Factors Influencing the Performance of Gas and Steam Turbines for Electricity Generation in Nigeria

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***Abstract*— The study examined the technical factors influencing the performance of gas and steam turbines for electricity generation in Nigeria, with a view to providing useful information on sustainability of thermal power generation technology in the country. A purposive sampling method was used to select some power plants in Nigeria. Precisely, gas turbines; Afam power station (Rivers State) and Delta power station (Delta State) while steam turbines; Egbin thermal station (Lagos State) and Sapele power station (Delta State) were considered. Data were obtained through primary and secondary sources. The data were analyzed using descriptive and inferential statistics. The result shows that Egbin power station with a life span utilization of 80% had the best value for all the performance indicators while Delta power station with a life span utilization of 46.68% had the second best value. Afam power station with a life span utilization of 104% had the third best value and followed by Sapele power station. The study therefore concluded that the key performance indicators confirmed the steam turbine technology is better than the gas turbine technology.**

***Keywords*— Performance Indicator, Gas Turbine, Steam Turbine and Electricity Generation in Nigeria**

I. INTRODUCTION

The access to reliable and stable supply of electricity is problematic for both the urban and rural occupants in Nigeria. This problem is more significant in the rural areas where only about 10% of the population have access to electricity [1]. Electricity production in Nigeria over four decades has varied from gas-fired, oil-fired, hydroelectric power stations to coal-fired stations with hydroelectric power systems and gas-fired (basically steam and gas turbines) systems taking superiority. This is based on the fact that the primary fuel sources (coal, oil, water, gas) for these power stations are readily available in the country [2].

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The prevailing generating capacity in Nigeria is dominated by gas-fired power plants, accounting for approximately 70% of all large-scale generation. The low capital cost to power ratio, high flexibility, high reliability without complexity, compactness, early commissioning, commercial operation and fast starting and quick shut down made gas turbine power plants to gain enormous attention. It is also known for its good environmental performance, manifested in the low environmental pollution [3], [4], [5]. There are four relatively large gas fired stations in the country, namely Egbin in Lagos state (1,320 MW), Sapele in Delta state (1020MW), Delta also in Delta state (912 MW) and Afam in Rivers state (710 MW) [6]. Nigeria currently has three large-scale hydro power stations, all in Niger State: the Kainji, Jebba (downstream from Kainji hydro station) and Shiroro hydro stations, which have a combined installed capacity of 1,940 MW [7].

The performance of a power plant in view of its efficiency, reliability and other operational factors has definite socio-economic significance both on the company operating the plant as well as the nation at large [8]. Conversely, in the absence of adequate and reliable electricity supply, socio-economic transformation would remain an illusion. In order to reasonably maintain facility performance in thermal power plants, daily control is made so that appropriate measures can be taken by monitoring the operation status. The performance of a power plant can be expressed through some common performance factors such as heat rate (energy efficiency), thermal efficiency, capacity factor, load factor, economic efficiency and operational efficiency.

Despite having over 8,000 MW installed capacity, the maximum available capacity has never exceeded 4,632.8 MW. According to TCN daily operational reports of 30th March, 2016, an average of 3,746.92 MW was generated out of which steam turbine generating stations had 694.15 MW from steam turbines representing 18.53% of total generation and 51.80% of total steam available capacity (1340 MW), 612.96 MW was generated from hydro turbines representing 16.36% of total generation and 48.17% of total hydro generation available capacity (1272.5 MW), 1588.29 MW is from gas turbines signifying 54.90% of total generation, 35.14% of total gas generation available capacity (4519.5 MW) while combined cycle power plants generated 851 MW representing 13.36% of total generation and 77.41% of total combined cycle available capacity (1100 MW) [9]. The available units could not be totally utilized due to various factors ranging from low water head and low gas level to poor grid network. It is therefore necessary to properly examine the technical factors influencing the performance of gas and steam turbines for electricity generation in Nigeria in order to be able to evaluate the appropriateness of each technology for both short and long term basis. Hence, this study.

