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RELIABILITY AND AVAILABILITY ANALYSIS OF A GAS TURBINE POWER PLANT

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ABSTRACT

Gas turbines play a crucial role in meeting power demands, However, in Nigeria, a significant number of gas turbines operate well below design standards due to inadequate maintenance, leading to Availability and Reliability levels far below the required standards. In this study, we conducted a Reliability and Availability Analysis and Performance Evaluation on a Gas turbine Power Plant (8 GTs) situated in the southwestern region of Nigeria.The findings from the period between 2016 and 2022 reveal substantial shortfalls in energy generation, ranging from 22.87% to 32.49%, compared to the acceptable value of 5-10%. The capacity factor of thepower plants varies from 21.81% to 51.70%, falling short of the international benchmark of 50-80%. Similarly, the Plant Use Factor and Utilization Factor, ranging from 67.51% to 74.95%, are well below the international best practice of over 95%, indicating severe underutilization of the generating units. These underutilization issues are attributed to insufficient routine maintenance and equipment faults.Reliability indicators analysis shows that the mean time between failures ranges from 66 to 609 hours, mean downtime varies from 40 to 655 hours, while plant yearly availability and reliability range from 44.82% to 68.53% and 30.67% to 61.94%, respectively. These figures are significantly lower than the Institute of Electrical and Electronics Engineers' recommended standard of 99.9%.The research highlights several reasons for downtime, including inadequate natural gas, poor maintenance culture, and high frequency from the National grid system. Additionally, design errors, human errors, and the use of substandard equipment contribute to early failures.In conclusion, this study emphasizes the urgent need for better maintenance practices and operational improvements in gas turbines across Nigeria. Addressing these challenges is essential to enhance the reliability and availability of power plants, bringing them closer to international standards and ensuring an efficient and stable power supply.

Keyword:Gas turbines, Reliability, Availability, Maintenance, Energy generation, Capacity factor, Utilization factor.

1. INTRODUCTION

The performance of a power plant by way of its efficiency and reliability, and otheroperating factors has definite socioeconomic significance both on the company operatingthe plant as well as the nation at large. However, without adequate and reliable electricitysupply, socioeconomic transformation would remain a mirage [1,2]. On aglobal scale, reliable electric power availability has been observed as effective andindispensable machinery for the rapid industrial and economic growth of any nation.Therefore, by its importance in the society and its necessity for national economic growth,electrical energy supply is expected to be available 24 h a day.

.The reliability of the power plants and transmission lines in the electricity industry is veryimportant in ensuring sufficient electricity is supplied to the customers. If the power plantsare not well taken care of and not reliable to be operated, a significant number of damageswould be possibly imposed to the society as a consequence of power shortage. The concept of power-system reliability is extremelybroad and covers all aspects of the ability of the system to satisfy the customer requirements [3]. The reliability of an electric power system can be increased byadditional system investment. This obviously increases the cost associated with electricpower. Power utilities have, therefore, to satisfy two conflicting requirements:

I. Supply of electric power at an acceptable level of reliability and,
II. Supply of electric power at a reasonable cost.

A modern power system is complex, highly integrated, and very large. In order to meetcustomer demands, the system can be divided into appropriate subsystems or functionalareas that can be analyzed separately [4].

Generating stations form an important and integral part of the overall power system andtheir reliability isreflected in the reliability of the overall national supply. Reliability of agenerating station is a function of the reliability of the constituent-generating units.

Accurate estimates of generating unit reliability are needed for generating capacityplanning and to aid improved criteria for future designs and operations. Reliabilityassessment of a generating system is fundamentally concerned with predicting if the systemcan meet its load demand adequately for the period intended [5, 6].

In the past two decades, the power demand in Nigeria has been on the increase whileavailable generatingcapacity remained largely static or even showing a decreasing long-term trend. The consequence of this was to load shed in order to ensure system stability(Maintain equilibrium between available generation and selective demand). Gas turbinesare designed to operate on availability and reliability of 90% to 98. but in Nigeria majorityof gas turbines are performing below design standard due to lack of proper maintenance,which result in having availability and reliability of about 20% to 60%, thus not meetingthe required demand.To meet these demands, it is therefore imperative to mitigate the effect of plant downtime to increase the reliability andavailability of the plant for maximum power output. This research will help check if therewas an improvement in managing the plant and if the recommendation from the previousreport was adopted. Hence a period of six years is recommended.

The reliability of turbines used in steam power plants using the failure mode and effectanalysis was investigated. The study focused on usingpast failure records of each of the components and the overall failure effect of eachcomponent on the plant to identify, classify and improve important components in theoperation of the plant, for improved reliability of the plant.however, the study failed to take cognizance of the attendant effect that time has on thereliability of equipment. [7].

Research on reliability assessment of Warrirefinery petrochemical (WRPC) power plant was carried out. The analysis was based on six years' database. The parameters used on the analysis were MTBF and MTTR from which was used estimated reliability of the plants. From the result it was discovered that increase in failurerate leads to decrease in availability and reliability.Hence, the researchers advised the management to abide by theeffective maintenance culture, and early replacement of spare parts to avert equipment'sfailure [8].

Similarly, [9] conducted research on reliability of Afam electric powergenerating station. The parameters used for their research were MTBF and MTTR, andfrom their findings, they reported that the station has no standard, no logbook to makeanalysis and thereby concluded that the station was not available.

[10] mentioned a reliability model to assess the combined cycle powergeneration plants and appliedit to a reliability analysis for gas turbine power plants andsteam turbine power plants. The reliability ofwas used to compute the systemavailability and the study compared the availability, but did not mentionthe importance ofmaintenance regarding the components in one system.

This work is a combination of various research carried out from 2010 to 2021 [11, 12, 13].

2. METHODOLOGY

Data used in this research work were extracted from the power Plant daily log books, stations operation data log sheet within the stipulated periods.

The data includes;

a. Number of operating hours per year.
b. Shutdown hours per year for compulsory or scheduled maintenance.
c. Unscheduled shutdown hours per year (and reasons).
d. Number of starts annually.
e. Number of trips during starts annually.
f. Number of trips during operation annually.
g. Average number of operating hours between 2 trips during operation.
h. Average number of operating hours between 2 successful starts.
i. Energy generated (in Megawatts) Daily monthly and annually.

The results were be analyzed using Power plant performance statistics, MATLAB and Weibull method to plot the reliability and maintainability results.

Power Plant Performance Statistics

The GT performance statistics are considered with respect to the plant reliability indices, plant factors, and plant operating figures. These are discussed below.

