Performance Analysis of Central Gas Turbine Power Station, Edjeba, Delta State, Nigeria

Adegboyega Gabriel A[1], Famoriji John O[2]

[1]Federal University of Technology, Akure, Nigeria
gabrieladis@yahoo.com

[2]Federal University of Technology, Akure, Nigeria
famorijijohn@yahoo.co.uk

Abstract: ***In this research paper, basic factors: Plant Capacity, Plant Use Factor, Load Factor and Utilization Factor were used to estimate the performance of a Central Gas Turbine Power Station. Information data were obtained from Edgeba gas turbine power station Delta state, Nigeria. These are inventory records of monthly energy generation between 2002 and 2012 and operational statistics. The data were used to determine the plant capacity, plant use factor, load factor and utilization factor. However, Edgeba gas turbine power station has Capacity Factor of 20.4% as against the target of 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 (Gas Turbine Procurement, Conditions and Ratings, 1997).***

Keywords: Plant Capacity, Plant Use Factor, Load Factor, Utilization Factor.

1. Introduction

The independent power projects (IPPs) in Nigeria are mainly established to make up for the short fall of power supplies from the national grid to mostly large scale industries, some are established to also add to the grid therefore increasing the amount of power available in the system. Obodeh and Isaac (2011) reported that in most recent years studies have shown that most IPPs owned by multinational companies and private individuals have been operating below their installed capacity for years as compared to the International Standard Organization (ISO) ratings for gas turbine power plants operated in the sub-Saharan Africa region. With the electric generation crisis in Nigeria and also with the added energy shortfall from various IPPs in the country owned by multinationals, socio-economic development would no doubt remain a mirage as more money would be spent on other more expensive sources of power by these companies, thus increasing the cost of production of goods or services. To rescue this ugly situation, a critical evaluation of factors contributing to low energy generation and erratic supply system is important and necessary. Nigeria produced 23.5 billion kWh in 2005 from about 6 GWe (giga watts electric) of plant and had final consumption of 17 billion GWh , giving per capita consumption of only 113 kW/yr (Ibitoye and Adenikinju, 2007; Nigerian Statistics Bureau, 2007). Current electric energy output is very low, with current installed capacity for energy generation put at 6,200MW, while actual output hovers between 2,500 MW and 3,200 MW (Nigerian Statistics Bureau, 2007). Nigeria's population size is 140 million, and to put the electric energy generation crisis in perspective, Sweden (population 9 million) generates 32,000 MW, South Africa (population 42 million) generates 36,000 MW and Lithuania (population 3 million) generates 3,000 MW (ECN, 2003; Ekeh, 2008; Ibitoye and Adenikinju, 2007). The government in power has for almost a decade advocated and emphasized the need to drastically improve energy generation output and efficiency of use. The government has backed up its desires by committing huge resources in this quest. However, the results achieved so far beg the issue (Iwayemi, 2008; Okoro and Chikuni, 2007). Other reasons have also been suggested as being responsible for the problem but hardly has any of these reasons considered the issue from the point of how the plants are performing.

2. General Overview of Edgeba Gas Turbine Power Plant

The Central Power Plant (CPP) is a Shell Petroleum Development Company (SPDC) facility located at the Edjeba community in the Warri south local government area of Delta State (Figure 1). The plant was commissioned between 1981 and 1982 and it consists of four (4) units of 2.8MW Ruston TB 5000 model gas turbines (with total installed capacity of 11.2MW).

Figure 1: The Central Power Plant (Shell, Edjeba)

The plant runs on dual fuel gas turbines, hence it was commissioned on diesel fuel firing, but Gas firing started in June 2000 after the completion of piping of natural gas from the Nigerian Gas Company (NGC) – a subsidiary of the Nigerian National Petroleum Company (NNPC) located at 5km east from the station. Since commissioning, the station has remained the main source of power for all the SPDC facilities that are operated in the Warri region.

The high load dissipated by these facilities is shown in Table 1 made it only of necessity that an Independent Power Plant (IPP) that was built by the organization (SPDC) to meet its power demands.

