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Performance Evaluation of Gas Turbine Plant in Niger Delta Region of Nigeria: A Case Study of Afam Power Plant

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ABSTRACT

This study evaluated the performance the of Afam IV and V gas turbine power plant over a period of nine years in order to ascertain its suitability as option for power generation in the region. The study reveals that only 12.01% of the installed capacity was available throughout the period of study. The percentage shortfall of energy generated ranged from 70.69% - 98.49% against an international best practice of 5% - 10%. The load factor of the plant was at an average of 41% against an acceptable value of 80%. The plant use factor is 23.5%. The capacity factor ranged from 1.5% to 29.3% against an international best practice of 50% to 80%, while the utilization factor is 29.3%. During the period under review, the plant was expected to generate 57237.84GWh of Energy, it generated 6873.6GWh amounting to a generation loss of 87.99%.This analysis revealed that the running of the gas turbine as an option for power generation in the region is not reliable.

Introduction

Industrial gas turbines are usually designed with temperate climatic condition in mind. This may be so for two reasons. First, most users of gas turbines are in the temperature region of the world. Secondly, the ambient conditions in the temperate regions are relatively closer to those required for gas turbine optimum performance. Two of these climatic conditions are low temperatures and low relative humidity, [1]. The Niger Delta region of Nigeria located in the equatorial rain forest where the conditions are not conducive for gas turbine optimum operation. It lies between latitudes 4^0N and 6^0N and longitudes 5^0E and 8^0E and the average relative humidity is 80%.

Power outage has been a perennial problem in Nigeria. This challenge had always stared every regime of government in the face. To arrest this huge energy deficit, the National Electric Power Authority on 30th September, 2013 was unbundled. Share certificates and licenses were handed over to electricity generation and distribution companies. As a result of this, the Niger Delta Power Holding Company was set to oversee the National Integrated Power Project, NIPP located in the Region.

Despite the fact that gas turbine optimum performance in the Niger Delta Region of Nigeria is questionable, all the NIPP plants in the region were gas turbines. These are: Alaoji Power Plant (1,131MW), Benin Power Plant (508MW), Calabar Power Plant (634MW), Egbema Power Plant (381MW), Gbarain Power Plant (254MW), Geregu Power Plant (381MW), Ogorede Power Plant (508MW), Olorunsogo Power Plant (754MW), Omoku Power Plant (265MW), Omotosho Power Plant (513MW). The plants have capacity to generate a total of 4,774MW of electricity (NIPP 2014).

It is no doubt that overcoming the deficit in electric power has been a daunting task for various dispensations of government in the face of existing technical, management and economic challenges. It is to this end that an analysis comprising of technical, managerial and inter-related factors that affect the viability of existing power plants becomes paramount. This will ensure that the new power plants will avoid such pitfalls.

Hence, the objectives of this study will include:

(1) The performance evaluation of Afam gas turbine power station over a period of nine years (2005 – 2013);

(2) To make recommendations on how it improve electric power generation in Afam power station, while hoping that the new power stations will take advantage of the findings presented in this work.

Research Elaborations

Afam Power Plc is located in Okoloma village within the oil rich Ndoki clan of Oyigbo Local Government Area of Rivers State. The power station is named after Afam which happens to be a nearby village from where the gas turbines are located. It is the first major gas turbine station built in Nigeria, it is located in the oil/natural gas region of the Niger Delta, because of the large reserves there of these natural resource. The station with its auxiliary units were built and installed by Brown Boveri.

The first phase, Afam 1 was constructed and commissioned in 1963. It consisted of four generating units (GT1- GT4) each. With the industrial growth experienced in the seventies there was a need for four additional generating units, each with an installed capacity of 23.9MW, which was commissioned in 1976 and known as Afam II. This was followed by four gas turbines of 27.5MW each, commissioned in 1978 and known as Afam III. In 1982, Afam IV with six units was commissioned with a total output of 450MW of type BBC IBD. In 2002, Afam V was commissioned, with two generating system/units each of installed capacity 138MW. The Afam V consists of GT19 and GT20 each Siemens V 94.2 A type.

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Since Afam, I, II, III decommisioning, only Afam IV and V are still in different stages of services as at the time of this research.

In carrying out the analysis, a visit was taken to Afam power station during which relevant data needed were obtained from the plant record. Such data includes; installed energy plant capacity, generated energy, and running hours. Extensive literature review was conducted, through browsing the internet, journals, annual reports of relevant governmental outfits, conference papers, and exploring expert analysis/opinion on the issue. The data used in this study was obtained from the records department of Afam Power Station. Table 1 shows a summary of data which presents the installed capacity, running hours, generated energy and quantity of gas consumed for the period under consideration (2005 – 2013). The data was used to evaluate the following: energy plant capacity, capacity factor, plant use factor, load factor, utilization factor, power outage cost, percentage power reduction and percentage power available.

