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Operation Management of a GTPPS Based on Field Failure Data: A Case Study

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Abstract

Reliability analysis for Gas turbine power plant over a period of 66-month was carried out. The most important failure modes units were identified and the descriptive statistics at failure and machine level were calculated. Several theoretical distributions were applied and best fit of failure data was identified. The reliability and hazard rate models of the failure data were determined to provide an estimate of the current operation management (i.e. maintenance policy, training, spare parts) and improve the line efficiency. It was found out that (a) the availability of the Gas turbine power plant unit (taken for case study) is 94.80%, (b) the failures due to mechanical and other causes amount to 45.1% of all the failures of the machine, (c) the time-between-failure (TBF) was drastically decreased there by suggesting that the probability to fail increased and the current maintenance policy should be revised, and (d) the failure times follow the lognormal distribution whereas the times-to-repair (TTR) a failure comply with the exponential distribution.

Keywords: *GTTPS, RELIABILITY, TTR, TBF.*

1.0 Introduction

A power plant may be defined as an assembly of machines or equipments that generate either mechanical or electrical energy from fuel and delivers it to the transmission section. Its main equipment is generator which is coupled to a prime mover to generate, electricity. The type of prime mover determines the type of power plants. which are divided into two types, viz. conventional and non conventional [9]. The different types of conventional power plants are steam, diesel, gas turbine, nuclear, and hydro electric power plants. The non-conventional power plants are thermo electric generator, solar energy, fuel cells, photovoltaic solar cell, magneto hydrodynamic generator (MHD) biomass and biogas, geo thermal, wind energy, ocean thermal energy conversion, wave and tidal wave power plants [2]. The power plant which uses natural gas or liquefied natural gas (LNG). as fuel are called Gas Turbine Power Plant System (GTPPS) [7].

Compared to large power stations, such as coal fired stations and nuclear stations, the capital investment of gas turbine driven power plants is lower and the construction lead times are shorter [8]. Moreover reserved natural gas is easy to transfer from one location to any other location and is sufficiently available with respect to other fuels [5]. The life cycle costs of GTPPS can be decomposed into three major elements: project investment cost, fuel cost, and plant operations and maintenance cost [3,12]. In modern times, it is observed that the operation and maintenance costs may comprise up to 15% to 20% of the total life cycle costs [10]. The productivity of GTPPS is optimized by generation scheduling, maintenance scheduling, outage planning, and advanced technology up-gradation. Every power plant had some unit commitment [8,15].

Gas turbine units degrade and deteriorate as they age. Different preventive maintenance activities such as combustion inspection, hot gas path inspection, and complete overhauling are scheduled at prescribed maintenance intervals for each gas turbine unit [1].

As for example, the maintenance interval for a MS7F gas turbine engine a model of G.E. Corporation, U.S.A. is 24000 factored fired hours and 900 factored starts, respectively, whichever happens first (G.E. service manual). In this context the maintenance practices may be optimized to achieve the maximum profit. by minimizing system maintenance cost rate considering generation scheduling and energy market. As GTPPS is a very complex system, the vital issue of the operating personnel is to identify its critical failures and measures to enhance Reliability.at the time of maintenance to minimize its downtime [13]. One of the most important requirements for a power generation system is to guarantee its technical availability. The availability of a complex system is strongly associated with the parts reliability and maintenance policy, which not only has influence on the parts repair time but also on the parts reliability affecting the system degradation and availability [14]. The reliability of its component parts will increase if the items are properly maintained.

The Power Generation activity is divided into two divisions mainly the generation activity and the transmission activity. The generation activity concentrates into the procurement of plant and equipments and spares for power generation, upkeepment of power plant, operation of power plants, and safety of operating personnel. The transmission activity concentrate into the transmission and distribution of the power to far reaching consumers and ensuring all activities related to transmission and distribution. Under the ongoing reformation of the electric supply industry in China and India, generation companies' primary function is limited to generation only and the transmission part is particularly taken care of separate power grid and as a result generation companies can concentrate more on power production and thus entering and capturing the power market for selling their product [4]. For the survival of existence in the power market, generation utilities are expected to improve the usability and reliability of machines by the most efficient measures.Here maintenance plays a key role as viewed by Chen chung Huang and John Yuan[17]

This paper contains description of subsystems of GTPPS, failures modes of subsystems of GTPPS. The methodology for analysing the field failure Data of GTPPS.

2.0 Description of GTPPS Components and Failures

The gas turbine obtains its power by utilizing the energy of burnt gases and air, which is at high temperature and pressure by expanding through the several ring of fixed and moving blades. A compressor is required to get the high pressure of the order of 4 to 10 bar of working fluid, The turbine drives the compressor and coupled to the turbine shaft.

Gas turbines are described thermodynamically by the Brayton cycle, in which air is compressed isentropically, combustion occurs at constant pressure, and expansion over the turbine occurs isentropically back to the starting pressure.

Gas turbines are constructed to work with oil, natural gas, coal gas, producer gas, blast furnace gas and pulverized coal with varying fractions of nitrogen and impurities such as hydrogen sulfide are used as Fuel. Each unit of GTPPS consists of five main components, viz turbine, compressor, combustion chamber, Generator and electric system supporting the whole unit. The various stages of operation are shown in the figure 1.

