

Gas Turbine Blade Reliability Of Generator Availability For Electric Power Supply Using Optimal Estimation Of Weibull Probability Distribution

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Abstract

The increasing demand of electricity power supply and its availability is indispensable to manage economically following to the rapid growth of population to energy consumption capacity which is a major concern making the electricity sector industries to experienced significant implication for power plant operation to provide basic energy services to the people particularly to the reliability of the engineering component under review To achieve this goal the study will engage the application of reliability technique in order to analyse the activities of the failure times of ten identical gas-turbine blade of similar "make" and mode of operations subjected to the same conditions in Afam power station over a period of ten years, from the results obtained, the gas-turbine blades were in their wear-out period of reliable maintenance to give out efficient performance following to the reliability of the three parameter weibull distribution $R(t)$ given as 0.60 this means that turbine blade actually required reliable maintenance. While, the failure rate of the turbine-blade $\lambda(t): 0.082577/\text{hrs}$, the mean time to failure (MTTF) : 13.55hours. The results obtained through the simulation of TPC windchill quality solution software estimated the parameters which shows suitable behaviour of the system components for early response for reliable maintenance. The reliability $R(t)$, failure rate $\lambda(t)$ and meantime to failure (MTTF) were successively computed. Conclusively, the probability that the gas turbine blades under investigation will continue to be operational in service without failures is about 70% while the mean time to failure of the gas turbine blade is about 14hours.

Keywords: Availability, Reliability, Electric Power, Weibull, Three-Parameters, Turbine Blade.

Introduction

Gas turbine-blade component reliability plays an important role in the performance of electricity power supply of power from the generating station which incidentally falls among the expensive equipment in the electricity power supply industry. Therefore it is a necessity to guide and reduce the risk of failures and forced outages by system design engineer technique on the view to perform preventive repairs to improve the existing reliability of the system (Kang *et al.*, 2018). The gas turbine blade wear-out of failure has leads to high cost of electricity outages and customer dissatisfaction. Thus, evaluation and analysis of the behaviour of this facilities/equipment requires strong knowledge about regular conditions of data collection in order to provide adequate information for effective system planning and operations. (Chen *et al.*, 2016)

This paper is aimed to evaluate the reliability studies, statistical analysis, performance-index analysis for purpose of useful life alternative in order to identify turbine-blade mode of failures and causes of sudden breakdown for purpose of maintaining useful life in order to enhance lowest cost operationally.

Energy utilization is the fundamental element for economic and social growth particularly in Nigeria. The migration of people from the rural-setting to urban cities as a form of socio-economic development constitute an over load in the network thereby characterizing the process as a form of complex and robust challenging problems to solve mathematically. Power system comprises generation transmission and

distribution network. Electric power is generated and distributed upto the point of utilization (consumer). In Nigeria the activities of transmission and distribution sector are characterized by constant outages due to system components failures as an interruption to the efficient power supply reliability. The cost of repairs, equipments down time, idle labour, loss of output schedule delays and customer dissatisfaction are thereby affected in small, middle and large economic business operations.

The main objective of engaging preventive maintenance is to reduce the total cost of providing services. The cost analysis between breakdown and preventive maintenance can actually indicate the preferred alternative. Essentially to conduct a cost-analysis an information must be available relative to:

- (i) Cost of breakdown
- (ii) Frequency of breakdown
- (iii) Cost of preventive maintenance to reduce or eliminate failures (otherwise preventive maintenance mean routine inspection and servicing).

However, it is designed to detect potential failure conditions and make correction that will prevent major operating difficulties. It is important to effect quick responses to machine service requirements that are known whose failures can be predicted with some level of accuracy. Preventive maintenance is desirable when it can increase the operating time of asset by reducing the severity and frequency of breakdown. Preventive maintenance might include cleaning, lubricating, inspecting, calibration, testing, critical part placement before failure or complete over-hauls.

However effective preventive maintenance required trained personnel, an accurate records system, regular inspections and servicing. This means that good maintenance records provide substantial assistance in estimating the probability for distributions of breakdown and repair times. It is however a strong practice to note that planning maintenance on schedule (that is daily, weekly, monthly etc) required more effective utilization of skilled personel which must be possible and steady power supply to its cizenry (Carneiro *et al.*, 2016).

2. MATERIALS AND METHOD

2.1 Materials

The materials used in this research include:

- (i) Data of the facilities (maintenance records)
- (ii) Data consists of times(t) to failure of ten identical gas turbine blades in the study case (Afam power plant)
- (iii) Application of TPC windchil quality solutions software tool.

These data were collected from the Port Harcourt Electricity Distribution Company (PHEDC/Research Desk and operation, Maintenance Department). The data collected was implemented into governing equations to get information of the turbine blade failures in order to predicts/estimate the plan to reduce early failure rate (Balakrishnan & Kateri, 2008).

2.2 Methodology

A reliability research strategy was utilized for this review following to the reliability model described by three parameter estimation of gas-turbine blade performance which can adequately examine the failure times of gas turbine blade for ten similar units, under investigation and evaluation.

Essentially, the methodology was based on the following considerations:

- (i) Collecting the frequency of turbine blade failure that results into outages and blackout
- (ii) Determination of mean time to failure (MTTF) and failure rate
- (iii) Determination of reliability function of the three parameter weibull distribution.
- (iv) Determination of unreliability that may either results into availability and unavailability.
- (v) Examination of life cycle of the system components for efficient planning.

2.3 Computation of the characterised reliability-index and three parameter weibull distribution

Case 1: The Mean time to failure of the three-parameter weibull distribution (MTTF) is given by:

$$MTTF = \gamma + \eta \Gamma\left(1 + \frac{1}{\beta}\right) \quad (1)$$

where;

$$\left. \begin{aligned} \gamma \geq 0 \text{ and } t, \beta, \eta > 0 \\ \Gamma(x) = \int_0^{\infty} e^{-x} x^{n-1} \end{aligned} \right\} \quad (2)$$

η : Scale parameter

$\Gamma(x)$: Gamma Function

γ : Location parameter

β : shape parameter

t : Time

That is the term (MTTF) is applied to non-repairable points which operates under specified condition. It is otherwise the ratio of sum of time to failure of each components to the number of components under test.

Case 2: Mean time between failure (MTBF)

This is the term which is applied to repairable terms, which measure the average time that a particular equipment will fail and remain in service. MTBF of an equipment may be reduced to potential defects introduced by poor maintenance procedures.