The reliability and availability analysis of the GT plants will be based on available data over a period of 7 years (2016–2022). The records of failure frequency of installations, containing the description and analysis of the failure and other materials filed by the Power Station Efficiency Department constitute the basic source of information on the failure frequency and rate of repairs of the plant.

In processing the available data, MTBF (m), mean time to repair (MTTR) (F) and availability (Ψ) will be obtained. [14]

Mean Time Between Failure (m) $m = \frac{1}{\lambda} = \frac{\beta_t}{\varphi_n} \quad (1)$

where, λ is the expected failure rate, φ_n is the number of failures between maintenance, β_t is the total operating time between maintenance. [14]

Mean Time to Repair (F)

$$\zeta = \frac{1}{\mu} = \frac{\psi_t}{\varphi_n} \quad (2)$$

where, ψ_t is the total outage hours per year, φ_n is the number of failures per year, l is the expected repair rate.

From (eqs. 1 and 2) for any given system or component, then the availability (ψ) and unavailability (U) can be expressed as:

Availability (ψ)

$$\psi = \frac{\mu}{\lambda + \mu} = \frac{m}{m + \zeta} \quad (3)$$

Unavailability (U)

$$U = \frac{\lambda}{\lambda + \mu} = \frac{\zeta}{m + \zeta} \quad (4)$$

The unavailability is then an adequate estimator of the probability of finding a unit out of service at some point in the future. In the generating system, unit unavailability is obtained by a traditional method known as the FOR. This index is defined as the ratio of the forced outage hours (FOH) to the sum of the FOH and the in-service hours (ISH) [15]

$$FOR = \frac{FOH}{FOH + ISH} \quad (5)$$

The reliability of a complex system like gas turbine is evaluated by using its operational period in the year such as from 1 to 8760hours. This includes the forced outage hours and the operational service hours in a year or within the period of test. Hence the overall reliability is given by

$$R(t) = \left[e^{-\left(\frac{\sum DT}{\sum UT}\right)} \right] \times 100\% \quad (6)$$

Where UT is Up time (OT+ST), and DT is down time in Hrs. [16]

DT in this research work includes hours the gas turbine tripped on faults, logistics and administrative delay time, and hours when National grid system collapsed. UT includes operating times and standby times. Standby times are period when machines are in good condition but cannot come up to national grid due to low capacity of National grid (high frequency) and when there were gas constraints to run the turbines.

Plant Operating Reliability

This is a parameter of dominant importance in the case of emergency reserve machines, peak regime GTs or auxiliary power sources designed for cyclic run. Starting reliability (SR) is used to assess plants and units whose life-time depends largely on the number of start-ups. [17]

Starting reliability (SR)

$$= \frac{No.\ of\ starts\ (Anually) - No.\ of\ trips\ During\ starts\ (Annually)}{No.\ of\ starts\ (Anually)} \times 100\% \quad (7)$$

Operating reliability (OR)

$$= \frac{No\ of\ starts\ (Annually\ ) - (No\ of\ trips\ during\ operation\ \ (Annually\ ) + No\ of\ trips\ during\ starts\ (Annually\ ))}{No\ of\ starts\ (Annually\ )} \times 100\% \quad (8)$$

Availability

Availability is the probability that a machine is available or ready to use when needed. Availability of a machine depends on mean time between failures [18]

(MTBF) $\frac{\text{total Up time}}{\text{number of failure s}}$

Mean down time (MDT) = $\frac{\text{Total down time}}{\text{number of failures}}$ *(9)*

Availability = $\left(\frac{\sum UT}{\sum UT + \sum DT}\right) \times 100$ *(10)*

Power Plant Factors

The plant factors used in evaluating a plant's performance are: CF, AF, plant use factor (PUF), LF, plant reliability factor (PRF), and utilization factor (UF). Analyses of these factors are stated below.

Availability factor

The AF is the ratio of the hours the unit was available for operation to the total hours in the period under consideration. Presented mathematically,

AF (As Installed) $= \frac{EOH-(POH+UOH)}{EOH}$ *(11)*

AF (As Available)= $\frac{EOH-UOH}{EOH}$ *(12)*

Where, EOH is the expected operating hours, POH is the planned outages hours, UOH is the unplanned outages hours.[15]

Utilization Factor

This is the ratio of the maximum demand to the rated capacity of the power plant. The UF measures the use made of the total installed capacity of the plant. [17]

UF= $\frac{L_{md}}{C_{in}}$ *(13)*

Where, L_{md} is the maximum (demand) load generated in each period, C_{in} is the installed (rated) capacity of the plant.

Capacity Factor

The extent of use of the generating plant is measured by the CF which is the ratio of the average energy output of the plant for a given period of time to the plant capacity. This is the ratio of the average load to the rated capacity of the plant.

CF= $\frac{E_p}{C_{in} \times T_h}$ *(14)*

Where, E_p is the total energy generated (MWh) in a given period, C_{in} is the installed (rated) capacity of the plant, T_h is the total hours of the year. [17]

Load Factor

This is the ratio of the average load to the maximum demand for a particular period. Since the average load is always less than the maximum demand, LF is always less than unity. The LF plays a key role in determining the overall cost per unit generated. The higher the LF of the power station, the lesser will be the cost per unit generated.

$$\text{LF} = \frac{L_{av}}{L_{md}} \quad (15)$$

Where, L_{av} is the average (demand) load generated; L_{md} is the maximum (demand) load generated in a given period.

Weibull Reliability;

Weibull reliability function is given by [19]

$$R(t) = Exp\{-\left(\frac{t}{\alpha}\right)^{\beta}\}, \text{ For ß>0, α>0, t>0} \quad (16)$$

Where β=Weibull shape parameter (slope) and α=Weibull scale parameter, and t=down time or failure time, ß, α and t are non-negative.

Weibull Cumulative Distribution function CDF F(t) is also given by

$$F(t) = 1 - Exp\{-\left(\frac{t}{\alpha}\right)^{\beta}\}, \text{For t>0, ß>0, α>0} \quad (17)$$

The CDF is also used to calculate the maintainability function using t as maintenance time (MT).