Plant performance indices

For the purpose of the study, the plant performance indices used includes:

Installed energy plant capacity (ϕ): It refers to the amount of energy the plant is capable of producing within a year.

$$\boldsymbol{\varphi} = \textbf{installed plant capacity (GW)} \times \textbf{Total hours of year (hrs)} \tag{1}$$

With an installed plant capacity of 0.726GW, the installed energy plant capacity is 6359.76 GWH

Energy Plant Capacity (ϑ): It refers to the amount of energy produced by the plant during operation or the expected generation of the plant within the running time. It is function of the plant's installed capacity and running time.

$$\boldsymbol{\vartheta = Installed\ plant\ capacity\ (GW) \times Running\ time\ (hrs)} \tag{2}$$

Capacitor Factor (ϖ): It indicates the extent of use of the generating plant. A low value indicates that the plant's capacity was unutilized for the period under consideration.

$$\boldsymbol{\varpi} = \frac{8}{\boldsymbol{\varphi}} \tag{3}$$

Where 8 = Energy generated over a given period.

Plant Use Factor (ω)

It measures the actual extent of usage of the generating plant under a specified period. A low value indicates plant generation below rated capacity while a high value indicates optimum performance of the plant. It differs from the capacity factor in the sense that only the actual number of hours that the plant was in operation is used.

$$\boldsymbol{\omega} = \frac{8}{\boldsymbol{\vartheta}} \tag{4}$$

Load Factor (LF)

This gives an idea of the stability in operation in terms of generated energy of the plant. Values closer to unity indicates stable operation. This can be expressed as

$$\boldsymbol{LF} = \frac{\boldsymbol{L_{ave}}}{\boldsymbol{L_{md}}} \tag{5}$$

Where; L_{ave} = average (demand) load generated

L_{md} = Maximum (demand) load generated in a given period

For the period under study (2005 – 2013), the load factor

$$\boldsymbol{LF = \frac{763.33}{1864.11} = 0.41}$$

Utilization Factor (UF)

This factor measures the extent of the usage of the total installed capacity of the plant and the level of effective management of the power plant during its down time.

$$\boldsymbol{UF} = \frac{\boldsymbol{L_{md}}}{\boldsymbol{\varphi}} \tag{6}$$

Substituting L_{md} and $\boldsymbol{\varphi}$ from Table 1 into equation 6, we get:

$$\boldsymbol{UF = \frac{1864.11}{6359.76} = 0.293}$$

Table 1. Energy Reduction from 2005 – 2013.

Year	Installed energy plant capacity (GWH)	Energy generated (GWH)	Energy Reduction (GWH)	Running hours
2005	6359.76	1838.86	4520.900	5110.34
2006	6359.76	1864.11	4495.650	5019.65
2007	6359.76	1393.93	4965.830	4928.76
2008	6359.76	305.34	6054.420	4378.65
2009	6359.76	151.86	6207.900	3476.98
2010	6359.76	95.95	6263.810	2020.76
2011	6359.76	391.28	5968.480	2920.65
2012	6359.76	497.88	5861.880	3678.54
2013	6359.76	334.39	6025.370	3597.70
Total	57237.84	6873.6	50364.240	

Source: Afam Power Station Annual Reports 2005 - 2013

Results and Discussion

The plant use factor which indicates the actual extent of usage of the generating plant under a specified period is presented in Fig. 1. The average value of the plant use factor form 2005 – 2013 is 23.5% as shown in Table 2 with a minimum value of 6.0% recorded in 2009 and a maximum value of 51.2% in 2006. This shows that the plant has failed excessively in utilizing the expected generated capacity.

Table 2. Plant use factor and running.

Year	Energy plant Capacity (GWh)	Energy Generated (GWh)	Plant Use Factor	Running Hours
2005	3710.11	1838.86	0.495	5110.34
2006	3644.27	1864.11	0.512	5019.65
2007	3578.28	1393.93	0.389	4928.76
2008	3178.90	305.34	0.096	4378.65
2009	2524.29	151.86	0.060	3478.98
2010	1467.07	95.95	0.065	2020.76
2011	2120.39	391.28	0.185	2920.65
2012	2670.62	497.88	0.186	3678.54
2013	2611.93	334.39	0.128	3597.70
			Ave=0.235	

Furthermore, Table 3 revealed an average capacity factor of 12.0% with a minimum value of 1.5% in 2010 and a maximum value of 29.3% in 2006. This is a far cry from the international best practice which ranges from 50% to 80% [2]. This implies that the plant is running at a huge loss.

Table 3. Annual Capacity factor.

Year	Capacity factor
2005	0.289
2006	0.293
2007	0.219
2008	0.048
2009	0.024
2010	0.015
2011	0.062
2012	0.078
2013	0.053

The plant under the period of review recorded a load factor of 41% against 80% suggested by [3]. This poor load factor value shows gross underutilization of the plant. Similarly, low utilization factor value of 29.3% was recorded which agrees with the load factor result, hence indicating poor management of the plant.