Thus,

$$MTBF = \frac{1}{n} \sum_{i=1}^n (t_k \dots t_{k-1}) = \frac{t_n - t_0}{n} = \frac{t_n}{n} \quad (3)$$

Since, $t_0 = 0$ at the beginning.

$$\text{Then, } MTBF = \frac{\text{Total operating time}}{\text{No. of failures in that time}}$$

Case 3: Availability performance

Availability performance is the ability of an item to be in a state to perform a required function under a given conditions that is for a given instance of time or over a given time interval, this mean that;

- (i) All items assumed operating conditions unless failed scenario.

- (ii) The exception would have been standby redundancy but this scarcely exists power station because of high power supply demand.

- (iii) The outcomes in the analysis are based on two fundamental rules for combining probabilities.

- (iv) If A and B are two independent events with probabilities $\rho(A)$ and $\rho(B)$ of occurring, then the probability $\rho(AB)$ that both events will occurs is the product;

$$\rho(AB) = \rho(A) \cdot \rho(B) \quad (5)$$

- (v) Similarly, if two events A and B are mutually exclusive so that when one occurs the other cannot occur, the probability that either A or B will occur is :

$$\rho(AB) = \rho(A) + \rho(B) \quad (6)$$

(Datsiou & Overend, 2018)

Case 4: Failure rate

Failure may be either partial or complete, gradual or sudden it may be caused by inherent weaknesses or misuse. These failures can manifest in the following forms as; catastrophic failures, primary failure and secondary failures.

Therefore, failure-rate is related to both number of failures per unit time that is the number of items which fails in a given time depends not only on the quality of the item, Hence;

- (i) If the number of components in operation at the time of failure is N_r Then failure -rate $\lambda(t)$ is given by;

$$\lambda(t) = \lim_{\Delta t \rightarrow \infty} \frac{1}{N_s} \times \frac{\Delta N_f}{\Delta t} = \frac{1}{N_s} \times \frac{\delta N_f}{\delta t} \quad (7)$$

Case 5: Operational availability

The operational availability (A_0) given as;

$$A_o = \frac{\text{Up-Time}}{\text{Operating-Time}} \quad (8)$$

Thus,

Availability,

$$(A_v) = \frac{\text{Available Hour}}{\text{Period Hour}} \times \frac{100}{1} \quad (9)$$

Since, Available Hours = period Hours- forced outages hours – scheduled outages hours.

Essentially, available performance is defined and considered in four (4) different form measurement as: Availability function limiting availability, average availability etc.

All these measurement are based on the function $x(t)$, which denotes the status of a repairable system, at time (t) . The instant availability at time (t) or point availability is defined by (Chaurasiya *et al.*, 2018):

$$A(t) = \rho(x)(t) = 1 \quad (10)$$

This is the probability that the system is operational at time, (t) which is defined as;

$$A = \lim_{t \rightarrow \infty} A(t) \quad (11)$$

This quantity is the probability that the systems will be available after it has run for a long time and is a significant measurement of the performance of a repairable system given as;

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^\beta}, t \geq \gamma \quad (12)$$

Case 6: Reliability function of the three (3) – parameter weibull distribution is given as;

The three –parameters weibull failure rate function is given by;

$$\lambda(t) = \frac{\beta}{\eta} \left(\frac{t-\gamma}{\eta}\right)^{\beta-1}, t \geq \gamma \quad (13)$$

Case 7: Weibull shape parameter(β)

The weibull shape parameter (β) is also known as the weibull slope. This is because the value of β is equal to the slope of a line in a probability plot.

- (i) When the shape parameter , $\beta < 1$ (this means that the failure rate decreases)
- (ii) When the shape parameter, $\beta = 1$ (this means that failure-rate is constant with time (t) and the distribution is equal to the exponential distribution)
- (iii) When the shape parameter, $\beta > 1$ (this means that failure rate increases)

Case 8: Weibull scale parameter, η

That is increasing the value of η while keeping β constant has the effects of stretching out the probability density function (pdf). A change in the scale parameter (η) has the same effect on the distribution as a change of the abscissa scale. Since the area under a pdf curve is a constant value, the peak of the pdf curves will also decrease with increase of η (Yang & Nie, 2007).

Case 9: Weibull Location Parameter, γ

The location parameter, γ actually accounts for the subtraction (positive or negative) value that places the points in an acceptable straight line. changing the value of the location parameter γ , has the effects of pushing the distribution and associated function if ($\gamma > 0$) or to the left if ($\gamma < 0$).

Case 10: Prediction Performance of Weibull Distribution Model

The prediction accuracy of the model in the estimation of the turbine-blade failures with respect to actual values were evaluated based on the correlation coefficient R^2 , root mean square error (RMSE) and coefficient of efficiency (COE) (Markovic *et al.*, 2009). These parameters are calculated based on the following equation as;

$$R^2 = \frac{\sum_{i=1}^N (y_i - z)^2 - \sum_{i=1}^N (x_i - z)^2}{\sum_{i=1}^N (y_i - z)^2} \quad (14)$$

Similarly, the root mean square error (RMSE) given as;

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (y_i - x_i)^2 \right]^{1/2} \quad (15)$$

The coefficient of efficiency (COE) given as;

$$COE = \frac{\sum_{i=1}^N (y_i - x_i)^2}{\sum_{i=1}^N (y_i - z)^2} \quad (15)$$

where y_i is the i^{th} actual data X_i is the i^{th} predicted data with the weibull distribution (z)

is the mean of the actual data, N is the number of observations.

Case 11: Reliability model of system component and weibull-two parameter characterization.

The rate of failure and mean time between failure (MTBF) are the key parameters of reliability in the turbine blades evaluation which are estimated using weibull distribution function and with available data for each parts, since weibull distribution technique is a vital tool used in the systematic modeling of failure rates, forecasting failures and in modeling of failure and fault-process stemmed from their aging (Di Noia *et al.*, 2017). Thus the distribution may be specified by two parameters of shape (β) and scale (α) respectively;

Provided the techniques used in the estimation of weibull parameters of average rating technique and the number of failure according to the equation are given as;

$$F_i = \frac{(i - 0.3)}{(N - 0.4)} \tag{16}$$

where; F_i is the average rank of occurring i -th failure. If equipment are considered as separate components, i is then the adjusted rank of age of failed component and N is the total ranking number of the component, hence weibull parameter would be determined using the least-square relationship as:

$$y_i = mx_i + c \text{ or } x_i = \ln(t_i) \tag{17}$$

where; t_i is the independent age (year) of failed component in rank i .