II. EXPERIMENTAL PROCEDURE

A) Research instruments

The study covered selected gas turbines (Afam power station in Rivers state and Delta power station in Ughelli, Delta state) and steam turbines (Sapele power station in Delta State and Egbin thermal station in Lagos state) electricity generating companies in Nigeria. These four thermal power generation stations were purposively selected for the study. Analysis of variance was used to establish significant differences among the means of performance indicators in various power stations and Duncan Multiple Range Test was used to separate the means. The following key performance indicators (KPI) were calculated using the following equation;

B) Station heat rate

This is the ratio of fuel energy input as heat per unit of network output.

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

Where;

Q_c = Station heat ate
V_g = Volume of fuel (gas) consumed
C_g = Calorific value of fuel
EG = Energy generated

C) Load factor

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

$$L_f = \frac{EG}{AI \times RH} \quad \ldots \quad (2)$$

Where;

L_f = Load factor
EG = Energy generated (MWH)
AI = Installed station availability (MW)
RH = Rated hours (Hrs)

D) Calculated cost

It is also known as generation unit cost. It describes the station expenditure in relation to the total energy generated by the station.

$$CC = \frac{ET}{EG} \quad \ldots \quad (3)$$

Where;

CC = Calculated cost
ET = Station's total annual expenditure
EG = Energy generated

E) Thermal efficiency

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

$$\eta T = \frac{EG}{QT} \quad \ldots \quad (4)$$

where;

ηT = Thermal efficiency
EG = Energy generated
QT = Heat input to the turbine

III. RESULTS AND DISCUSSION

A) Evaluation of performance

Table I shows the summary of turbines installed in each of the power stations. Egbin and Sapele stations have six steam turbines (11.54%) each, while Delta has twenty gas turbines installed which constitute 38.46% of the total number of turbines considered. Egbin power station has six steam turbines installed with each having a capacity to generate 220 MW at base load. These turbines were manufactured by Hitachi and installed between late 1985 and 1987.

Table I: Summary of Power Stations Considered

Station	Year of Installation	No of units	%	Technology
Egbin	1986	6	11.54	ST
Sapele	1978	6	11.54	ST
Delta (Total)			**38.46**	
Delta I	1966	2	3.85	GT
Delta II	1975 (2002)	6	11.54	GT
Delta III	1978 (2003)	6	11.54	GT
Delta IV	1990	6	11.54	GT
Afam (Total)			**38.46**	
Afam I	1963	4	7.69	GT
Afam II	1976	4	7.69	GT
Afam III	1978	6	7.69	GT
Afam IV	1982	6	11.54	GT
Afam V	2002	2	3.85	GT
TOTAL		**52**	**100**	

Key: GT – Gas Turbine, ST – Steam Turbine
Source: Field Survey

Sapele power station also has six steam turbines installed. Each of these turbines has a capacity of generating 120 MW at base load. These turbines were manufactured by ABB and installed between 1977 and 1979. Afam power station has twenty gas turbines installed at various times. The nomenclature Afam I – V is given to differentiate the machines according to their period of installation. Afam I was the first set of turbines to be installed. It comprises of four gas turbines manufactured by BBC and they were installed in 1963. Afam II also comprises of four BBC gas turbines. They were installed in 1976. Each turbine in Afam II has an installed capacity of 23.9MW. Afam III consists of the third set of turbines installed in Afam. It comprises four BBC gas turbines installed in 1978 each with an installed capacity of 27.5MW. Afam IV consists of six ABB gas turbines, each with capacity of 75MW and installed in 1982. The last set of turbines installed in Afam (Afam V) consists of two (2)

Siemens gas turbines each with an installed capacity of 138MW.