From the analyzed data, there is a huge gap between the installed capacity of the plant and the operational capacity. It is expected that the plant should yield 57237.84GWh of electric energy from 2005 – 2013 but rather it generated 6873.60 GWh of electric energy. This implies that only 12.01% of energy was available throughout the period of review. This low value is due to the fact that out of the 726MW installed capacity from turbines GT13 to GT18 in Afam IV and GT19 to GT 20 in Afam V, only turbine GT17 and GT18 from Afam IV are operational with an available capacity of 70%. As shown in Table 5, the other turbines in Afam IV are not operational due to compressor blade failure. While the two turbines in Afam V are in need of a major overhaul. This is worrisome because Afam V was commissioned in 2002 and as at the time the data was collected, it was no longer functional. This clearly shows that maintenance culture in the plant is very poor.

The poor condition of the plant can be attributed to the following:-

Environmental Problems

The atmosphere surrounding the plant due to its geographical location has high humidity, and considering gas flaring activities in the environment the ambient air consists of high moisture content, salts and containments like SO_2, SO_3. These attack the compressor blade causing corrosion, pitting, sulphidation and subsequently failure of the blade.

Management Lapses

Maintenance of the plant by the management is not done systematically and the attitude of the workers towards maintaining the plant is not sufficient for optimum production. This could be due to the absence of effective workers motivation and welfare schemes.

Economic Factors

Generally, the budgetary allocation for the power sector is low; this affects timely corrective maintenance of the plant. This is also the reason why the plant has only two turbines out of eight in working condition at the time of this research. When the turbine sub system parts fail, there is no allocation to replace them.

Conclusion

Performance evaluation and economic analysis was carried out on Afam power plant based on performance indices such as installed plant capacity, energy generated, capacity factor, load factor, utilization factor and plant use factor.

The study showed that only 12.01% of the plant installed energy was available within the period of study. It also revealed that the percentage loss in power ranged from 70.69% in 2006 and 98.49% in 2010. This is a huge departure from 5% - 10% which is the international best practice [4]. The average capacity factor is 12.0% with a minimum value of 1.5% in 2010 and maximum of 29.3% in 2006. When compared to the international standard of 50% - 80% it is seen to be grossly inadequate. The plant use factor ranged from 6.01% to 51.2% with an average value of 23.5%. The load factor stood at 29.3% as against the international best practice of 80% and above. The utilization factor of the plant was evaluated to be 41% as against the international practice which is 95% and above [4].

This study shows that the plant is in a deplorable condition and needs urgent attention from the Federal Government of Nigeria in other to attain NIPP goals.

Recommendations

In other to revitalize the plant, the following technological, management and economic recommendations are made:

Technological: The design of the air intake system should take into consideration the nature of the contaminants and site environmental conditions. A dehumidifier should be incorporated into the system so that ambient air condition (of 27^0C and 80% R.H) can leave the dehumidifier at a lower temperature and relative humidity that would not enable condensation as it passes through the compressor blades. The absence of this caused the unit to be prone to fouling, sulphidation, pitting, erosion and corrosion of the compressor blades.

Table 4. Power Station Status and Installed Capacities.

STATION	UNIT	INSTALLED CAPACITY (MW)	AVAILABLE CAPACITY (MW)	REMARKS
AFAM 1 De-commissioned	GT 1	10.3	Nil	Unavailabe, Unit Obsolete
	GT 2	10.3	Nil	Unavailabe, Unit Obsolete
	GT 3	17.5	Nil	Unavailabe, Unit Obsolete
	GT 4	17.5	Nil	Unavailabe, Unit Obsolete
AFAM II De-commissioned	GT5	23.9	Nil	Unavailabe, Unit Obsolete
	GT 6	23.9	Nil	Unavailabe, Unit Obsolete
	GT 7	23.9	Nil	Unavailabe, Unit Obsolete
	GT 8	23.9	Nil	Unavailabe, Unit Obsolete
AFAM III De-commissioned	GT 9	27.5	Nil	Unavailabe, Unit Obsolete
	GT 10	27.5	Nil	Unavailabe, Unit Obsolete
	GT 11	27.5	Nil	Unavailabe, Unit Obsolete
	GT 12	27.5	Nil	Unavailabe, Unit Obsolete
AFAM IV	GT 13	75.0	Nil	Compressor blade failure. Awaiting spares
	GT 14	75.0	Nil	Compressor blade failure. Awaiting spares
	GT 15	75.0	Nil	Compressor blade failure. Awaiting spares
	GT 16	75.0	Nil	Compressor blade failure. Awaiting spares
	GT 17	75.0	45	Available
	GT 18	75.0	60	Available
AFAM V	GT 19	138.0	Nil	Awaiting Major Overhaul
	GT 20	138.0	Nil	Awaiting Major Overhaul
Total		987.20	105	

Source: Afam Power Station Annual Report 2005 to 2013

Management

The Federal Government should come to the aid of the power station by setting up a well-defined framework that could respond quickly to corrective maintenance operations in the plant. It is necessary to increase the motivation of staff working in power stations through welfare schemes and safety programmes so as to elicit maximum worker productivity and commitment in the discharge of duties.

Economic

The Nigerian government needs to increase budgetary allocations for the power sector so that maintenance of power systems will be more efficient.

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