Therefore,

$$y_i = \ln \ln \left[\frac{1}{1 - F_i} \right] \tag{18}$$

From, (17) and (18) are the weibull shape parameter (β) which can be calculated given as;

$$\beta = m = \frac{\sum_{i=1}^N x_i y_i - \frac{\sum_{i=1}^N x_i \sum_{i=1}^N y_i}{N}}{\sum_{i=1}^N x_i^2 - \frac{\left[\sum_{i=1}^N x_i \right]^2}{N}} \tag{19}$$

Similarly, the constant (c) given as;

$$C = \frac{\sum_{i=1}^N y_i - m \sum_{i=1}^N x_i}{N} \tag{20}$$

The life or scale parameter (α) can be determined given as;

$$\alpha = \ell \left[\frac{c}{m} \right] \tag{21}$$

- (i) By the estimation of two-parameters technique for the prediction if the system behavior of the component are according to the equipment – curve distribution.
- (ii) Weibull probability distribution function $f(t)$ shows probability of failure in certain time (t) given as;

$$F(t) = \left(\frac{\beta}{\alpha} \right) \left(\frac{t}{\alpha} \right)^{\beta-1} \ell \left(\frac{t}{\alpha} \right)^\beta ; \text{ for } \begin{cases} \alpha > 0 \\ \beta > 0 \\ 0 \leq t \leq \infty \end{cases} \tag{22}$$

- (iii) The cumulative distribution function $F(t)$, which shows the probability of failure in time (t) would be calculated as;

$$F(t) = 1 - \ell \left(\frac{t}{\alpha} \right)^\beta ; \text{ for } \begin{cases} \alpha > 0 \\ \beta > 0 \\ 0 \leq t \leq \infty \end{cases} \tag{23}$$

Essentially, reliability function $R(t)$ which shows probability of remaining intact till the time (t) and the rates of failure $\lambda(t)$ which can be expressed as;

$$R(t) = 1 - F(t) = \ell \left(\frac{t}{\alpha} \right)^\beta \text{ or } \tag{24}$$

$$\lambda(t) = \frac{F(t)}{R(t)} = \left(\frac{\beta}{\alpha}\right) \left(\frac{t}{\alpha}\right)^{\beta-1} \quad (25)$$

From observation, the shape –parameter (β) affects the shape distribution curve that is when the shape parameter changed, the curve $f(t)$ varies differently in shape. For example if the curve turns to exponential distribution while $\beta = 1$

- (i) That is the failure rate will be decreasing while $\beta < 1$, means that the component is in the early failure state.
- (ii) Similarly, when failure rate is constant while, $\beta = 1$, the components is in the occasional failure condition. Incidentally, the failure rate is increasing while $\beta > 1$ this means that the component is in the loss failure condition (Abbasi & Malik, 2016).

Case 12: The Mean and standard deviation of a weibull distribution evaluation

The mean and standard deviations are presented in terms of shape and scale – parameter given as:

$$\mu = \mu \Gamma\left(1 + \frac{1}{\beta}\right) \quad (26)$$

and

$$\delta^2 = \alpha^2 \left[\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right) \right] \quad (27)$$

where;

$\Gamma(\cdot)$ represents the gamma function which could be estimated in the following form as:

$$\Gamma = \sqrt{2\pi t}^{(t-0.5)} e^{-t} \left(1 + \frac{1}{12t}\right) \quad (28)$$

- (i) In the consideration for long term unavailability without considering restriction related to repair or replacement time of equipment in order to estimate equipment failure-rate, the Meantime to failure (MTTF) and the mean time between failure (MTBF) should be equal.

Therefore, MTBF = $\alpha \Gamma\left(1 + \frac{1}{\beta}\right)$ (29)

While, the total failure-rate for turbine–blade are considered as an important components for reliable performance given as:

$$\lambda(t) = \sum_{i=1}^N \lambda_i(t) \quad (30)$$

Where, $\lambda_i(t)$ is the rate of failure in i-th critical part of equipment and n is the total subcomponents of the turbine-blades under observations (Suwanasri *et al.*, 2014).

2.4 Collection of Failure Time (t) of a Gas Turbine-Blades performance

Presentation of the failure time (hrs) of a ten identical gas turbine–blades that are similar–make and similar –model while working under same stress conditions, stated as;

Table 1: The rating –order of turbine blade failures in time (hrs)

Rank	Failure Time, (hrs)
1	1047
2	1279
3	1340
4	1578
5	1598
6	1749
7	1804
8	1841
9	1847
10	1869
11	1879
12	1890
13	1939
14	1948
15	1949
16	1956
17	19087
18	1995
19	2004
20	2005
21	2047
22	2214
23	2287
24	2436
25	2439
26	2442
27	2581
28	2617
29	2926
30	2978

Sources: Research Desk/Maintenance Department Afam power Generating Station.

3. Results and Discussion

3.1 Results

Table 1 shows that failure times (hours) of ten similar gas turbine blades performance reliability having identical configuration in the make and model when subjected to the same stress level conditions under investigations were determined. The existing failures data is analyzed using weibull analysis software TPC windchill Quality solutions to obtain three-parameter weibull estimates of location, shape and scale parameters in order to produce the following weibull probability plot, probability density function (PDF) - plot , and 3D contour plot as presented in table 2, given as:

Table 2: Three (3) – parameter weibull estimates using windchill quality solutions application tool

Function	Shape – parameter (β)	Scale – parameter (η)	Location parameter (λ)
Probability ()	4.1652	33.6733	-3.1855
Reliability with time	4.1652	33.6733	-3.1855
Unreliability with time	4.1652	33.6733	-3.1855

