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ANALYSIS OF ENERGY GENERATION SPECTRUM AND MANAGEMENT IN A PRIVATE POWER PLANT IN OGUN STATE, NIGERIA

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Abstract: The country's energy sector has evolved series of massive transformations in recent time in order to get it right, because that's vital for economic and social development. Thus, with a growing population of more than 180 million people, she still generates about 4000 MW of electricity from a potential of 12,522 MW. The resultant effect is the insufficient and unreliable electricity which has severely constrained economic development and growth. The study has been carried out for the period 2015 to 2017. The station is a Thermal Open Cycle Power Plant consisting of five unit gas turbines (GT) with installed capacity of 45 MW each, giving a total installed capacity of 225 MW. The study revealed that the Private Power Plant produced 2.7 % of the energy from the national grid feeding the whole country and still having excess spinning reserve after its maximum demand fed to a large cement plant. The extra capacity should be evacuated to the national grid to add to the paltry 4000 MW generated by the Generation Companies (Gencos) thus bringing benefit to the Government and additional profit as return on investment to the privately owned power firm leading to increase in the plant capacity factor.
Keywords: Capacity factor, Integrated Power Plant, Energy, spinning reserve, Genco

1. INTRODUCTION

The lubricant and critical factor for a sustainable economic growth is energy, which facilitates the development of the economy by increase in productivity and creates employment opportunity. Energy remains the key catalyst in wealth generation and a key component for national, industrial, technological, social, economic, and sustainable development (Oyedepo and Nwaokocha, 2018; Oyedepo et al., 2019). Electrical energy sector has become one of the main elements of economic and social development in this modern world; where the advancement of any country is measured in terms of the per capita consumption of electrical energy. In other words, electricity is the driver of any meaningful economic activities. Therefore, lack of constant access to reliable power costs businesses and the economy as a whole as adequate power supply is an unavoidable prerequisite to any nation's development (Rapu et al; 2015; Badejo et al; Fashola 2016).

The largest economy in Sub-Saharan Africa (SSA) is Nigeria, but with high limitations in the power sector with constraint of growth. It is endowed with solar, hydro, oil and gas resources and has the potential to produce 12,522 megawatt (MW) of energy from existing power plants, but unfortunately generates an insufficient quantity of around 4000 MW (Fashola, 2016 and White House, 2016). The access to unreliable energy, makes running a business including micro, small and medium enterprises (MSMEs) more challenging than usual, thus making firms in the informal sector to lose revenues cheaply. These losses on the wider economy come with a negative consequences and an unhealthy impact in domesticating the laudable Sustainable Development Goals (SDGs) in Nigeria (White House, 2016 and Oyedepo, 2012).

Nigeria has continued to suffer inadequate power supply from the national grid and this has impeded the economy potential growth of the country. So for Nigeria to get it right, massive transformation policies and palliatives is highly necessary. Increase in energy consumption has a direct link with growing energy demand and this has also contributed to greenhouse gas (GHG) emission and environmental pollution (Rapu et al; 2015; Oyedepo et al; 2019; Fashola 2016, Giwa et al; 2019; Sambo,2009). Thus, with an increasing population of over 180 million people, the generation limit of 4000 MW within a potential capacity of 12,522 MW will remain a critical constrain to the national economic health; this fact a recent high-powered economic retreat admitted as worrisome and the need for both temporary and permanent solution (Fashola, 2016; White House, 2016; Oyedepo, 2012; Aized, 2018; Oyedepo 2013).

Power shortages and outages have quite a number of knock-on effects. This could include the noticeable reduction in production, closure of industries and relocation of industries in some cases which result into loss of jobs as the industries were relocated or closed down. The outages results in revenue losses to the companies and industries. When outages occur and production is on-going, the goods and product are damaged and get wasted. Therefore, power outages in the industries affect everyone directly through the cost of goods and services.

The pivot for both the technology and economic development is electricity, but in Nigeria, the inadequate supply of electricity is impediment to the growth of the economy. Ogundipe in 2013 asserted that the increase in energy is a vital component for an emerging economic growth. The frequent blackout as a result of unstable electricity supply in Nigeria is a resultant effect of government's ineffectiveness in policy implementation despite the privatization of the power sector (Ogunleye, 2017). The power sector currently has an installed generation capacity of 12,522 MW, which is driven by the IPPs, the GenCos and NIPP generation stations (Ogundipe, 2013; Oladipo et al., 2018).