Delta power station, just like Afam, consists of twenty gas turbines, grouped as Delta I - IV to differentiate their period of installation. Delta I was the first set of turbines to be installed in 1966 and comprise two gas turbines manufactured by Stal Laval, each with an installed capacity of 36MW. Delta II and III had six gas turbines each manufactured by General Electric (GE) and installed in 1975 and 1978 respectively with an installed capacity of 20 MW per unit. However, these machines had stopped working by mid-1990s due to unavailability of spare parts and difficulty in maintaining the turbines. A new set of Delta II and III units were installed in 2002 and 2003 respectively and they consist of six Hitachi machines each with an installed capacity of 25MW per turbine. Delta IV consists of six GE gas turbines each with an installed capacity of 100MW each installed in 1990. For the purpose of this study, Delta II-IV and Afam III-V were considered. This is because both Delta I and Afam I-II had either been scrapped or ceased to work since mid-1990s. Based on the above assumptions, Delta power station could be said to have an installed capacity of 900MW, Afam power station had an installed capacity of 836MW, while Egbin and Sapele power stations had 1300MW and 720MW respectively (Table II). From this table, the average number of staff used to produce 1MW in Delta, Afam, Egbin and Sapele is 0.48, 0.58, 0.43 and 0.60 respectively. This shows that Egbin power station requires the least number of people to generate 1MW while Sapele power station requires the most number of personnel to generate 1MW. Also the average number of technical staffs required to produce 1MW in Delta, Afam, Egbin and Sapele power stations were 0.25, 0.27, 0.25 and 0.36 respectively. This also followed the same trend as that of average number of staff required to generate 1MW. This shows that Egbin is the most efficient in terms of personnel utilization while Sapele is the least efficient.

B) Average life utilization of power stations

Since most turbines in each station were installed at different times and years, it is necessary to calculate the average life of each power plant. This is the average number of years in which the station had been in operation. Table III shows the calculated average life of each power plant. It also shows the percentage utilization of the station which is a ratio of the average life of the station and the expected (theoretical) life of the station which is 25 years for gas turbines and 30 years for steam turbines. From Table III, Delta power station is the most recent power station with an average station age of 11.67 years (46.68% life span utilization), this is followed by Egbin power station with an average station age of 24 years (80.00% life span utilization). Afam power station has an average station age of 26 years (104.00% life span utilization) while Sapele power station has the highest average station age of 32 years (106.67% life span utilization).

Table II: Summary of Installed capacity, Total number of Staffs and Technical Staffs

	DELTA	AFAM	EGBIN	SAPELE
Installed Available Capacity (MW)	900	836	1300	720
Total No of staff	439	489	561	432
No of Technical staffs	233	227	327	266
Average No of staff/MW	0.48	0.58	0.43	0.60
Average No of Technical Staffs/MW	0.25	0.27	0.25	0.36

Source: Field Survey

Table III: Summary of Average Plant Life

Station	Average life of Station (years)	Expected life of Station (years)	Percentage life span utilization (%)
Egbin	24	30	80
Sapele	32	30	106.67
Delta	11.67	25	46.68
Afam	26	25	104

Source: Field Survey

C) Evaluation of performance indicators

The result of the analysis for the performance indicators of gas and steam turbine generation stations are shown in Table IV. There were significant differences ($F = 14.34$, $p < 0.05$) among the means of heat consumed in the stations. The heat consumed in Egbin ($1.104 X 10^4$ kJ/kW) was the lowest. However, the heat consumed in Delta ($1.408 X 10^4$ kJ/kW), Sapele ($1.451 X 10^4$ kJ/kW) and Afam ($1.564 X 10^4$ kJ/kW) were significantly different ($F = 47.14$, $P < 0.05$) and consumed more heat. Therefore, from the analysis, the performance of Egbin is the best when compared with the heat consumed per kW of the other stations since it requires the least energy to generate a kilowatt of power. This is followed by Delta, Sapele and Afam. Afam power station is the least efficient as it required the highest quantity of energy to generate a kilowatt of power. This means that more fuel