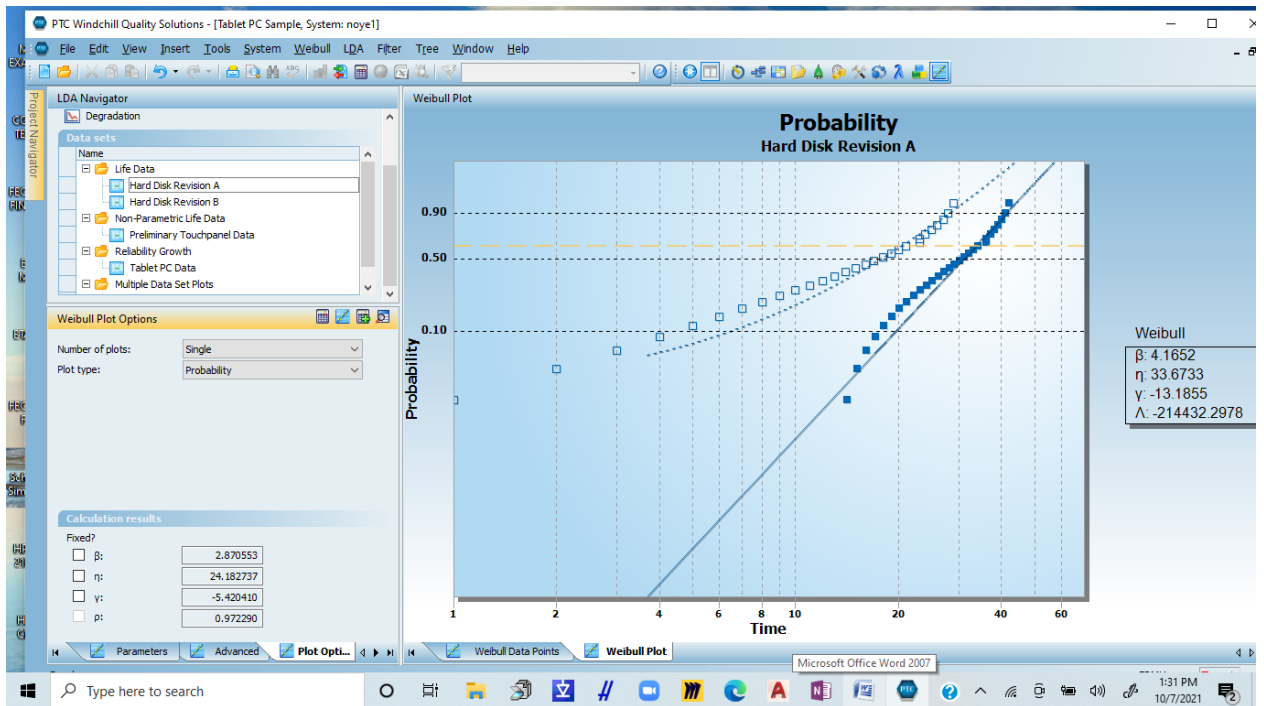


Figure 1: Probability plot against time, t in hours

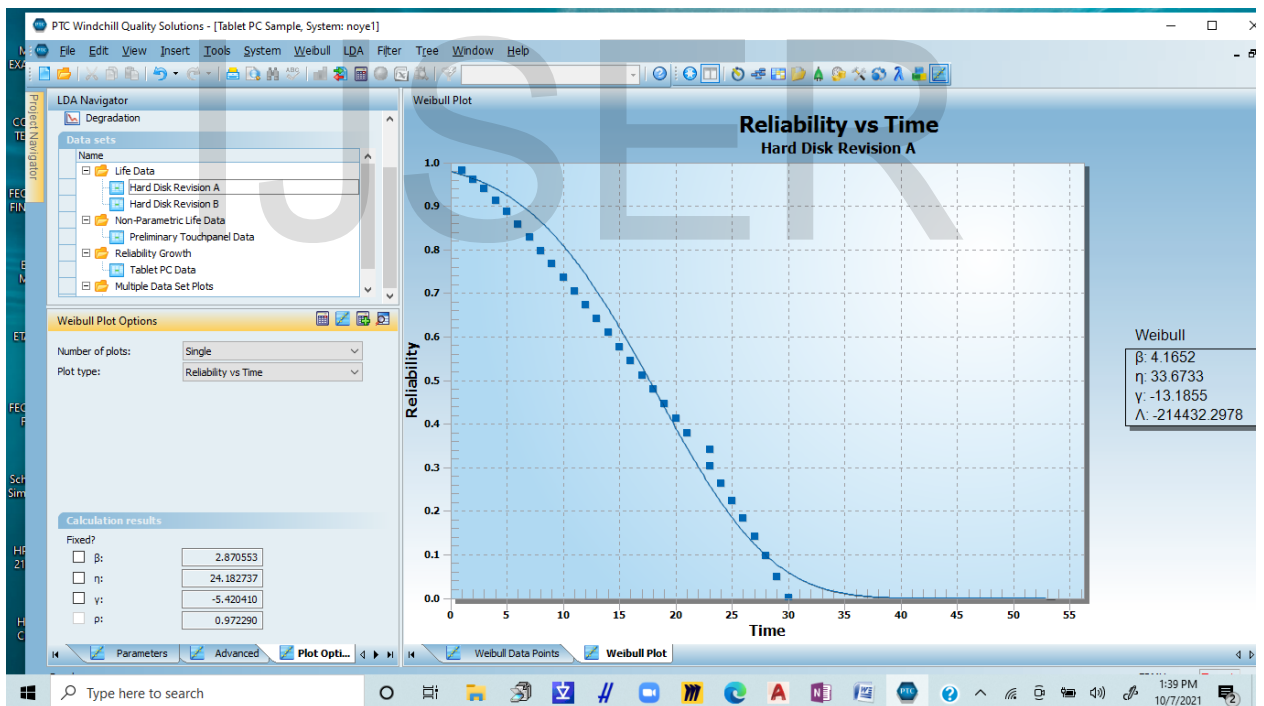


Figure 2: Reliability versus time in hours