Also, the probability density function (PDF) is given by *B S Dhillion*, [19, 20, 21]

$$f(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{(\beta-1)} Exp - \left(\frac{t}{\alpha}\right)^{\beta} \quad \text{For t>0, ß>0, α>0} \quad (18)$$

And the Weibull MTBF is given by MTBF=$E(t) = \alpha \Gamma\left(\frac{1}{\beta} + 1\right)$ *(19)*

Where Γ is gamma function

Then hazard function H(t) or failure rate is gotten by dividing (3.20) by (3.18)

$$H(t) = \frac{(\frac{\beta}{\alpha})\left(\frac{t}{\alpha}\right)^{(\beta-1)} exp - \left(\frac{t}{\alpha}\right)^{\beta}}{exp - \left(\frac{t}{\alpha}\right)^{\beta}}$$

$$H(t) = \left(\frac{\beta}{\alpha}\right)\left(\frac{t}{\alpha}\right)^{(\beta-1)} \quad \text{t>0, ß>0, α>0} \quad (20)$$

Pearson's Correlation Equation;

Correlation is the degree of association between two variables or measure of strength of association. It measures the linear best fit of two variables [22],

3. RESULT AND CONCLUSION

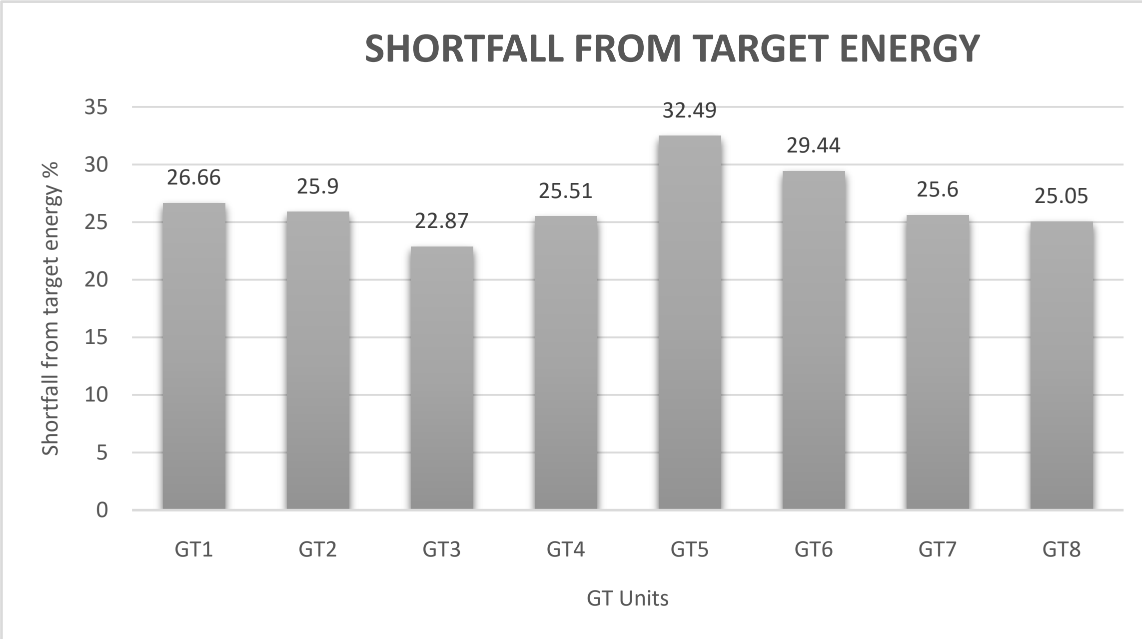
Percentage Shortfall from Target Energy

Unit energy generated and operating hours for gas turbine power plant

YEAR		2016	2017	2018	2019	2020	2021
ENERGY GENERATED (MWH)	GT1	55,259	68,251	91,264	187,021	159,842	172,653
	GT2	142,083	3	268,361	156,169	195,914	201,071
	GT3	119,041	173,104	770	246,039	181,119	211,913
	GT4	169,515	171,886	139,875	94,058	194,768	89,402
	GT5	85,800	136,855	206,081	212,066	188,545	156,103
	GT6	93,035	156,699	38,953	206,663	175,563	176,968
	GT7	187,399	137,696	154,360	198,798	170,535	170,969
	GT8	140,881	220,720	118,203	203,963	170,050	184,647
OPERATING HOURS	GT1	1847.76	2578.38	3247.75	4477.09	4873.27	5603.63
	GT2	4443.03	0.14	8152.58	5171.23	6195.16	6460.52
	GT3	3636.51	5853.67	33.22	7836.09	6099.94	6541.43
	GT4	5384.58	5185.13	4236.96	2969.38	6108.32	2857.56
	GT5	2845.49	4636.95	6590.22	6640.59	6103.66	5505.28
	GT6	2952.58	5280.26	1256.74	6567.32	5457.47	5971.90
	GT7	6057.79	4580.77	5073.55	6141.32	5412.89	5471.13
	GT8	4562.47	7330.19	3886.21	7081.74	5420.94	5865.80
EXPECTED MAXIMUM ENERGY (MWH)	GT1	77,605.92	108,291.96	136,405.50	188,037.78	204,677.34	235,352.46
	GT2	186,607.26	5.88	342,408.36	217,191.66	260,196.72	271,341.84
	GT3	152,733.42	245,854.14	1,395.24	329,115.78	256,197.48	274,740.06
	GT4	226,152.36	217,775.46	177,952.32	124,713.96	256,549.44	120,017.52
	GT5	119,510.58	194,751.90	276,789.24	278,904.78	256,353.72	231,221.76
	GT6	124,008.36	221,770.92	52,783.08	275,827.44	229,213.74	250,819.80
	GT7	254,427.18	192,392.34	213,089.10	257,935.44	227,341.38	229,787.46
	GT8	191,623.74	307,867.98	163,220.82	297,433.08	227,679.48	246,363.60

The table Above shows the actual Energy generated for the period under review, the operating hours, and the Expected Maximum Energy if the Turbine were working at full capacity. These Energies were calculated in Megawatt Hour (MWH).

The expected full load installed capacity of the power plants under study is 42MW per GT. From the Table above, the station units' targets operational capacity is far from installed capacity. The average installed capacity of the plant from data obtained ranges from 67.51% to 74.95%. This shows a gap between installed capacity and actual operational capacity of the plant which may be due to aging-generating facilities that are poorly maintained, lack of spare parts for repair of the broken-down units or insufficient supply of gas to the plant.



