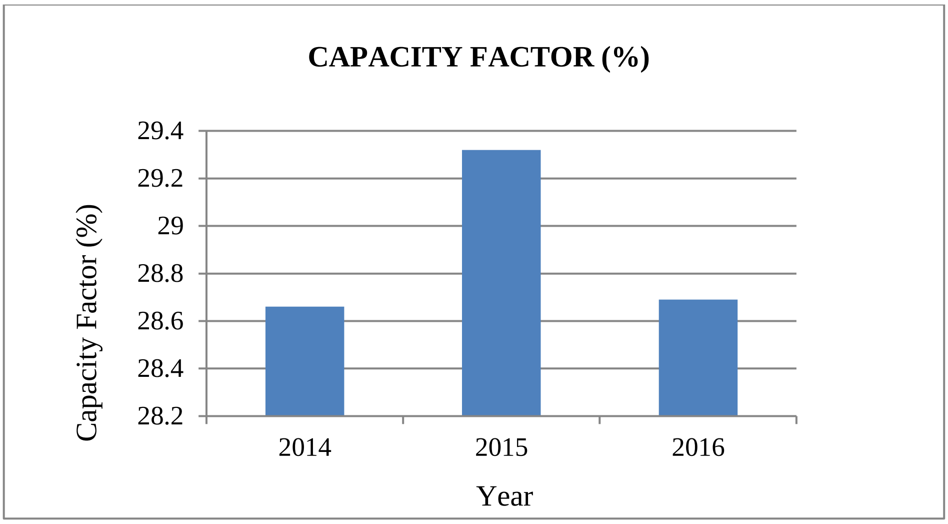

Figure 3. Capacity Factor for Ibom Power Plant.

The load factor of a power plant is an indication of the utilization of power plant capacity and is expected to be high so that the total capacity of the plant may be utilized to the maximum which will culminate to lower cost of electricity being generated. Data from the inventory record shows that the average load for Power Plant was 110.44MW and the maximum demand on the unit was 125.17 MW. The typical load factor for the Power Plant averages 88.23% for the period under review, thus exceeding the international best practice average of 80% and above [18]. The high load factor as evaluated is a desired quality which means a greater number of the power units available at the power station generated power to meet the maximum demand. This however means that the fixed cost which is proportional to the maximum demand can be distributed over a greater number of the power units supplied which would at the same time lower the cost of supplying electrical energy. The reduction in cost with good load factor is due to the fact that the overall working cost per unit becomes low, the fixed charges having been distributed over more units of energy generated.

Ibom Power Plant has a rated capacity of 191 MW and accordingly, the plant capacity as evaluated using equation (3) showed that the total capacity of Ibom Power Plant is 1,673,160 MWH while the average generating capacity of the plant from plant records, for the years under review is 483,333.84 MWH. Evaluating the utilization factor from equation (4) using an average maximum demand of 125.17 MW from the plant inventory record resulted in 65.53% as against international best practice of 95% as recommended in Iwuamadi and Dike [18].

Using equation (5) to (7) alongside the data presented in Table 2, the overall efficiency and the thermal efficiency were determined. The results indicated that for the years under review, the overall efficiency of the plant varied between 25.50% - 30.49% as against international best practice and standards of 60% and above [19] (with the maximum efficiency in 2014 and the minimum efficiency in 2016); the average for the overall efficiency stood at 27.37%. For the thermal efficiency, this ranged from 26.02% - 31.11% against international best practice of 75% and above [19] (with the maximum thermal efficiency in 2014 and the minimum thermal efficiency in 2016) with an average of 27.92%. These results are captured in Figure 4.

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[18] Iwuamadi Obioma C., Dike Damain Obioma (2012). "Emperical Analysis of Productivity of Nigerian Power Sector". IOSR Journal of Electrical and Electronics Engineering, 3(4), 24-38.

[19] Adeoye O.S. and Bamisaye A.J. (2016). *"Performance Evaluation and Analysis of Omotosho Power 2016 in Nigeria".* Innovative Energy and Research, 5 (1) 1000134.

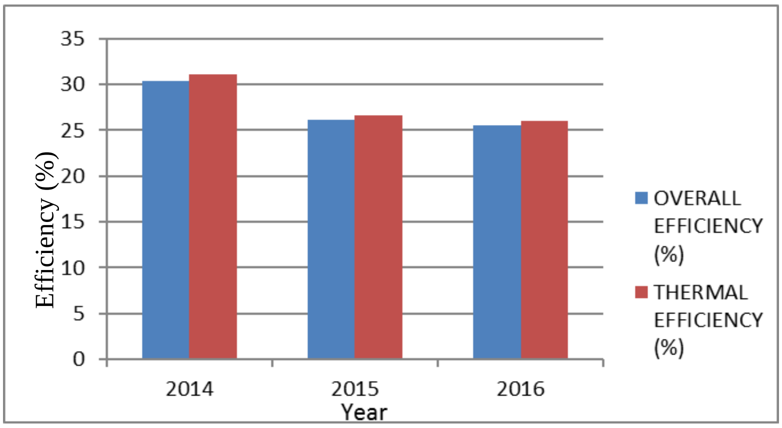

Figure 4. Overall and Thermal Efficiency of Ibom Power Plant.