In order to cushion the adverse effect of power inadequacies and its attendant effects on cement business in the country, the management, decided to build and operate a state of the art captive power plant with an installed total generating capacity of 225 MW with a hundred-percent availability and reliability and having excess capacity, wholly owned by the private company (Oyedepo and Nwaokocha, 2018; Fashola, 2016; Oyedepo et al., 2014).

The power industry in his attempt to achieve efficiency in service power delivery, it unbundled the Power Holding Company into generating companies which comprises of twenty-eight generating stations co-owned by private concern and the government; transmission company (i.e. Transmission Company of Nigeria, TCN), and with eleven Distribution Companies. The percentage of ownership of the unbundling power system is shown in Table 1. Currently, the Nigeria Electricity Transmission system has about 5,523 km of 330 KV lines and another 6,801.49 KM of 132 KV lines, with a capacity to transmit about 4000 MW (Oyedepo et al., 2019; Ogundipe, 2013; Oyedepo et al., 2014).

Table 1: Percentage Ownership of Nigeria Energy Sector

Energy Arms	Government (%)	Private (%)
Generation (Gencos, NIPP, IPP)	20	80
Transmission (TCN)	100	-
Distribution (Discos)	40	60

2. ELECTRICITY EQUIPMENT MAINTENANCE IN NIGERIA

Maintenance of electrical energy equipment is vital in cultivating a good maintenance culture. This best practice helps reduce funds spent on replacement of poorly maintained power equipment over years of operation (Onohaebi and Lawal, 2010). Investors hardly showed interest in Nigerian Electricity Supply Industry (NESI) after some few years of its unbundling advertisement. The current state of power equipment in this industry is not encouraging to attract investors. The equipment has been poorly maintained apart from the fact that they are aged and needs replacement or total overhauling. Numerous meetings, seminars and workshops have been organized to address these persistent and unending challenges of maintaining engineering infrastructure (Onohaebi and Lawal, 2010; Awosope, 2004).

— Power Systems in Nigeria

≡ National Integrated Power Projects (NIPPs)

The NIPPs is the concerted effort of the Federal Government in combating the power challenges in the country. It was birthed in 2004 as a pilot initiative of the Federal Government and to be co-funded by the private sector in a bid of improving the generation capacity of Nigeria's energy supply. Seven of these were initially established in gas producing States of the country and four more were later established, making the total of eleven NIPPs to help deliver additional capacity to the National Grid (Oyedepo et al., 2019; Fashola, 2016; Obi et al., 2013; Okoro, 2014).

≡ Independent Power Producers (IPPs)

IPPs are corporate power plants established and managed by the private sector of the economy. Before the privatization era, IPPs existed in Nigeria and more than seventy licenses has recently been issued in order to upgrade the power status of the country (Fashola, 2016; Oladipo et al., 2018; Awosope, 2004; Okoro, 2014).

The Case Study is one of the earliest operational IPPs in Nigeria. The Plant has been operating in Ogun State, Nigeria since 2012 on an island mode. The station is a Thermal Open Cycle Power Plant consisting of five unit gas turbines (GT) with an installed capacity of 45MW each, giving a total combined installed capacity of 225 MW. The principle of operation is based on the Brayton Cycle as shown in Figure 1. The compressor takes in fresh air at ambient temperature where it is raised with the pressure. These high pressures continue with action into the combustion chamber and burns fuel at constant pressure. These goes further into the turbine where it expands to atmospheric pressure passing through the nozzle vanes. The expansion accounts for the spinning of the turbine blade which then turns the shaft inside the generator. As the shaft in the generator rotates, electrical current is produced and then distributed through a transformer, but the exhaust gases leaves the turbine in the open cycle are thus not re-circulated (Okoro, 2014; Yee et al., 2008).