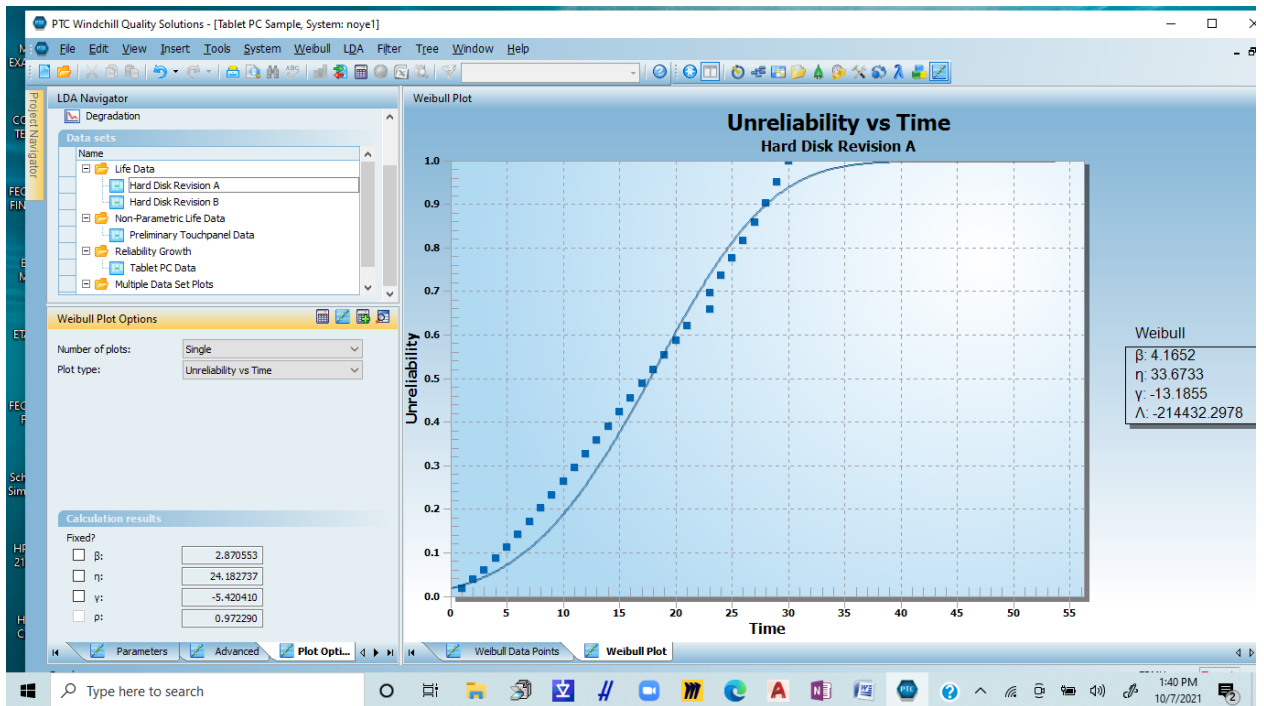


Figure 3: Unreliability versus time, (t) in hours

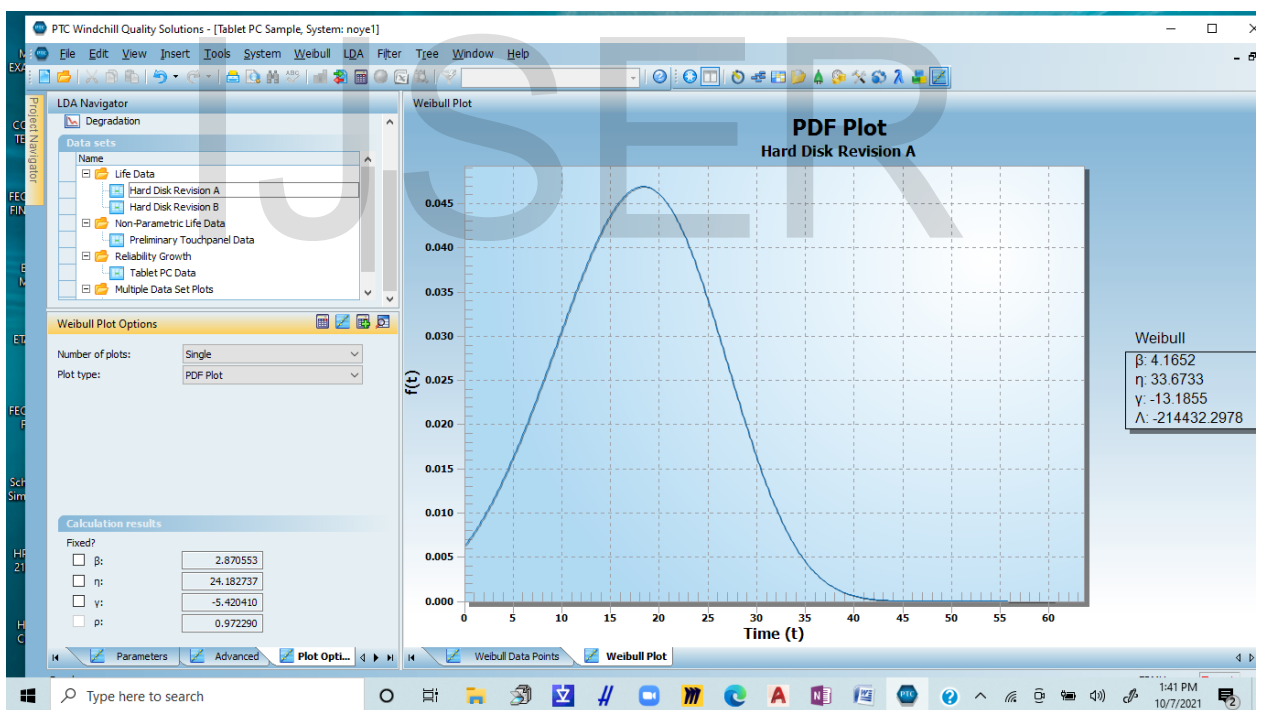


Figure 4: Probability density function (PDF), versus time (t) in hours