The result of the operating margin for each relevant year for the period under review is presented in Table 4. To aid in the calculation, the CO_2 emission factor of natural gas is 56 $KgCO_2/GJ$ [20] and as evaluated, the generation weighted emission factor ($EF_{OM,y1-y3}$) gives 26.17 $KgCO_2/MWH$.

Table 4. Operating Margin Emission Factor for the Period under Review.

Year	**Emission Factor $Ef_{grid,Omsimple,Y}$ ($Kgco_2/Mwh$)**
2014	23.35
2015	27.26
2016	27.92
Generation Weighted $Ef_{om,Y1-Y3}$	**26.17**

From international best practice, the emission factor for Nigeria from electricity specific factors is 0.43963136 $KgCO_2/KWH$ and for the International Energy Agency (IEA) composite electricity/heat factors is 0.4034043 $KgCO_2/KWH$ [21] both of which are 439.63136 $KgCO_2/MWH$ and 403.4043 $KgCO_2/MWH$. These when compared to the operating margin emission factor for Ibom Power Plant with a value of 26.17 $KgCO_2/MWH$ is much lower that the values stated for the international standard. This variation in the difference is experienced for a number of reasons. The type of fossil fuel used, the Liquefied Natural Gas which is used to generate electricity at Ibom Power Plant; another reason for the difference is that different power plants have different levels of generation.

The analysis carried out on Ibom Power Plant shows that economic activities contributed the most to the value of the operating margin emission factor. Electricity demand is high putting pressure on the low supply of the power plant. Thus, one cannot link the increase in power generation to economic growth but link the increase in economic activities to the calculated value of the CO_2 emission factor.

[20] Natural Resources Canada 2013, ARCHIVED – Appendix B – CO_2 Emission Factors, accessed 26 August, 2017; <googleweblight.com/i?u=http://www.nrcan.gc.ca/energy/efficiency/industry/technical-info/benchmarking/canadian-steel-industry/5193&grqid=yhid6ym7&hl=en-NG>
[21] Econometric (2011). Electricity-specific emission factors for grid electricity.

In each of the evaluated parameters, the plant had lower performance indices than set standards (some considerably low and some others acceptable). A number of reasons were deduced to be responsible for this shortfall in performance. These include low plant availability due to breakdowns/failures, obsolete technology relative to advancement in the field, instability of the national grid system, ageing of plant components, disruption in gas supply, among others[22 23 24 17].

For the faults and the number of outages of the power plant, Table 5 gives a vivid representation of this:

Table 5. Number and Percentage Failure Occurrence in the Power Plant.

YEAR	SYSTEM FAULT	PLANT FAULT	GAS FAULT	OPERATION FAULT	TOTAL FAULT	SYSTEM FAULT (%)	PLANT FAULT (%)	GAS FAULT (%)	OPERATION FAULT (%)
2014	144	10	7	2	163	88.34	6.13	4.29	1.24
2015	127	13	8	2	150	84.67	8.67	5.33	1.33
2016	100	11	5	1	117	85.47	9.40	4.27	0.86

Conclusion

The performance of a power plant is primarily hinged on the plant's generated energy which is a function of the available power output and the running hours. Higher energy generation however demands that the units generate to maximum possible capacity and operate for higher running time and invariably break down and fail less frequently. More so, some of the Plant's units are long overdue for replacements, hence, to increase their capability of responding to changing circumstances, it is necessary to prolong the life of the plants by stepping up the level of regular maintenance. Some policy implication could be drawn, and they include

- The Nigerian government should ensure the security of the fuel source for power generation by mandating oil companies to channel their flared gases to power plants.
- Improvement in energy efficiency practice and implementation of energy efficiency policies in the power sector by the Nigerian Government.
- Initiate energy conservation measure in the residential houses to reduce the wastage of electrical energy by the increasing energy demand for electricity by Nigeria's growing population.

Promoting electricity rationing will be a good option while efforts for increased electricity generation, transmission, and distribution (a call for the expansion of the national grid) be intensified by the government.

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[23]Seebregts AJ, Giorgio S, Giancarlo T (2010). "Energy technology system analysis program". IEA ETSAP Technology Brief E-02, pp: 1-5. 6. Corporation NN (2015) Upstream oil Production.
[24] S.O Oyedepo, R. O. Fagbenle, S.S. Adefia and S. A. Adiavbiele (2014). "Performance evaluation and economic analysis of a gas turbine power plant in Nigeria. Energy Conversion and Management 79 (2014), 413-440.