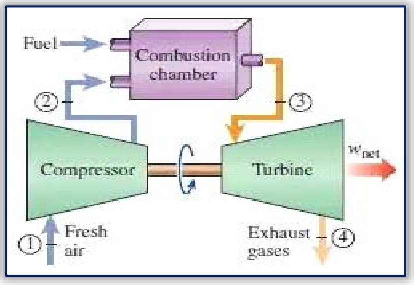

Figure 1: Brayton Cycle (Vuorien, 2011)

The plant comprises of three desalination units used to produce de-mineralized water for the purpose of water injection for the gas turbines usage to enable the control NOx emission and to conduct Compressor wash. The units which are fitted with dual fuel nozzles, operates on gaseous fuel always except on rare occasions where there are interruptions or intermittent supply of the gas at low pressure that the units will run on liquid fuel without distortion of the power being generated.

However, owing to the high cost of automotive gas oil, and to overcome the low pressure of natural gas, a gas compressor plant had been installed to raise the output pressure up to the range of the input pressure to the gas turbines. Brayton cycle can thus achieve a normal efficiency of around 55% when compared to the single cycle steam power plant, limited to 35 – 45% (Vuorien, 2011; Mehta and Mehta, 2004).

— **Definition of Technical Terms**

≡ Percentage Energy Generated (%EG): This is the ratio of energy generated by the IPPs (MWh) compared to the overall energy generated to the National Grid, as given in Equation 1,

$$\%EG = \frac{\text{Energy Generated by IPP}}{\text{Energy Generated from National Grid}} \quad (1)$$

≡ Energy Plant Capacity (EPC): The expected overall amount of power (MW) and energy (MWh) the plant is able to produce (Mehta and Mehta, 2004), as represented by Equation 2,

$$\text{EPC} = \text{IC X RH} \quad (2)$$

where: EPC = Energy Plant Capacity, IC = Installed Capacity, RH = Running Hours

≡ Capacity Factor (CF): This is the ratio of the average loading to the actual rated capacity of the plant, thus measuring actual plant usage (Oyedepo et al., 2014; (Mehta and Mehta, 2004). This is represented in Equation 3,

$$\text{CF} = \frac{\text{Ep}}{\text{IPC x RH}} \quad (3)$$

where: Ep = total energy generated (MW) in a given period, IPC = installed power capacity (MW) of the plant, RH = total running hours.

≡ Percentage of Energy Consumed: This explains the ratio of the energy consumed as compared to the energy generated by the power plant per given period. The expression is given in Equation 4.

$$\%EU = \frac{\text{EC}}{\text{EG}} \quad (4)$$

where: EC = Energy Consumed, EG = Energy Generated

3. MATERIALS AND METHODOLOGY

The method of study entails observation, data collection and data analysis using a realistic assessment of problems and potentials for improvement. To carry out this study, three years (2015 - 2017) data was collected from the Transmission Company of Nigeria (TCN) and a cement industry and presented in Tables 2 and 3. The data entails the monthly energy generated by the Private Power Plant (MWh) from 2015 to 2017, the monthly energy generated by the Gencos (MWh), the installed Power Capacity (MW), the monthly energy used in the power station (MWh) and the maximum energy demand from the power plant.

Table 2: Energy Generated by the Gencos and IPP (2015- 2017)

Month/year	GENCOs (Mwh)			IPPs (Mwh)		
	2015	2016	2017	2015	2016	2017
January	2605886.68	3084826.56	2170932.4	46987.32	48761.9	53005.28
February	2344547.12	2684687.59	2401817.19	47853.09	49087.76	60325.68
March	2491638.18	2521816.53	2771437.4	43657.54	47865.54	67184.43
April	2272850.63	2266606.78	2462258.42	47908.54	50012.87	65499.17
May	2014226.51	1958501.69	2621363.27	48093.01	50564.09	58980.55
June	2477279.51	1580615.45	2470285.73	53452.65	45987.08	61236.94
July	2835807.13	2102006.73	2469411.61	59012.51	52365.32	61655.02
August	2942747.32	2405004.17	2470928.57	51231.86	58098.45	62519.55
September	2861683.7	2441498.09	2450624.43	60853.12	60342.41	46307.56
October	2854908.9	2596764.29	2609318.53	43098.86	49924.01	58944.25
November	2928271.5	2452004.19	2554708.23	57654.8	59065.23	53699.83
December	2885021.34	2437653.28	2841319.03	51654.93	52682.52	63985.77
Annual total	31514868.52	28531985.34	30294404.81	611458.2	624757.2	713344

Source: Transmission Company of Nigeria and cement industry

Using equation 2:

EPC (IPP) = IC x RH = 225 (24 x 365 days) = 1,971,000 MWh

The percentage energy generated by GENCO for the years is shown in Table 4 using Equation 1 to determine the value. The historical data for energy consumed in the power station (MWh) by IPP are presented in Tables 5 and 6.