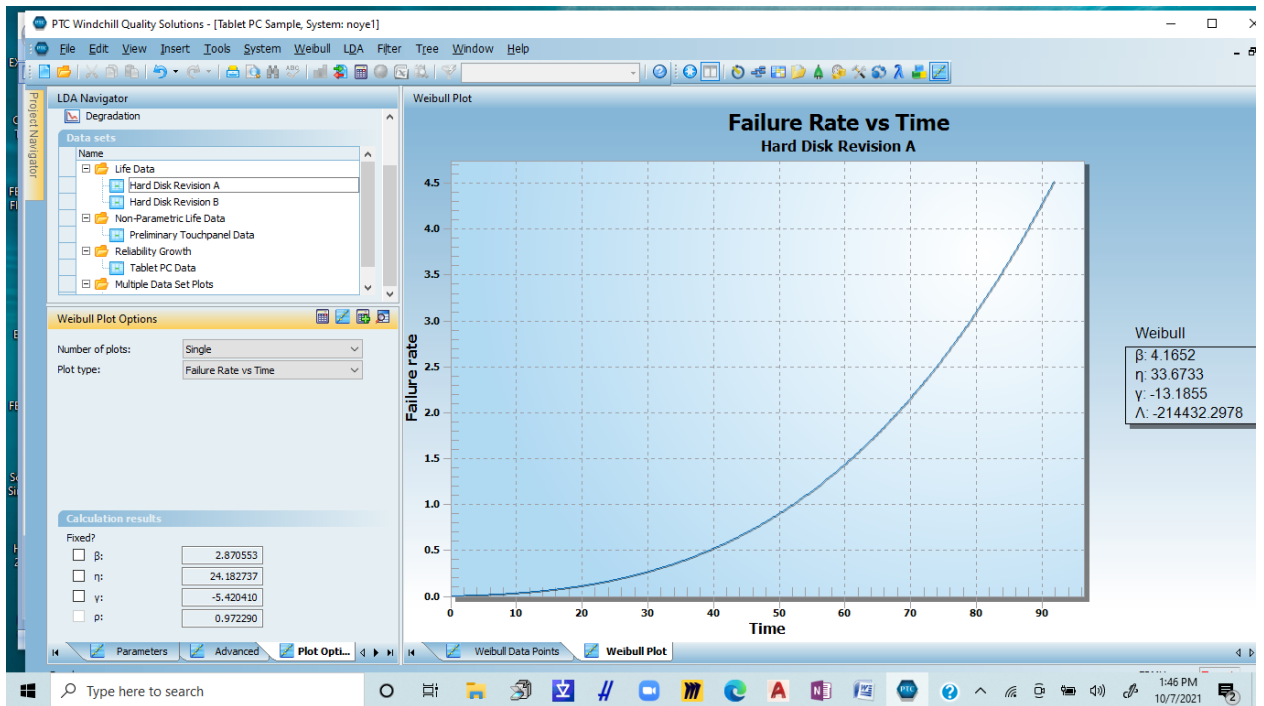


Figure 5: Failure rate versus time, t in hours

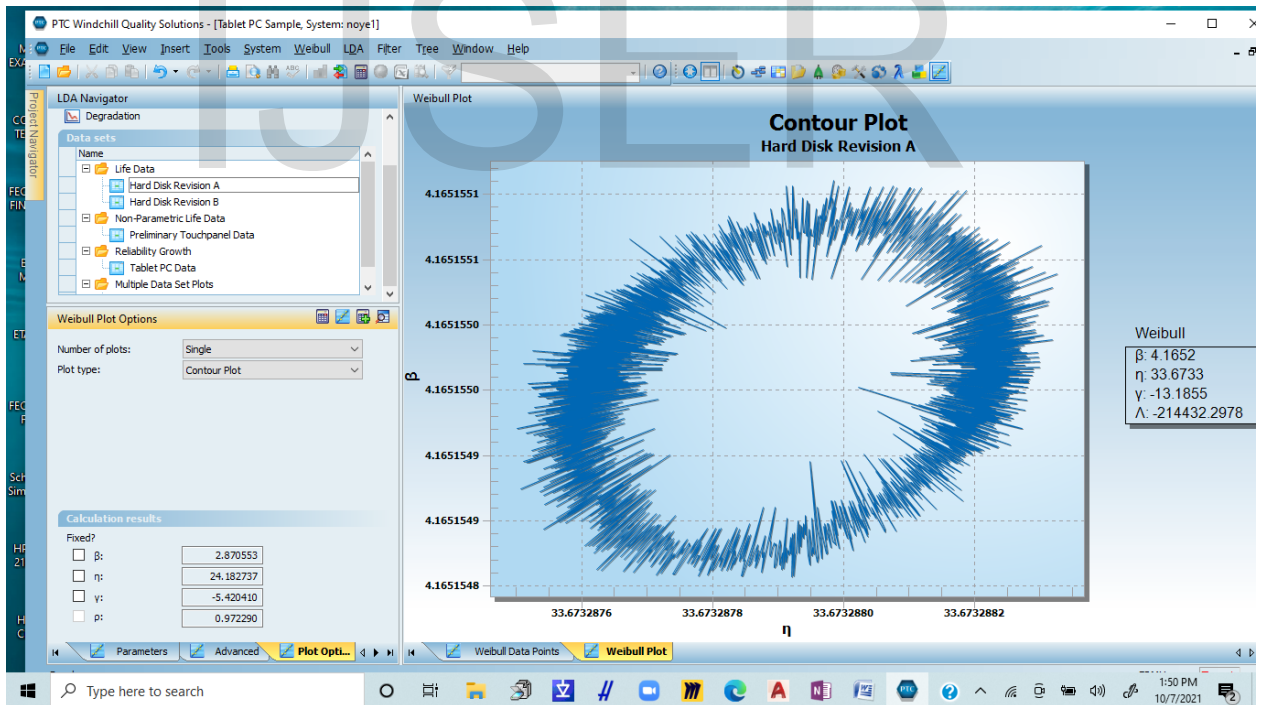


Figure 6: Contour representation plot.