Table1: SPDC Facilities and Load Demands

S/N	*SPDC Facility*	*Load (MW)*
1	Edgeba Office/ Engineering	1.3
2	Edgeba Residential Area	0.4
3	Ogunu Main Office Area (MOA)	2.4
4	Ogunu Industrial Area/Clinic and Telecom	1.4
5	Ogunu Residential Area	2.5
Total Load (MW)		8.0

The main components that are required for the generation of electricity in a gas turbine power plant are the Compressor module, Combustion module and the Turbine module. These three modules form an assembly that is termed 'Gas generator' which is mechanically coupled via a gear box to the Alternator .This four systems now forms the entire Gas Turbine. Figures: 2 and 3 show the gas generator assembly and natural gas fuel line respectively.

Figure 2: Gas generator-Alternator assembly

Figure 3: Natural Gas (fuel) Lines

A gas turbine power plant essentially brings together air that it compresses in its compressor module, and fuel, that are then ignited. Resulting gases are expanded through a turbine. That turbine's shaft continues to rotate and drive the compressor which is on the same shaft, and drives also a generator coupled to the turbine shaft as well and thus generating electrical energy. The functional tree of a gas turbine power station as obtained from Fernando and Francisco is given (Figure 4).

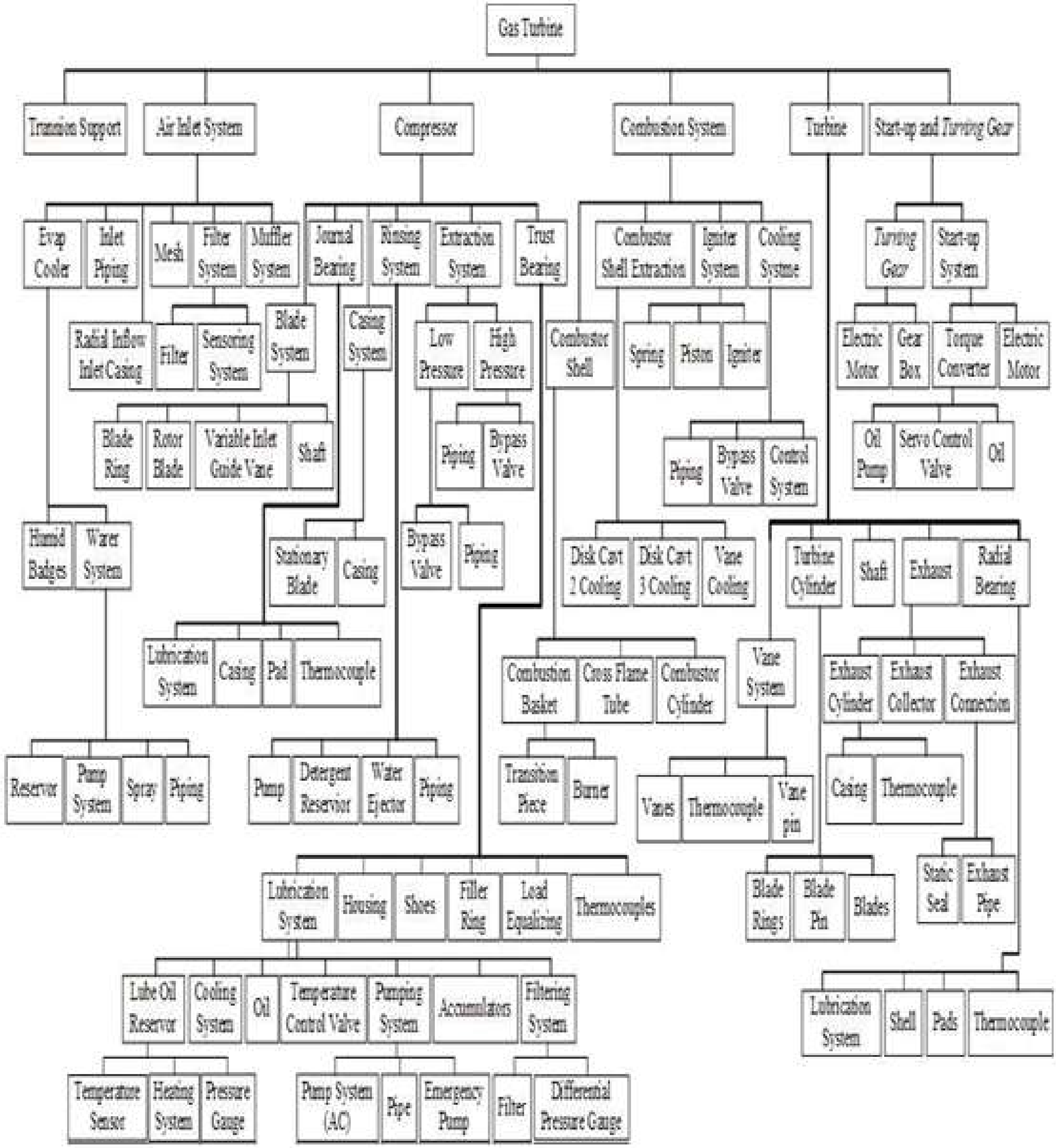

Figure 4: Gas Turbine Functional Tree

3. Materials and Method

Data were obtained from Edgeba Power station's logbook. Data are inventory records of monthly energy generation between 2002 and 2012 and operational statistics that show the period when each of the plant units was first commissioned, period of major outage and the time of maintenance. In analyzing the data, load factor, capacity factor and utilization factor were obtained. Equations 1 to 9 were used to estimate plant capacity (PC), capacity factor (CF), plant use factor (PUF), load factor (LF) and utilization factor (UF).

$$Plant\ Capacity = Power\ generated\ (MW) \times Runninghours\ (H) \quad (1)$$