Table 3: Installed Capacity of the Power Stations (Study Area)

S/N	Power Station	Type (MW)	Installed Capacity (MW)
1	"A" IPP	Gas/Diesel	225
2	Genco	Hydro/Thermal	12522

Table 4: Percentage Energy Generated by IPP (2015 - 2017)

Month	2015	2016	2017
January	1.80	1.58	2.44
February	2.04	1.83	2.51
March	1.75	1.20	2.42
April	2.11	2.21	2.66
May	2.39	2.58	2.25
June	2.16	2.91	2.48
July	2.08	2.49	2.50
August	1.74	2.42	2.53
September	2.13	2.47	1.89
October	1.51	1.92	2.26
November	1.97	2.41	2.10
December	1.79	2.16	2.25
Annual total	23.47	26.18	28.29

4. ANALYSIS AND DISCUSSION

The energy generated by the IPP varies from 43098.86 to 67184.43 MWh between years 2015 to 2017 as depicted in Table 2. The highest yearly total energy generated was 713344.03 MWh in 2017 as reflected in Table 2. There has been variability in the monthly and yearly energy generation from 2015 to 2017 due to customer demand, plant maintenance and repairs. The month with the highest energy generated was in March 2017 with 67184.43 MWh and the month with the lowest energy generated (due to low customer demand and plant maintenance) was in October 2015 with 43098.86 MWh. This is depicted in Figure 2.

Table 5: Energy Consumed and Percentage of Energy consumed from 2015 to 2017 by IPP using Equation 5.

	2015		2016		2017	
MONTH	E^0 CON (MWh)	% E^0 CON	E^0 CON (MWh)	% E^0 CON	E^0 CON (MWh)	% E^0 CON
January	1329.79	2.83	1441.64	2.96	1242.80	2.35
February	1222.50	2.56	1325.33	2.70	1142.52	1.89
March	2004.85	4.59	2173.48	4.54	1873.69	2.79
April	1567.33	3.27	1699.16	3.4	1464.79	2.24
May	1506.51	3.13	1633.22	3.23	1407.95	2.39
June	1492.68	2.79	1618.24	3.52	1395.03	2.28
July	1448.66	2.46	1570.51	3.00	1353.89	2.20
August	1058.17	2.07	1147.18	1.98	988.95	1.58
September	869.66	1.43	942.81	1.56	812.76	1.76
October	1868.34	4.34	2025.49	4.06	1746.11	2.96
November	1282.75	2.22	1390.65	2.35	1198.83	2.23
December	1783.71	3.45	1933.75	3.67	1667.02	2.61
Total	17434.95	2.85	18901.44	3.03	16294.35	2.28

Note: E^0 CON= Energy Consumed, % E^0 CON = Percentage Energy Consumed

Table 6: Monthly Capacity Factor from 2015 to 2017 for the private power plant as defined by equation 3

			2015		2016		2017	
MONTH	IC (Mw)	RH (hr)	EGR (Mwh)	CF %	EGR (Mwh)	CF (%)	EGR (Mwh)	CF (%)
January	225	744	46987.32	28.07	48761.90	29.30	53005.28	31.66
February	225	672	47853.09	31.65	49087.76	32.47	60325.68	39.90
March	225	744	43657.54	26.08	47865.54	28.59	67184.43	40.13
April	225	720	47908.54	29.57	50012.87	30.87	65499.17	40.43
May	225	744	48093.01	28.73	50564.09	30.21	58980.55	35.23
June	225	720	53452.65	33.00	45987.08	28.39	61236.94	37.80
July	225	744	59012.51	35.25	52365.32	31.28	61655.02	36.83
August	225	744	51231.86	30.61	58098.45	34.71	62519.55	37.35
September	225	744	60853.12	36.35	60342.41	36.05	46307.56	27.66
October	225	744	43098.86	25.75	49924.01	29.82	58944.25	35.21
November	225	720	57654.80	35.59	59065.23	36.46	53699.83	33.15
December	225	744	51654.93	30.86	52682.52	31.47	63985.77	38.22
SUM		8784	611458.23	30.96	624757.18	31.61	713344.03	36.09