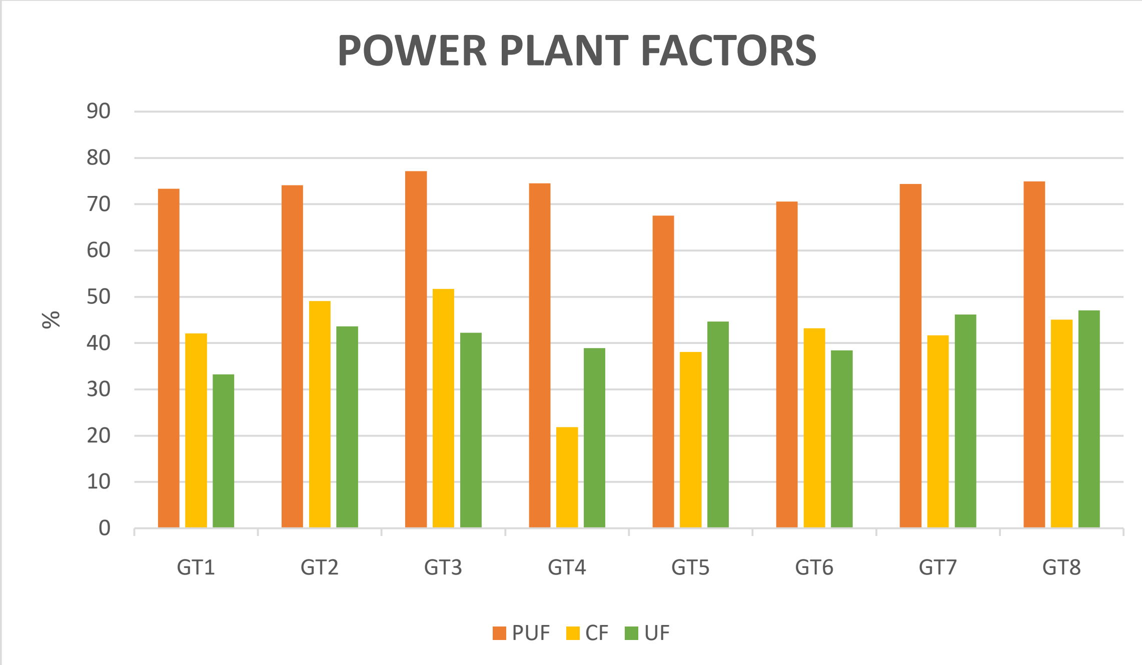
The figure above shows a graphical repersentation of the Shortfall trom targeted energy.

A reduction in shortfall signifies better performance of the plant and this may be as a result of concerted efforts made by the management in carrying out preventive maintenance in the plant. For the period under review, the average shortfall ranges from 22.87% to 32.49%. GT units with least average shortfalls are GT5, 32.49% and GT6 29.44%. These values of percentage shortfalls in energy are far from average acceptable value of between 5% and 10%. The percentage shortfalls in energy in the plant are similarto that obtained by Obodeh and Isaac for Sapele thermal plant (ranged from 27.4% to 49.1%) within the period. This shows the general problem of the wide gap between installed capacity and actual operational capacity of thermal power plants in Nigeria.

Power Plant Factors (PUF, CF AND UF)

The average plant CFs GT units for the period under review are presented in Figure below. The average CF of the plants varies from 21.81% to 51.70% as against industry best practice of between 50% and 80% [23]. Thus, the characteristic behavior of generating plant and the extent of use of the generating plant depend substantially on the CF. High CF is desired for economic operation of the plants. In general, low CF indicates that the average energy generation is low, there is excessive plant failure which implies capacity of the plant remains underutilized for major part of the year. Hence, operational cost would be high compare to revenue. High CF is desired for economic operation of the plant [1]. If scheduled routine maintenance of the plant is significantly improved, the frequency of failure will reduce and high CF will be attained.

The figure below also shows the average PUF for GT units. The PUF for the period under review varies from 67.51% to 77.13. High PUF indicates high ratio of actual generation to expected generation, while low PUF is an indication of low ratio of actual generation to expected generation. Low Use Factor also indicates excessive plant failure and hence plant’s generation below rated capacity.



The Average UF for GT units is also presented in Figure above. The average value of UF for the period under review ranges from 33.26% TO 47.04%. The UFs for the plant is far from international best practice of over 95%. The trend of UF reflects how effectively managed the station is in terms of downtime. This result shows that the generating units were utilized less than their normal hours of utilization all year round. This is due to inadequate routine maintenance and equipment fault development. To reduce downtime occurrences and hence increase UF, planned and routine maintenance should be upheld and enhanced in the selected power plants

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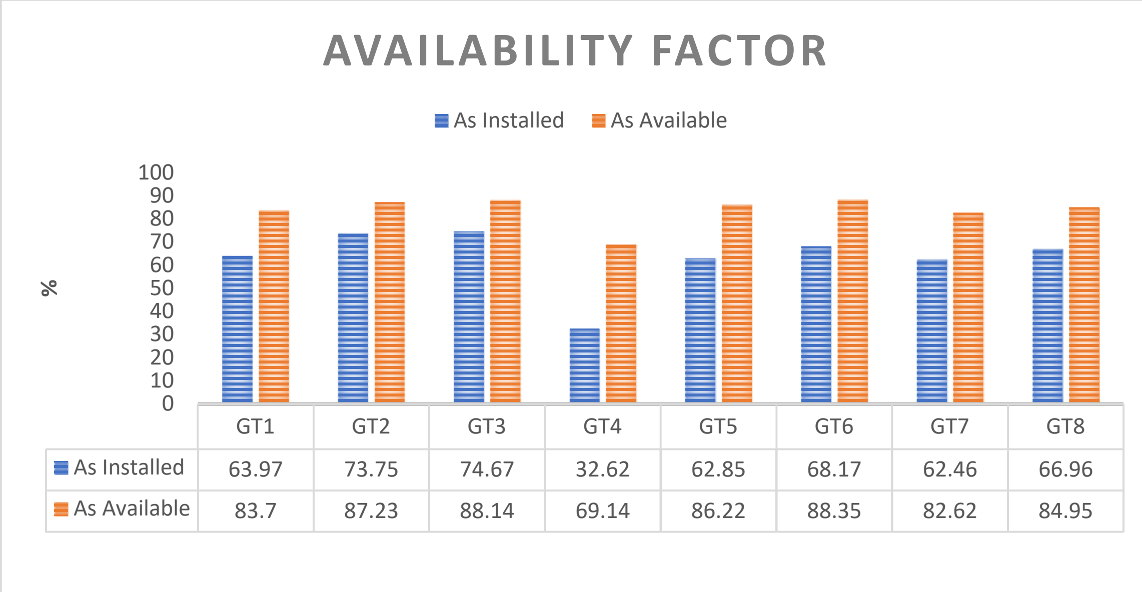
Power Plant Availability Factor

The figure below shows the AF "as installed" varies from 62.46% to 74.67%. The AF "as available" for the GT units varies from 69.14% to 88.35%. The low value of "as installed" AF shows that so much time was lost on rehabilitation of the units. On the other hand, the low "as available" AF indicates that there were a lot of outages which kept the unit idle even when they were not generally mechanically unfit.