$$Capacity\ Factor = \frac{Average\ Demand}{Rated\ Capacity} \times 100\% \quad (2)$$

$$Capacity\ Factor = \frac{Maximum\ Demand}{Rated\ Capacity} \times Load\ Factor \quad (3)$$

$$Capacity\ factor = \frac{Total\ Energy\ Generated\ (MWH)}{Maximum\ possible\ energy\ that\ would\ have\ been\ produced} \times 100\%\ (4)$$

$$Capacity\ Factor = \frac{Total\ Energy\ Generated\ (MWH)}{Rated\ capacity\ of\ plant\ (MW) \times Hoursof\ the\ year(H)} \times 100\%\ (5)$$

Where:
Rated capacity of the plant is 11.2MW [2.8 MW×4 (units)],

Total hours of the year are 8760 [24 hours×365 days],
Maximum energy= 11.2MW×8760 hour = 98,112MWH.

$$PUF = \frac{Total\ energy\ generated\ (MWH)}{Rated\ capacity\ of\ the\ plant \times number\ of\ operating\ hours} \times 100\%\ (6)$$

PUF is power use factor

$$Load\ Factor = \frac{Average\ Demand}{Maximum\ target\ load} \times 100\%\ (7)$$

$$Load\ Factor = \frac{Average\ load\ generated}{maximum\ target\ load} \times 100\%\ (8)$$

$$Utilization\ Factor = \frac{Maximum\ load\ generated}{Rated\ capacity} \times 100\%\ (9)$$

4. Results and Discussion

Plant Capacity

Plant capacity 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 the Central Power Plant, Edgeba, total plant capacity for each year is calculated using equation 1 as follows.

PC = Installed Power (MW) × Expected Running hours (H)
PC = 11.2 (MW) × 24 hrs ×365 (*days*)
PC = 98,122 MWH

and the results, for the review period, are presented in Table 2 and graphically shown on Figure 5 Thus, the total capacity of the plant is 98,122MWH while the average generating capacity of the plant from plant records, for the years under review is 21,147,49 MWH. Therefore the generating capacity is 21.76% of the total installed plant capacity. Of this generating capacity, average of 2630.64 MWH of energy (constituting 13.7% of generating capacity) is used by the plant while the remaining 18,360.89 MWH (86.3% average) is sent to the various load users connected to the plant.