IC= Installed Capacity, RH= Running Hours, EGR = Energy Generated Record, CF = Capacity Factor

The expected load capable of been generated by the private (IPP) power plant station is 1,971,000 MWh as shown in Table 3, but the energy generated for the period of the 3 years ranges from 611458.23 MWh and 713344.03 MWh (Table 6), thus making it about 36.19% average energy generated. This reflects a gap between the expected energy generated and actual design capacity of the plant which may be impacted by the under-utilization of the plant in terms of load demands leading to excessive spinning reserve and eventual shutting down of available capacity (standby) while awaiting load. This gap could also be traced to the periodic and corrective maintenance at both the power plant and the captive plant leading to generating facility to be on redundancy or on standby.

The relevant percentages by month are shown in Figure 3. This shows an appreciable effort by the private power firm because, for instance, in April 2017, the power plant produced 2.66% of energy from the grid in the same month.

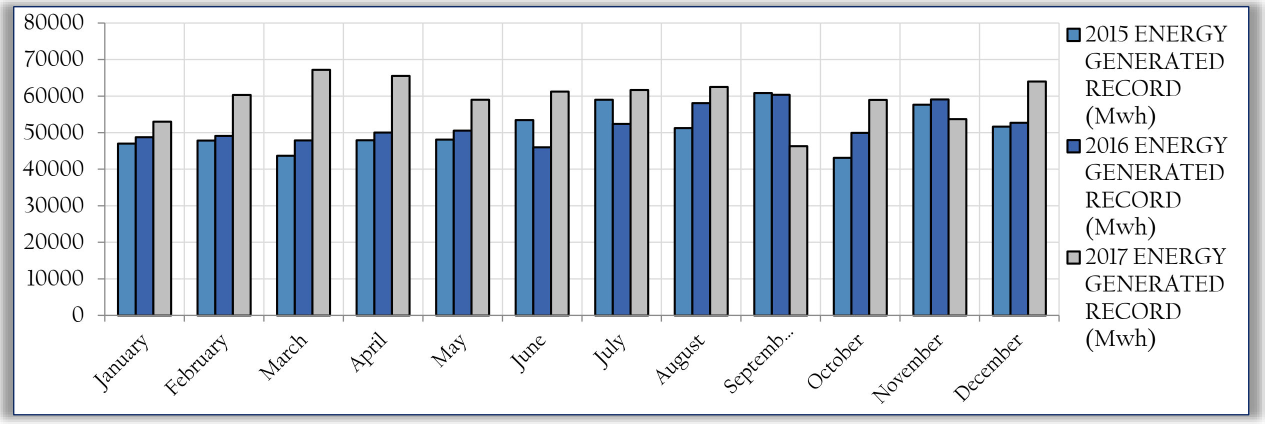

Figure 2: Monthly energy generated from 2015 to 2017

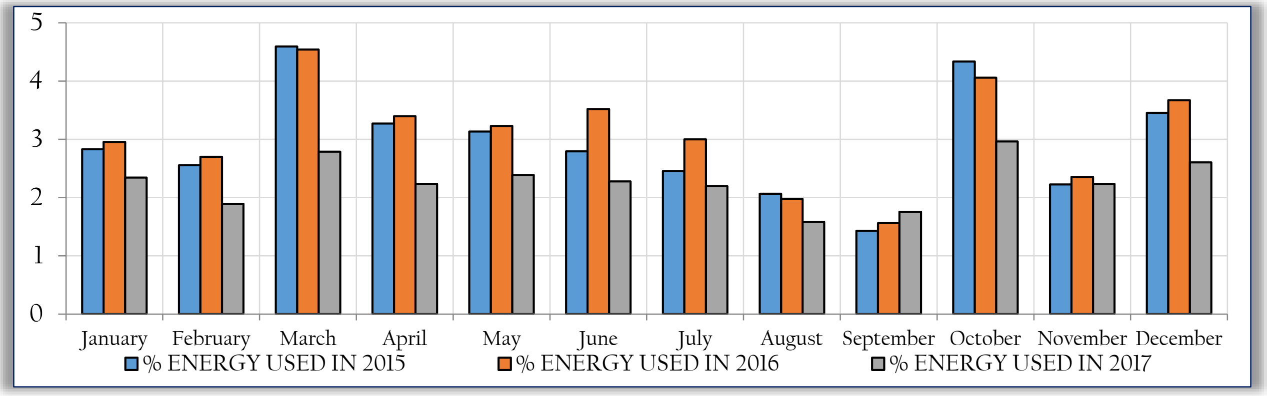

Figure 3: Percentage of energy used from 2015 -2017

The energy used monthly in 2017 varies from 812.76 to 1873.69 MWh, as in Table 5. The highest monthly energy used of 1873.69 MWh was obtained in March and the month with the lowest energy used was in September with 812.76 MWh. There has been variability in the monthly energy generated in 2017. The increase in energy consumption was due to the additional startup of generating units (turbines), together with its auxiliaries and Balance of Plant (BoP) equipment as a result of higher load demand from the Cement Plants.

Table 6 indicates the capacity factor of the IPPs for the years 2015-2017. For 2015, the average monthly capacity factor is 30.94% with a minimum average monthly capacity factor value of 25.75% in October and the highest value of 35.25% in July, which disagrees with industry best practice standard marked between 50% and 80%. A high capacity factor is required for a healthy economic operation of the IPP. A low value of average capacity factor of 30.96% indicates that the energy generation is low on an average scale. For the year 2016, the average monthly capacity factor for the plant is 31.64% with a lowest value of 28.39% in June and a highest value of 36.46% in November which is also not in agreement with industry standard of between 50% and 80%. The low average capacity factor (31.61%) also indicates the average energy generation is low.