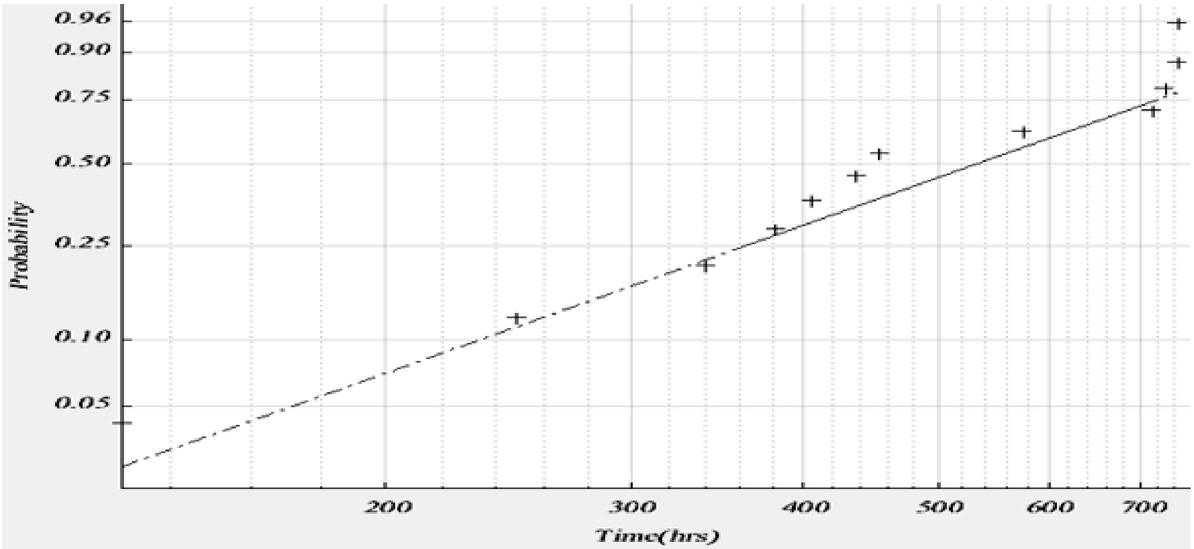
Results of Weibull Parameters

Weibull Probability (RA) analysis results

Failure time (Hrs.)	MR	CDF	R(t)	PDF	H(t)
128.96	0.056	0.0434	0.9566	0.0007	0.0007
248.54	0.137	0.1613	0.8387	0.0012	0.0015
340.4	0.218	0.2886	0.7114	0.0015	0.0021
381.94	0.298	0.3519	0.6481	0.0015	0.0024
405.93	0.379	0.3891	0.6109	0.0016	0.0025
435.58	0.46	0.4353	0.5647	0.0016	0.0028
453.32	0.54	0.4628	0.5372	0.0015	0.0029
576.83	0.621	0.6432	0.3568	0.0013	0.0038
712.84	0.702	0.7997	0.2003	0.0009	0.0047
730.1	0.782	0.8156	0.1844	0.0009	0.0049
744	0.863	0.8278	0.1722	0.0009	0.005
744	0.944	0.8278	0.1722	0.0009	0.005
			0.4961		

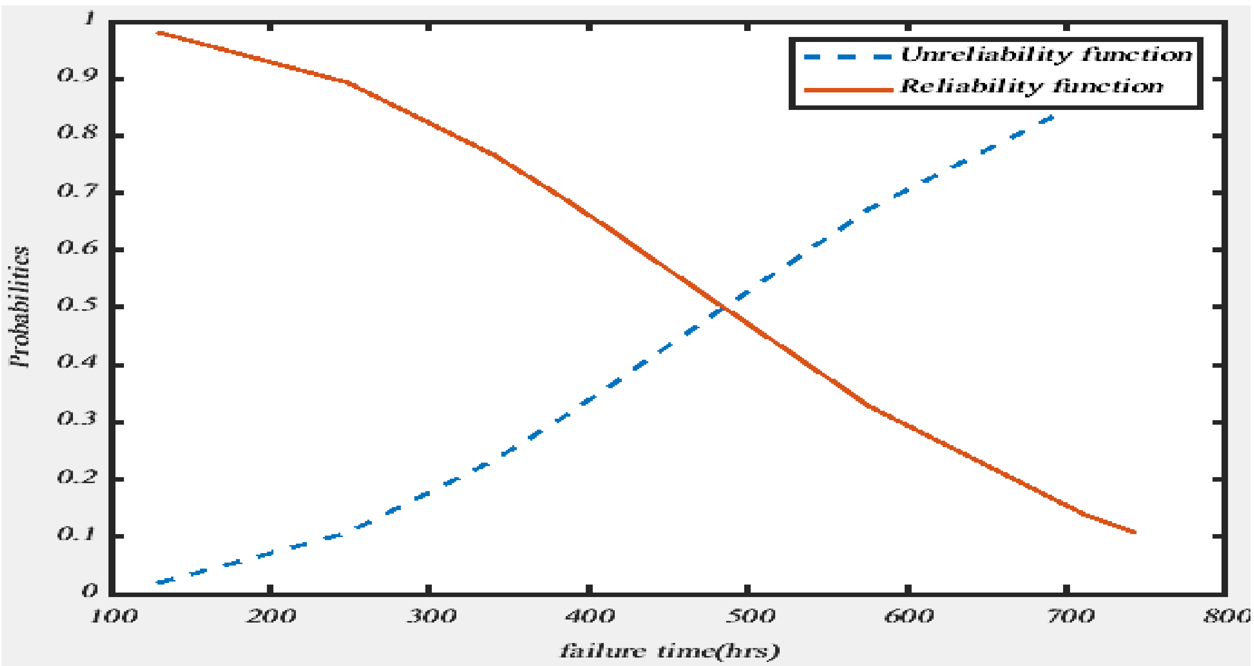
The result of the table above was calculated using equations 16 to 20, these were simulated using MATLAB and Python Chart in plotting the various graphs
From the table above, the Failure time indicates how many hours the plant fails to operate on a yearly average. This was calculated from the available data gotten from the plant operation log books. The MR is Median Rank Regression giving by Bernard's approximation. Also, the Weibull Reliability function (R(t)), Cumulative Distribution Function (CDF), the Probability Density Function (PDF), and the Hazard Function (H(t)) were all calculated for all the GTs under review.