Table 2: Central Power Plant Energy Generation Profile

Year	*Energy Generated (Mwh)*	*Used (Mwh)*	*Sent Out (Mwh)*	*Used (%)*	*Sent (%)*	*Generated (%)*
2002	16,845.52	2246	14,589.50	13.3	86.7	100
2003	17,004.62	2267	14,737.30	13.3	86.7	100
2004	17,088.30	2274	13,620.30	13.3	86.7	100
2005	31,212.80	3468	27,233.8	10.9	89.1	100
2006	30,701.90	4176	26,525.90	13.6	86.4	100
2007	12,130.34	2021	10,109.10	16.6	83.4	100
2008	2,928.03	732	2,196	25	75	100
2009	26,940.44	2993	23,947.40	11.1	88.9	100
2010	28,123.40	3124	24,999.50	11.1	88.9	100
2011	22,519.78	3134	23,993.20	11.5	88.5	100
2012	22,147.49	2502	20,017.80	11.1	88.9	100
Average	21,147.49	2630.64	18,360.89	13.7091	86.2909	100

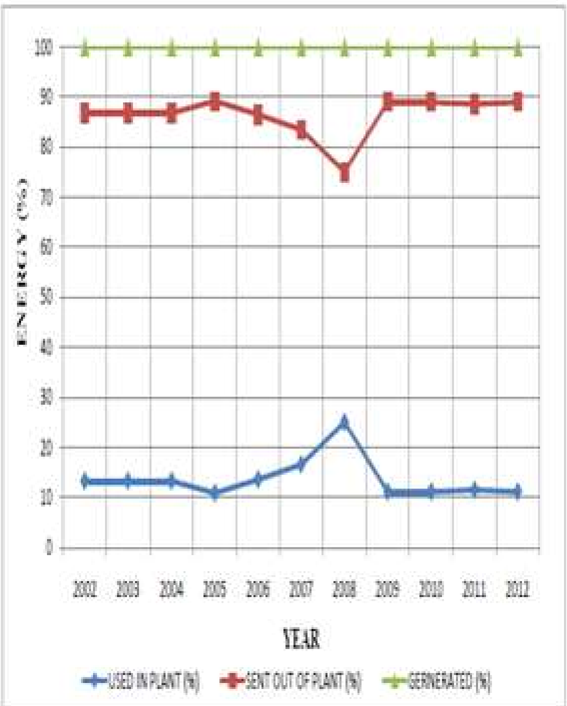

Figure 5: Variation of Energy Generated, Consumed and Transmitted with year.

Plant Factors

The plant factors are other indices in evaluating a plant performance which are capacity factor, plant use factor, load factor and utilization factor.

4.2.1 Capacity Factor

The extent of use of the generating plant is measured by the capacity factor (CF) which is the ratio of the average energy output of the plant for a given period of time to the plant capacity. The plant capacity factor is calculated using equations 3 and the results, for the review period, are presented in Table 3 and graphically shown on Figure 6. As shown for the review period between 2002 and 2012, the average capacity factor is 20.4% with a minimum of 2.98% in 2008 and a maximum of 31.81% in 2005 as against industry best practice of between 40 and 65%. It should be noted that a low capacity factor (such as 2.98% in 2008) signifies that the average energy generation is low, excessive plant failure and also means that most of the plant's capacity remains unutilized for a major part of the year and so operational cost would be high compared to revenue. However, if scheduled maintenance of the plant is significantly improved, the frequency of failure will reduce, high capacity factor would be attainable and cost of generation would be considerably economical.