Finally, for the year 2017, the average monthly capacity factor is 36.13% with a lowest value of 27.66% in September and a highest value of 40.43% in April also in disagreement with industry best practice value range of 50% to 80% as indicated in Table 6. The low average capacity factor of 36.09% for the plant indicates that the average energy generation is quite low. These are due to the fact that at least a unit (45 MW) is always on standby and the running units still have available capacity called the spinning reserve as a result of drop in load at the cement plant end occasioned by preventive, corrective or breakdown maintenance and market forces of products .

This study indicated that for the 12 months in 2017, energy generated when compared to the national grid is quite appreciable which needs a commendation from the Federal government of Nigeria.

However, it is obvious that 36.19% of the installed capacity of the plant was fully available from year 2015 to 2017. Also, the average capacity factor of 32.89% and a minimum capacity factor value of 30.93% in 2015 and 36.09% highest capacity factor value in 2017 all disagreed with international best practice standard of 50–80%. The above evaluated parameters had a low value far from international best practice standard, as it not operating at its designed nameplate value, still having unused and healthy available spinning reserve capacity. Notwithstanding, there is huge room for improvement as performance indices indicates that the expected generation capacity of the station was a total of 5,913,000 MWh, of electricity from the year 2015 to 2017, but a reduction of 3,963,440.56 MWh was recorded due to underutilization of the plant due to low load conditions. The plant is an open cycled power plant which could be improved upon to generate more units when it becomes a closed cycle.

5. CONCLUSION

Since electrical energy could not be stored, management of the power firm is advised to obtain On Grid licenses from the Nigerian Electricity Regulatory Commission (NERC) so that excess capacity be evacuated to the National Grid to add to the paltry 4000 MW generated by the Gencos thus bringing benefit to the Federal Government, and while also bringing additional profit as return on investment to the privately owned power firm leading to increase in the plant capacity factor and better management of the energy being produced.

Moreover, at minimal cost the waste heat from the exhaust stack of the Open Cycle Gas Turbine, could be routed or molded to a Steam Turbine through Heat Recovery Steam Generator (HRSG) system to produce up to 50% of additional electricity using the same gas. Such systems are called Combined Cycle Gas Turbine or power plant.

Therefore, the Federal Government should create policies and programs that will encourage both private and foreign investors to construct more power generating plants to shore up supply to the national grid using this private power plant state of the art turbine model.

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