Weibull Probability plot



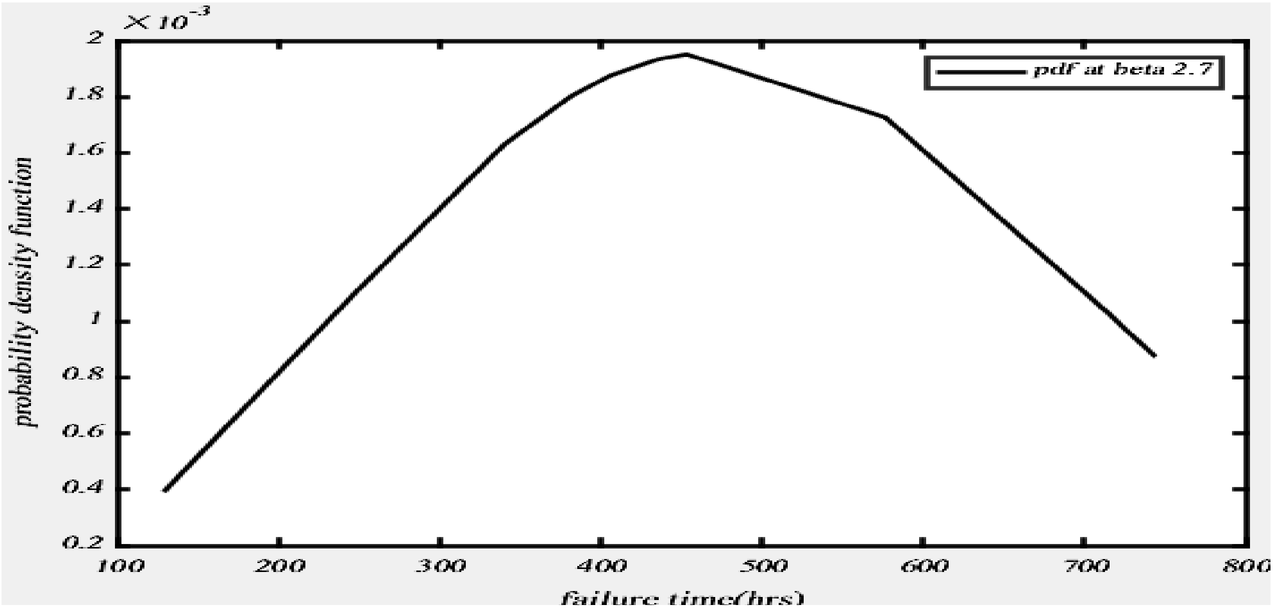
From the graph it shows the variables conform to Weibull distribution, and with a strong correlation value of 0.9763.

Combined plots of Reliability and cumulative distribution function



The reliability function shows the survival path while the unreliability path shows the area that has failed. At the point where the two graphs intersected the failure and reliability are at 50% each.

Probability Density function (PDF) graph



The graph shows early life "wear out", failure rate increases with time.

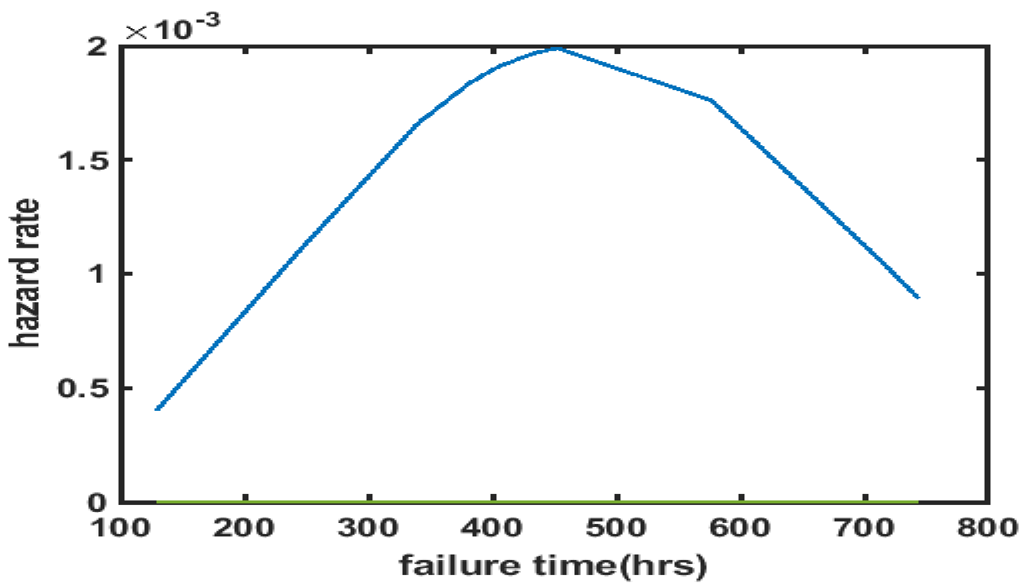
Using MTBF equation, MTBF can be estimated to predict the next failure time.

MTBF = 492.4439Hrs

That is to say that, the unit will be in successful operation between the period of 492.4439hrs, and any time above the estimated hours, the turbine unit is expected to fail.

Therefore, a thorough preventive maintenance is suggested after operating at most 490hrs to avoid catastrophic failure of the plant.

Hazard Function Graph H(t)



Looking at PDF and H(t) graph, they seemed the same figure but have slight difference. The reason is because R(t)≤1. The equation of hazard function was gotten by dividing PDF by R(t) thats equation MDT by MTBF, when the value of R(t) approaches 1, the value of H(t) and pdf looked same but they are not the same.

Difference between PDF and hazard function H(t)

i. PDF is probability density but H(t) is not probability, its failure rate

ii. PDF is unconditional probability that the machine may fail in the interval of time t, but H(t) indicates that the machine will fail at same interval of time but has survived until time t

iii. PDF is a failure density but H(t) is a failure rate

Estimated Weibull MTBF (Hrs.) of the Turbine Units for Failure Predictions

The Weibull MTBF (hrs.) for Predictions

	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8
2016	85.1468	458.4540	456.4769	324.5888	101.4533	112.5699	204.5844	278.6966
2017	93.72	0	345.5859	865.5868	987.4996	375.4594	201.8922	397.1539
2018	151.3205	484.3421	101.5488	562.5696	134.8928	102.0168	634.8505	885.4935
2019	280.7279	530.2618	47.1746	0	101.7055	86.3251	602.669	177.8551
2020	451.9244	487.6812	0	0	1238.138	355.1208	542.4169	483.6822
2021	486.7998	472.3576	465.3066	492.4175	440.0785	235.2282	563.8389	545.1578

GT1 from 2016 to 2021 exhibits exponential decay like behavior known as early wear in, with decreasing failure rate. This behavior may be caused by carried over faults from previous years that were not properly repaired or inherent design faults. GT2 came up 2018 after long time standby, behaved like unit1 2019 and 2020 but changed 2021 to constant failure rate after some preventive maintenance were carried out. GT7 had its useful life in service with constant failure rate in 2016 but had early wear in 2017 maybe unknown fault hidden previous year that manifested out early, and the ‘wear in’ continued till 2021. Again, GT8 had early wear in (decreased failure rate) continuously from 2017 to 2019 after some preventive maintenance were carried out in 2021, it had useful life at constant failure rate for a long time. GT1, GT5, GT6, GT7 and GT8 has always been in service since the period of this research, the maintenance team is advised to always carry corrective, preventive, predictive and turn-key maintenance to all other turbine units not in service as a result of insufficient natural gas supply or high frequency. More over those in operation are required to carry out bores-cope inspection at the combustion chambers and compressor side to avoid failure and to improve availability and reliability of the plant.