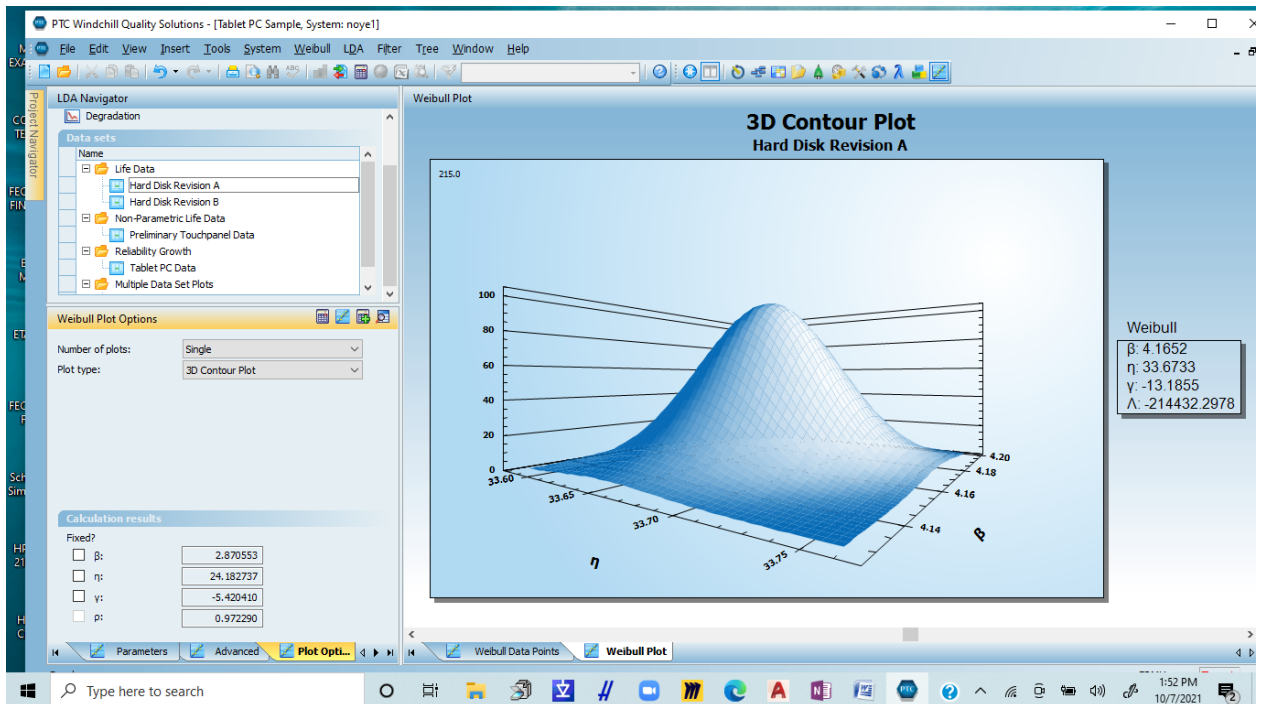


Figure 7: 3D Contour representation plot

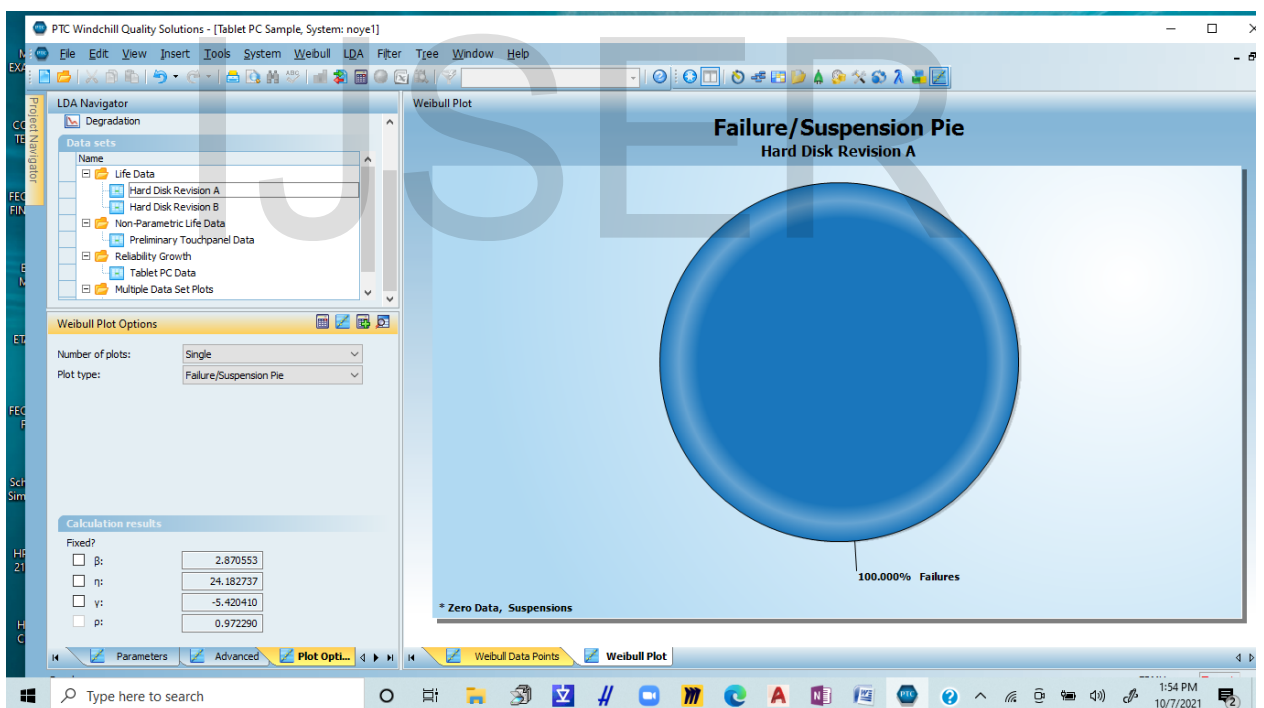


Figure 8: Failure suspension plot representation.

The application of reliability evaluation of three-parameter weibull distribution, shows from the simulation results obtained in the TPC windchill software reliability application tool given as:

shape (β) = 4.1652
 scale (η) = 33.6733
 location (λ) = -13.1855
 time (t) = 16.1867 hours

Thus, the reliability function of the three-parameter weibull distribution given as:

$$R(t) = \ell - \left(\frac{t - \lambda}{\eta} \right)^\beta, \text{ for } t \geq \gamma \quad (31)$$

Similarly,

The three-parameter weibull failures rate function is given by:

$$\lambda(t) = \frac{\beta}{\eta} \left(\frac{t - \lambda}{\eta} \right)^{\beta-1}, \text{ for } t \geq \gamma \quad (32)$$

and

Mean-time to failure of the three-parameter weibull distribution is given as:

$$MTTF = \gamma + \eta + \left(1 + \frac{1}{\beta} \right), \text{ where } \gamma \geq 0 \text{ and}$$

$t, \beta, \eta > 0$

that is,

$$\Gamma(x) = \int_0^\infty \ell^{-x} x^{n-1} \quad (33)$$

where;

- η : scale parameter
- $\Gamma(x)$: gamma function
- γ : location parameter
- β : shape parameter
- t : time

Thus, the reliability analysis for the weibull distribution parameters are determined and calculated as ;

$$R(t) = \ell - \left(\frac{t - \gamma}{\eta} \right)^\beta,$$

$$t = 16.1867 \text{ hours}$$

$$\ell = 2.718$$

$$\beta = 4.1652$$

$$\eta = 33.6733$$

$$\gamma = -13.1855$$

$$R(t) = \ell - \left(\frac{16.1867 - 13.1855}{33.6733} \right)^{4.1652}$$

or

$$R(t) = \ell - \left(\frac{29.3723}{33.6733} \right)^{4.1652}$$

or

$$R(t) = \ell^{-0.56598} = 2.718^{-0.56598}$$

or

$$R(t) = \ell^{-0.56598} = 2.718^{-0.56598}$$

or

$$R(t) = \frac{1}{2.718^{0.56598}} = \frac{1}{1.7610695}$$

$$R(t) = 0.5678 \approx 0.60$$

Similarly, the failure rate is calculated as:

$$R(t) = \frac{\beta}{\eta} \left(\frac{t - \gamma}{\eta} \right)^{\beta-1} \text{ for } t \geq \gamma$$

$$\beta = 4.1652,$$

$$t = 16.1867 \text{ hrs}$$

$$\eta = 33.6733$$

$$\gamma = 13.1855 \text{ hrs}$$

$$\lambda(t) = \frac{4.1652}{33.6733} \left(\frac{16.1867 - 13.1855}{3.6733} \right)^{4.1652}$$

or

$$\lambda(t) = 0.12369 \left(\frac{29.3723}{33.6733} \right)^{3.1652}$$

or

$$\lambda(t) = 0.12369 (0.872272)^{3.1652}$$

or

$$\lambda(t) = 0.12369 \times (0.648862)$$

or

$$\lambda(t) = 0.0802577 / \text{hours}$$

Thus, the Mean time to failure (MTTF) of the three-parameter weibull distribution calculated as;

$$MTTF = \lambda + \eta \Gamma \left(1 + \frac{1}{\beta} \right), \text{ for } \gamma \geq 0 \text{ and } t, \beta, \eta > 0$$

$$\gamma = -13.1855,$$

$$\eta = 33.6733$$

$$\beta = 4.1652,$$

$$\Gamma 1.2400 = 0.7940$$

$$MTTF = -13.1855 + 33.6733 \Gamma \left(1 + \frac{1}{4.1652} \right)$$

$= -13.1855 + 33.6733 \Gamma(1 + 0.24008)$ parameters which increases gradually while the value of the scale-parameter observed to be slightly affected

or

$$MTTF = -13.1855 + 33.6733 \Gamma(1 + 240084)$$

or

$$= -13.1855 + 33.6733 \times 0.7940$$

or

$$= -13.1855 + 33.6733 \times 0.7940$$

or

$$= -13.1855 + 26.7366002$$

or

$$= +13.551102hrs$$

3.2 Discussion of Weibull Distribution Plot

Following to the presentation plot of figure 1 the probability of failure versus time are shown. The scope of the probability plot is seen to be decreasing at the beginning but as it get to the end of the plot it is observed to be gradually increasing which is pushed to the right. Provided the value of the location parameter is positive.