Table 3: Capacity Factor (2002 - 20012)

Year	*Energy Generated (Mwh)*	*Total Plant Capacity (Mwh)*	*Capacity Factor (%)*
2002	16,845.52	98122	17.19
2003	17,004.62	98122	17.33
2004	17, 088.30	98122	17.33
2005	31,212.80	98122	31.81
2006	30,701.90	98122	31.28
2007	12,130.34	98122	12.36
2008	2,928.03	98122	2.98
2009	26,940.44	98122	27.45
2010	28,123.40	98122	28.66
2011	27,127.21	98122	27.64
2012	22,519.78	73920	30.46
Average	21,147.49	98122	20.40

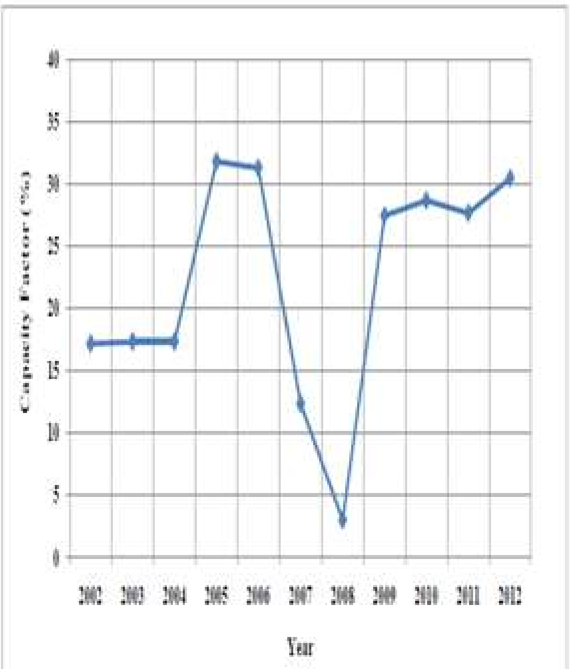

Figure 6: Variation of Capacity factor

4.2.2 Plant Use Factor

This is a modification of plant capacity factor in that the actual number of hours that the plant was in operation is used. Using equation 6, the plant use factor for the review period 2002 – 2012 is evaluated and presented in Table 4 and Figure 7. For the period under review, the average plant use factor is 29.2% with a minimum of 5.96% in 2008 and a maximum 55.29% in 2011. A high plant use factor indicates high to actual of expected generation while low plant use factor indicates excessive plant failure (downtimes) and thus a measure of plants generation below rated capacity.

Table 4: Plant Use Factor

Year	*Actual Generated Energy (Mwh)*	*Total Running Hours (H)*	*Unit Capacity (Mw)*	*Expected Maximum Energy (Mwh)*	*Plant Use Factor (%)*
2002	16,845.52	26,280	2.8	73584	22.89
2003	17,004.62	35,040	2.8	98122	17.33
2004	17,088.30	26,280	2.8	73584	23.22
2005	31,212.80	25,438	2.8	71226.8	43.82
2006	30.701.90	33,683	2.8	94312.4	32.55
2007	12,130.34	35,040	2.8	98122	12.36
2008	2,928.03	17,520	2.8	49056	5.96
2009	26,940.44	26,280	2.8	73584	36.61
2010	28,123.40	35,040	2.8	98122	28.67
2011	27,127.21	17,520	2.8	49056	55.29
2012	22,519.78	19,174	2.8	53687.2	41.9
Average	21,519.78	27,027	2.8	75677.85	29.9