The exponential values of MTBF and MDT (values in Hours)

		2016	2017	2018	2019	2020	2021
GT1	MTBF	115.49	117.20	108.24	407.01	487.34	266.84
	MDT	432.02	282.07	183.77	391.54	391.06	150.3
GT2	MTBF	459.03	0	543.81	344.75	387.2	538.38
	MDT	269.81	0	40.19	239.25	0	191.62
GT3	MTBF	110.20	292.68	0	435.34	0	594.68
	MDT	155.26	146.52	0	51.33	0	201.69
GT4	MTBF	153.86	272.90	105.92	0	0	317.51
	MDT	96.44	189.41	113.08	0	0	655.83
GT5	MTBF	142.28	257.61	411.89	442.71	609.99	393.23
	MDT	295.73	230.39	135.61	141.29	268.41	232.48
GT6	MTBF	110.14	122.80	66.14	593.86	321.03	373.24
	MDT	49.14	81.48	394.91	79.98	195.68	174.26
GT7	MTBF	407.11	143.15	153.74	511.78	541.29	455.93
	MDT	141.89	131.35	111.71	218.22	337.11	274.03
GT8	MTBF	147.18	385.80	185.06	442.61	542.09	542.09
	MDT	135.40	76.52	232.09	104.89	336.31	336.31

The values of table above were calculated using data from the service and failure spreadsheet and MTBF equation and MDT. MTBF is mean time between failures while MDT is mean down time. The inverse of MTBF gives the failure rate for exponential distribution method.

The turbine estimated Availabilities and Reliabilities

The turbine estimated Availabilities and Reliabilities

		2016	2017	2018	2019	2020	2021
GT1	Availability (%)	21.09	29.35	37.07	50.97	55.48	63.97
	Reliability (%)	2.37	9.01	18.31	38.21	44.82	56.93
GT2	Availability (%)	50.72	0.00	93.12	59.03	70.53	73.75
	Reliability (%)	37.85	0.00	92.88	49.96	65.84	70.05
GT3	Availability (%)	41.51	66.64	0.38	89.45	0.00	74.67
	Reliability (%)	24.44	60.62	0.00	88.88	0.00	71.24
GT4	Availability (%)	61.46	59.03	48.37	33.90	0.00	32.62
	Reliability (%)	53.41	49.95	34.39	14.23	0.00	12.67
GT5	Availability (%)	32.48	52.79	75.23	75.81	69.44	62.85

	Reliability (%)	12.51	40.89	71.95	72.68	64.40	55.37
GT6	Availability (%)	26.44	60.11	14.35	88.13	62.13	68.17
	Reliability (%)	6.19	51.50	0.26	87.40	54.36	62.70
GT7	Availability (%)	72.74	52.15	57.92	70.11	61.62	62.46
	Reliability (%)	68.74	39.95	48.35	65.29	53.64	54.82
GT8	Availability (%)	52.08	57.85	44.36	80.84	61.71	62.85
	Reliability (%)	39.85	48.26	28.53	78.90	53.77	55.37
Yearly Av. Availability (%)		44.82	53.99	52.97	68.53	63.49	62.67
Yearly Av. reliability (%)		30.67	42.88	42.09	61.94	56.14	54.89

The results were evaluated using equations (6) and (10). GT2 unit has very good reliability and availability results in 2018, and 2021 but failed drastically in 2017 due to inadequate maintenance culture and substandard equipment used.

GT4 and GT3 has the lowest reliability and availability. GT4 responded to stage three of the Bathtub curve, having early wear out or fatigue failure. The unit requires serious corrective and preventive maintenance with standard equipment to improve its reliability and availability.

4 CONCLUSION

The gas turbine unit reliability and availability of the power station wereevaluated using data from daily log books from 2016 to 2022. The methods used for theanalysis were Weibull distribution and exponential distribution. The year Availability andreliability was seen to be increasing from 2016 to 2019, with a slight reduction in 2020 and2021. The Availability and reliability for 2021 was calculated as 62.67% and 54.89%. Fromthe research many down times were as a result of insufficient natural gas from the NigerianGas Company, and high frequency from National grid system. Others were design errors,human errors and substandard equipment used that causes early failures. Some others wereexcitationfailures, failure of some auxiliaries and high vibration. It is advised that Nigerianmaintenance men have their professional training on gas turbine maintenance instead ofwaiting for arrival of foreign personnel which increases the down times more, so thatNigerians will be able to maintain everything maintainable in gas turbine units. From the table above it was seen that increase in MTBF and decrease in MDT result in correspondingincrease in reliability and availability when compare to the results in table above, thereforeadequate preventive, corrective and predictive maintenance is required in Power Plant to reduce the down times and increase operational service hours (up times)which will in turn increase reliability and availability.

REFERENCES

1. *Adegboyega, G. A., and J. O. Famoriji. 2013. Determination of the central gas turbine efficiency and reliability, Edjeba, Delta State, Nigeria. Int. J. Eng. Res. Technol. 2:482–490.*
2. *O Ighodaro (2010). "Reliability and Availability Analysis of Gas Turbine Plants." International Journal of Engineering and Technology 2(1), (pp. 38-50), (ISSN 2141- 8756).*
3. *Tanrioven, M., and M. S. Alam. 2005. Reliability modeling and assessment of grid-connected PEM fuel cell power plants. J. Power Sources 142:264–278.*