Table IV: ANOVA Analysis of Performance Indicators for Gas and Steam Turbines

	Factors: Mean Ratings			
	Heat Consumed Per kw (KJ/KW) x 10^4	Thermal Efficiency (%)	Load Factor	Calculated cost (Kobo/KWH)
AFAM	1.5636^b	23.47^a	0.15^a	225.55^a
DELTA	1.4076^b	25.69^a	0.37^b	115.65^a
EGBIN	1.1040^a	32.68^b	0.54^c	100.29^a
SAPELE	1.4505^b	25.10^a	0.12^a	291.51^a

Means of the same letter along the same column (within the same performance indicator) are not significantly different ($P<0.05$).
Source: Field Survey

will be consumed to generate a kilowatt of power in Afam while Egbin will require the least fuel. There were significant differences ($F = 23.84$, $p < 0.05$) among the means of thermal efficiencies in the stations. The thermal efficiencies of Afam, Sapele and Delta stations were not significantly different ($F = 23.84$, $p < 0.05$) with mean ratings of 23.47%, 25.10% and 25.69% respectively.

However, the thermal efficiency of Egbin station was significantly higher ($F = 23.84$, $p < 0.05$) than other stations with mean rating of 32.68%. This implies that the two steam turbine stations, Egbin and Sapele, have the best and third best thermal efficiency mean rating while the two gas turbine stations, Delta and Afam, have the second best and the least thermal efficiency mean rating. Therefore, Egbin with the highest thermal efficiency is the best plant. Also, since there was no significant difference in the thermal efficiencies of Delta, Afam and Sapele stations, it was not possible to distinguish which is better. However, among these three stations, Delta has the highest thermal efficiency while Afam has the least thermal efficiency.

At 95% confidence level, all the four generation stations showed significant effect of load factor on the performance of each technology. Egbin (0.54) was the most significant, followed by Delta (0.37), Afam (0.15) while Sapele (0.12) was the least significant of the stations. This means that Egbin with the highest load factor was able to make a load generation of 54.11% of its forecasted power generation. This is followed by Delta with 37.33%, Afam with 14.78% while Sapele with the least load factor was able to make a load generation of 11.89% of its forecasted power generation (Table 4). Also, the analysis of variance (Table 4) shows that at 95% confidence level, the calculated cost for Sapele (291.51 k/kWH), Afam (225.55 k/kWH), Delta (115.65 k/kWH) and Egbin (100.29 k/kWH) were not significantly different ($p < 0.05$). However, both steam turbine stations, Egbin and Sapele have the highest and the least calculated cost while the two gas turbine stations, Delta and Afam have the second and the third best calculated cost respectively. This means the cheapest electricity generation comes from Egbin power station while the most expensive electricity generation comes from Sapele power station. Delta power station and Afam power stations follow Egbin as the second and third cheapest stations respectively. Table 5 shows the summary of the key performance parameters which were analysed. Egbin power station, which is the second newest station, emerged as the best station having achieved the best thermal efficiency, load factor, calculated cost and heat consumed per kilowatt value. Delta power station (the newest station) was the second best while Afam power station (the third newest station) and Sapele power station (the oldest station) both tied at third.

Table V: Summary of Performance Indicators Evaluation Results

	STEAM TURBINE		GAS TURBINE	
	Egbin	Sapele	Delta	Afam
Thermal efficiency	4	2	3	1
Load factor	4	1	3	2
Calculated cost	4	1	3	2
Heat consumed (per KW)	4	2	3	1
Average	4	1.5	3	1.5

Key: best = 4, second best = 3, third best = 2, fourth best = 1
Source: Field Survey

IV. CONCLUSION

The study concluded that the steam turbine technology is better than the gas turbine technology from the analysis of the key performance indicators. Therefore, government should concentrate more on installation of steam turbine power plants as against her current policy where over 90% of her new projects are gas turbines. This will ensure greater availability of electricity in the nation.

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