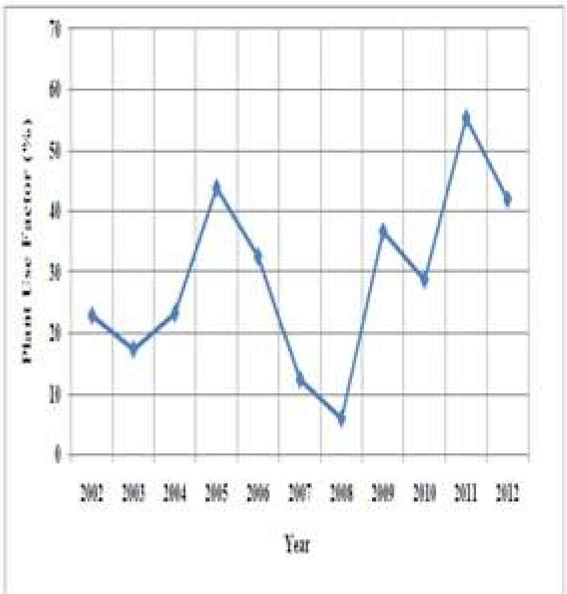

Figure 7: Variation of Plant Use Factor

4.2.3 Load Factor

Load factor is defined as the ratio of the average load to the peak load during certain prescribed period of time. It is an indication of the utilization of power plant capacity. The load factor of a power plant should be high so that the total capacity of the plant is utilized for the maximum period that will result in lower cost of the electricity being generated. Typical load factor for the Central Power Plant averages 81.76% (from 1st to 3rd quarter of 2012) while international best practice value stands at 80% and above. High load factor is a desirable quality. It means a greater number of power unit is being generated for a given maximum demand. Thus, the fixed cost which is proportional to maximum demand can be distributed over a greater number of units supplied. This will lower the overall cost of supply of electric energy. The load factor is calculated using equation 8 and presented in Table 5 with its plot shown in Figure 8.

Table 5: Load Factor (2012)

Month	*Average Actual Generation (Mw)*	*Available (Maximum) Capacity (Mw)*	*Load Factor (%)*
January	4.5	5.5	81.81
February	3.9	5.5	70.91
March	4.5	5.5	81.81
April	4.8	5.8	82.76
May	4.2	5.5	81.81
June	5.7	6.6	86.36
July	5.4	6.6	81.81
August	5.4	6.6	81.81
September	5.7	6.6	86.36
Average	4.90	6.02	81.72

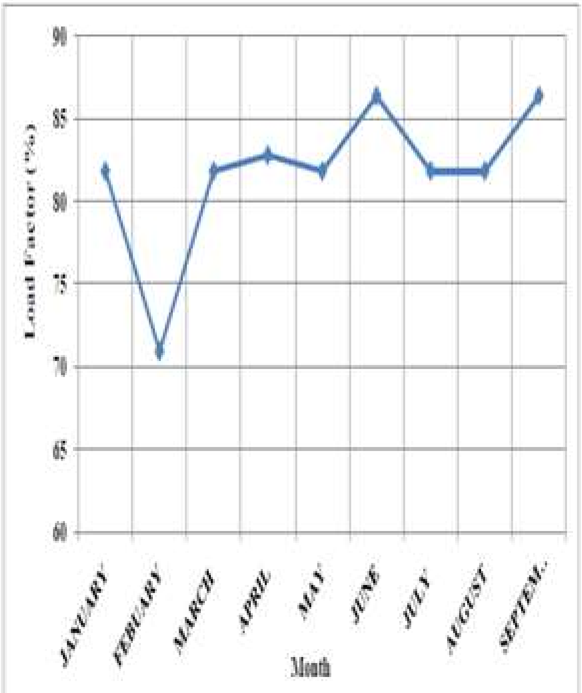

Figure 8: Variation of Load Factor

4.2.4 Utilization Factor

Utilization factor reflects how effectively managed a station is in terms of down times. It is a measure of the utility of the power plant which is a ratio of maximum demand to the rated (installed) capacity of the plant. Using equation 9, the utilization factor of for the Central Power Plant, Edgeba is calculated and shown in Table 6 and Figure 9.

Table 6: Utilization Factor

Month	Available (Maximum) Capacity (Mw)	Installed (Rated) Capacity (Mw)	Utilization Factor (%)
January	5.5	11.2	49.1
February	5.5	11.2	49.1
March	5.5	11.2	49.1
April	5.8	11.2	51.7
May	5.5	11.2	49.1
June	6.6	11.2	58.9
July	6.6	11.2	58.9
August	6.6	11.2	58.9
September	6.6	11.2	58.9
Average	6.02	11.2	54