4. *Gupta S, Tewari P.C, Sharma, A.K (2009) Reliability and availability analysis of the ash handling unit of a steam thermal power plant. South African Journal of industrial engineering. Vol., 20(1), Pp 147-158.*
5. *Adamu Mutala Z, Adegboye Babtunde,Bajoga Buba G, Ambati James G and Omokhafe Tola (2012) ReliabilityEvaluation of Kainjihydro electric power station in Nigeria. Journal of energy technologies and policy, Vol. 2 page 2*
6. *Hooshmand, R. A., M. Moazzami, and A. A. Nasiri. 2009. Power system reliability enhancement by using PowerformersTM. Serb. J. Electr. Eng. 6: 315–331.*
7. *Dewangan, D.N., Kumar, M.J. and Banjare, Y.P. (2014) Reliability Investigation of Steam Turbine Used in Thermal Power Plant. International Journal of Innovation Research in Science, Engineering and Technology (IJIRSET), 3, 14915-14923.*
8. *Obodeh O. and Esabunar T. (2011) Reliability assessment of Warri refinery petrochemical WRPC gas turbine power plant. Journal of Mechanical Engineering Research Vol. 3(8) page 286-292, academic Journal.*
9. *Eti M.C, Ogaji S.O.T and Probert S.O (2004), Reliability of Afam Power Generating station. Applied Energy vol(7) pages 309-315.*
10. *Sabouhi Hamed, and Ali Abbaspour (2016) Reliability modeling and availability analysis of combined cycle power plants. International Journal of Electrical Power & Energy Systems Volume 79, July 2016, Pages 108-119*
11. *Obanor A I,Tabowei S.I and Egware H.O (2014) Reliability and availability assessment of the Omotosho phase 1 thermal power plant. Journal of Nigerian institute of production engineers vol17. Pp 1114-127*
12. *Fernando J.G.C and Gilberto F.M (2009), Availability Analysis of Gas turbines used in power plants. International Journal of thermodynamics, Vol12, No. 1 Pp28-37.*
13. *D. R Dolas, M.D Jaybhaye, S.D Deshmukh (2014) Estimation of the system Reliabilities using Weibull Distribution , international Proceedings of Economics Development and research volume 75, page 144-148*
14. *Oyedepo, S. O., and R. O. Fagbenle. 2011. A study of implementation of preventive maintenance Programme in Nigeria Power Industry—Egbin Thermal Power Plant case study. Energy Power Eng. 3:207–220.*
15. *Obodeh, O., and F. O. Isaac. 2011. Performance analysis for Sapele thermal power station: case study of Nigeria. J. Emerg. Trends Eng. Appl. Sci. 2:166–171. 23.*
16. *Kamal, D. 1988. Reliability modeling of power system components using the CEA-ERIS data base. Ph.D. thesis, University of Sakatchwan, Canada.*
17. *Bertling, L., and R. Eriksson. 2005. A reliability- centered asset maintenance method for assessing the impact of maintenance in power distribution systems. IEEE Trans. Power Syst. 20:23–46*
18. *Barringer H.P (1997) An overview of Reliability Engineering Principles, energy week, penn well publishing co. Tufa Oklahoma Fulton Wes Winsmith Weibull probability plotting soft ware, http://www.weibullnews.com*
19. *Dhillion B.S Design Reliability; fundamentals and applications , CRC press Boca Raton FL 1999*
20. *Dhillon B.S (2006) A textbook on Maintainability, Maintenance, and reliability for engineers. C.R.C Press Tailor & Francis Group U.S.A*
21. *Abernathy R.B (2007), Textbook on The New Weibull Handbook, fifth edition Indiana University of Medicine India.*
22. *Brown, R. E. 2009. Electric power distribution reliability. 2nd ed. Taylor and Francis Group, New York, NY*

23. *Popoola, J. J., A. A. Ponnle, and T. O. Ale. 2011. Reliability worth assessment of electric power utility in Nigeria: residential customer survey results. Aust. J. Technol. 14:217–224. 10. [9].*
24. *Ubani N.O, Eze C.C, Dara J.E, Ekpo A.A, Ubani A.C, Okpe B, Okoro U.I and Humphery C.O (2017),*
25. *Availability and reliability analysis of IBOM power plant .Umudike Journal of Engineering and technology Vol3, no2,*
26. *HungundC.P.S and Shrikant Patil (2014), Reliability analysis of thermal power generating units based on working hours. Department of statistics Gulbargar university. Journal of Reliability and statistical studies Vol(7) page 113-123.phase 1 thermal power plant. Journal of Nigerian institute of production engineers vol17. Pp 1114-127*
27. *Hafid Budiman (2015) Increasing compressor reliability with Weibull Distribution Analysis. Department of Rotating equipment Engineering, South Sumatera Indonesia.*
28. *Aneke A.C, Odukwe A.O and Onah T.O (2017), The effect of failure rate on system reliability of a gas turbine power plant using Ugheli power station as a case study. International Journal of Multidisciplinary Research and Development, Vol 4 issue7, Page 68-73*
29. *Kesavakumar M.V, Srihari V and Sarvesh B (2015) Improvement in reliability indices of a power distribution system. Journal of research in engineering and technology Pp 2321-7308*
30. *, L. J., and M. N. Nwohu. 2011. Reliability evaluation of hydro-electric power stations in Nigeria: (A case study of Kainji units 1G7 & IG8 and Shiroro units 411G1 & 411G2). J. Asian Sci. Res. 1:320–327.*
31. *Rausand, M., and A. Hoyland. 2004. System reliability theory: models statistical method and application. 2nd ed. John Wesley and Sons Inc., Canada.*
32. *J. C. 2008. Positioning the power sector for electricity sufficiency in Nigeria to meet up with vision 2020, 20th Public Lecture Series, Covenant University, Ota, Nigeria*
33. *Okah-Avah, B. E. 1996. The science of industrial machinery and system maintenance. Spectrume Books Ltd, Lagos, Nigeria.*
34. *Christian Emeka Okafor, Augustine A.A, and Ugochukwu C.O (2016) Availability assessment of steam and gas turbine Units of a thermal Power station using Markovian Approach. Archives of current research international 6(4); Pg 1-17*
35. *D. R Dolas, M.D Jaybhaye, S.D Deshmukh (2014) Estimation of the system Reliabilities using Weibull Distribution , international Proceedings of Economics Development and research volume 75, page 144-148*
36. *Dash S, Das D. Availability assessment of generating units of Balimelahydro electric power station (510MW). American journal of engineering research 2014 vol. 3(2) 44-49*
37. *Francisco Curvaro and Giancarlo Giacchetta (2017), Reliability, Availability and Maintainability study of reciprocating compressor API 618, Advanced research involving science and engineering.*
38. *Harish G, Monica R. and S.P Sharma (2013) Reliability analysis of engineering system using intuitionistic Fuzzy set theory. Journal of quality and reliability engineering Vol. 2*
39. *Desai, (2016), Applied Thermal and Hydraulic Engineering*