Similarly, in figure 2, shows the plot of the probability density function (pdf) observed to be increasing at steady condition up to certain time, $t = 18$ hours but from this point further there is a sharp decrease. Subsequently, in Figure 3 which shows the reliability plot, it is observed to be initially very high at the beginning but over time becomes decreasing, which means that the gas turbine are aging with time that is there is a gradual drop in reliability. Similarly, 4, shows the plots of the failure rate which is increasing at a time (t). This indicates that gas turbine blade are tilting towards their wear-out period of reliable maintenance.

Figure 5, shows vivid presentation of the contour plot of 3D, from the plots it is observed that the values of the estimates of three-parameter weibull vary along the contour axes. Significantly, that is moving from the bottom of the location and shape

4. Conclusion and Recommendations

4.1 Conclusion

The analysis of the parameter estimation of weibull distributions using reliability evaluation technique was formulated with implementation of the input data collected in the study case under investigation. The study evaluated the analysis of the failure times of ten similar turbine blade in an identical modes of operations using TPC windchill quality solution software in order to obtain the estimates of the three parameters of weibull (location, shape and scale parameters). The estimates were successfully obtained which represents the probability that gas-turbine blade existing state will continue to be operational in service without components failure which is about 70% reliability level, while the mean-time to failure to the turbine blades is about 14 hours.

The results of the analysis evaluated indicates that the blades were tilting towards their wear-out period of their numerical value of shape-parameter (β) which becomes 4.1652 that is greater than one. From the TPC windchill estimates obtained the reliability $R(t)$, failure rate $\lambda(t)$ and mean-time to failure of the blades are adequately computed.

4.2 Recommendations

This research paper is a lead study and a challenging area in widespread practice especially in the area of management of system components of power plant unit availability that should conform to local and international standard of operations. The following recommendation are strongly addressed to improve the existing reliability of power quality as:

- (i) The electric power station should align in the development of equipment/components for specific operations and maintenance (O&M) procedures and program.

- (ii) Energy demand and load growth should be monitored from the station, based on the following subsequent demand rate and frequency.
- (iii) Electric power station should embrace the ideas or the use of dedicated high profile software – package for analysis, estimate and evaluations.
- (iv) Reliability indices and parameters analysis should give self-contained information to give a useful practical introduction to standard availability performance evaluations.
- (v) Wear-out period of system components (turbine blade) should be replaced and service immediately to avoid total breakdown of other facilities that may affect or attract more cost to the machine (turbine power plant) etc.

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The acknowledged sourced includes:

- The availability investigation covers from 2005 to 2021 (10 years) was done through the exhaustive collection of data from samples.
- The investigation used in IEEE standard 762 generator performance indices collected data.
- Function outage parameter (op) using the numerical values in the table of values and graph.
- The use of a historical failure data base to identify critical components for power supply availability to support economic growth.

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Nomenclature & Units

η : Scale parameter

$\Gamma(x)$: Gamma Function

γ : Location parameter

β : shape parameter

t : Time

APPENDIX A: Turbine Blade configuration



Plate 1: Turbine-blade design configuration.

APPENDIX B: Afam VI Power Station (Gas-Turbine Power Plant)

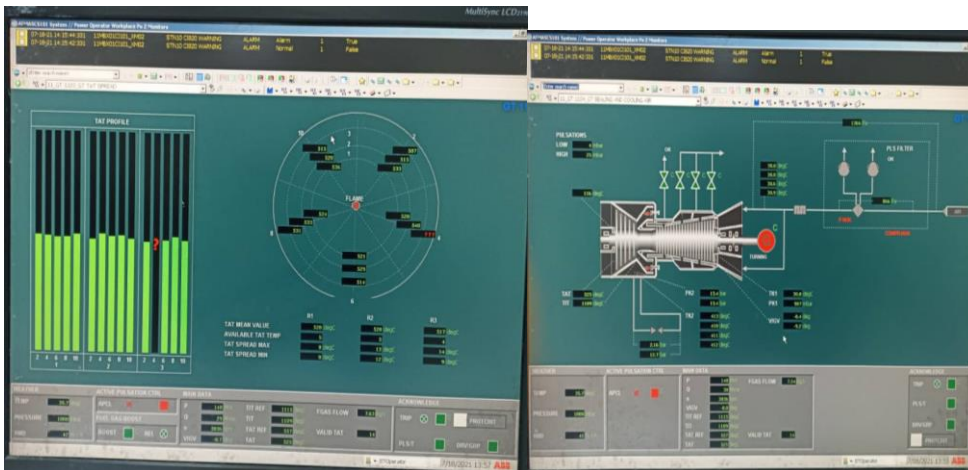


Plate 2: Afam VI Combine Cycle and System Interface Communication and Control Circuit Representation

APPENDIX C: Afam VI Power Plant Combination Cycle with System Internal Configuration Parameters and detail

Afam VI combine Cycle power plant CAPP.

configuration: 331. Three Gas turbine, Three Heat Recovery Steam Generator HRSG, One Steam Turbine.

Capacity, Gas turbine 150WM each.

Steam turbine 200MW.

Total 650WM

Gas Turbine Model 13E2 Asltom Machine.

Axial 21 stage compressor blade,

3000rpm.

Gas, natural gas. Operating Gas pressure (22.5-25.5) bar.

Gas turbine exhaust temp at base load (550-555)C,

Minimum load (540-550C Exhaust pressure (1,010-1,025) bar

Cooling system. Heat exchanger for gas turbine, lub oil system for bearing (57-61)C. Water system for generator coil (32-34)C.

Steam turbine Model Hangzhou HTC.

Dual Pressure Steam turbine, capacity 200MW.

Superheated dry Stream of 550C.

Pressure type, HP and LP

HP High pressure steam turbine

LP Low pressure steam turbine

HP temperature (548-550)C

HP pressure (78-79.5bar

Steam flow (99.5-100)TH

Boilers of Drums.

Feed water storage tank (150-180)C

LP drum temp (270-290)C

pressure (4.4-5.0) bar.

HP drum or boilers (550.5650)C. Pressure (80-82.5)