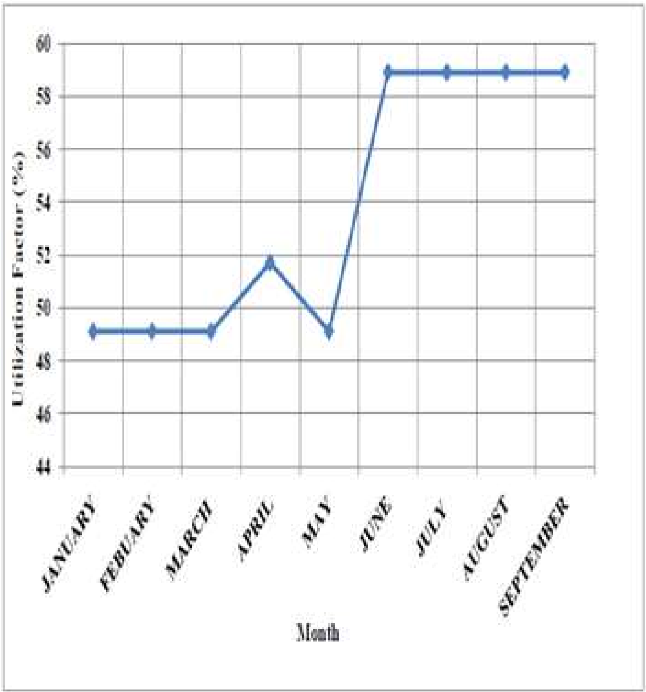

Figure 9: Variation of Utilization Factor

For the review period, typical utilization factor ranges from 49.1-58.9% as against international best practice of over 85%. This stands to mean that some generating units were utilized for less than their normal hours of utilization all year round and this is due to inadequate routine maintenance and equipment fault development.

To reduce downtime incidences and hence increase utilization factor planned and routine maintenance should be keenly upheld and enhanced and repair of down time equipment timely executed.

5. Conclusion

Performance analysis of the Central Power Plant (CPP), Edgeba has been carried out with specific emphasis on the five (5) key performance indicators: Plant capacity, Capacity Factor, Plant Use Factor, Load Factor and

Utilization Factor of the plant. For the review period, the average capacity factor was 20.4% (2.98% minimum in 2008 and 31.81% maximum in 2005), while the plant use factor averages 29.14% (5.96% minimum in 2008 and 55.29% in 2011) as against set standards of 40-65% and 50-70% respectively. From the 1st to 3rd quarter in the year 2012, the average load factor was 81.72% (70% in February and 86.36% in September) while the utilization factor had an average of 54% (49.1 minimum in February and 58.9% in September) while international best practices standards are 75% and above and 80% and above respectively. In each of the evaluated parameter, the plant had lower performance indices than set standards (some considerably low and some others acceptable). A number of reasons could be adduced to be responsible for this shortfall in performance. This includes plant availability due to breakdown/failures, overdue overhaul of units, obsolete technology relative to advancement in the field, load instability, ageing of plant components among others.

References

[1] O. Obodeh, F.O. Isaac, Performance Analysis for Sapele Thermal Power Station: Case Study of Nigeria, J. Emerg. Trends Eng. Appl.Sci., 2(1): 166 – 171, 2011.
[2] F. I. Ibitoye, and A. Adenikinju. Future Demand for Electricity in Nigeria, Applied Energy Journal. 84(5): 492-504, 2007.
[3] Nigerian Statistics Bureau (ed). 2007. Nigerian Statistical Information, available online from http://www.nigerianstat.gov.ng
[4] ECN (ed), 2003. The Nigerian Energy Policy, Energy Commission Publication Abuja, Nigeria.
[5] O. I. Okoro and E. Chikuni,. Power Sector Reforms in Nigeria: Opportunities and Challenges, Journal of Energy, Southern Africa. 18(3): 52-57, 2007.
[6] J. C Ekeh. Positioning the Power Sector for Electricity Sufficiency in Nigeria to Meet Up with Vision 2020, 20th Covenant University Public Lecture Series, March 27, 2008, Ota, Nigeria.
[7] A. Iwayemi, Investment in Electricity Generation and Transmission in Nigeria: Issues and Options, International Association for Energy Economics Journal, First Quarter, 2008 Edition: 37-42