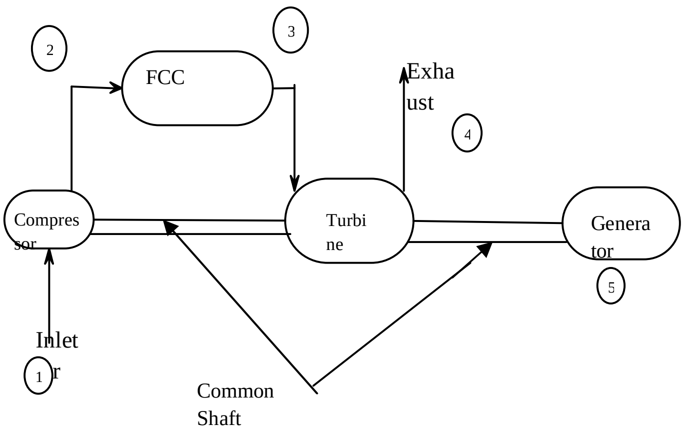

Figure 1: Block Diagram of Single Shaft Gas Turbine Power Plant

The main components of the GTPPS plant is described with following section

(1) Compressor: The compressor in a GTPPS power plant handle a large volume of air or working media and delivering it at about 4 to 10 atmosphere pressure with highest possible efficiencies The axial flow compressor is used for this purpose. The kinetic energy is given to the air as it passes through the rotor and part of it is converted into pressure. The common types of failures found in the compressor of GTPPS system is as follows.

(a) Exhaust temperature high.

(b) Air inlet differential Trouble: During the winter season due to fog air filter become clogged so the filter module cannot suck the exact amount air which is required during the suction stroke. So the load will be reduced. When the air inlet differential pressure crosses the 4 inches of Water column then air inlet differential trouble occurs.

(2) Combustion Chambers: The combustion chamber perform the difficult task of burning the large quantity of fuel, supplied through the fuel burner with extensive volume of air supplied by the compressor and releasing the heat in such a manner that air is expanded and accelerated to give a smooth stream of uniformly heated gas at all conditions required by the turbine. The common types of failures found in the combustion chambers of GTPPS system is as follows

(a) Loss of Flame: At the end of the compression or at the end of Cranking of the turbine spark is created by the 2 (two) numbers of spark plug.

(b) Servo Trouble.

(3) Gas Turbine: A gas turbine used in power plant converts the heat and kinetic energy of the gases into work The basic requirements of the turbines are lightweight, high efficiency; reliability in operation and long working life. The common types of failures found in the Gas Turbine component of GTPPS system is as follows

(a) High Pressure (H.P) Turbine under speed :

(b) Low Pressure (L.P) Turbine Over speed: If in any certain case if this droop speed mode value falls or cross the upper limit then High Pressure (H.P) Turbine under speed alarm will appear in the turbine and the turbine will be trip.

(c) Wheel space differential temperature high:

(d) Mist eliminator Failure/Trouble:.

(e) Turbine Lube Oil Header Temperature High:

(f) Low hydraulic pressure:

(g) Bearing drain oil temperature high:

(4) Generator: Generator is a machine which converts mechanical energy into electrical energy (or power).In a generator, an e.m.f. is produced by the movement of a coil in a magnetic field. The common types of failures found in the Generator of GTPPS system is as follows

a) P.M.G bolt broken: The role of permanent magnet generator is to supply the initial torque to the rotor. If PMG bolt is broken than the generator will stop working and Power production will hamper.

(5) Electrical systems: The A.C. power circuit ignition system receives an alternating current that is passed through a transformer and rectifier to charge a capacitor. The main function is linking the produced generation to hungry consumers'. The common types of failures found in the Electrical systems of GTPPS system is as follows

(a) De synchronization with Grid.

3.0 Field failure data for gas Turbine Plant:

Failure and repair data of the gas Turbine plant were collected from the plant of the technical department by the end of each shift. They had been recorded in print by the technicians in charge.(mechanical and electrical). Out of all the units we have selected Unit no 5 as our case study, even though we have analyzed all the failures of the plant.
The availability of the gas Turbine power plant machine unit no 5 is defined as

$$A_m = \frac{mean\,TBF}{mean\,TBF + mean\,TTR} = \frac{(1/n\sum_{i=1}^{n} TBF_i}{\left(\frac{1}{n}\right)\sum_{i=1}^{n} TBF_i + \left(\frac{1}{n}\right)\sum_{i=1}^{n} TTR_i}$$

$$\frac{266}{266+15} = 0.9466 = 94\%$$

where n is the total number of failures studied within the frame of this investigation. The records included the failures occurring per shift, the action taken to repair the failure, the down time, and the exact time of failure. Therefore, there is the exact time both for the machine failure and between failures. This means that the precision in computing the time-between-failure (TBF) of a failure and the time-to repair (TTR) a failure were both recorded in hours. In this research study TBF and TTR data of gas turbine power plant and their failure modes are arranged in chronological order for applying statistical analysis to estimate the reliability and the maintenance policy of the machine. These files covered a period of 1825 days that is about 5 years. Over this period, the line operated a total of 42300 hour without failures and during the remaining 1700 h the machine was under repair. TBF of repairable equipment is defined as the time elapsing from the moment the equipment goes up and starts operation after a failure, until the moment it stops operation because of a new failure. TTR is defined as the time during which equipment is in the failure state, until the moment it starts the operation after the repaired has been completed. The failure data are operation dependent failures, meaning that a machine may fail while being in operation. Moreover, it could be assumed that both TBF and TTR may have independent and identical distribution in the time domain. The currently applied maintenance policy of the Gas Turbine machine is corrective maintenance; that is unscheduled and carried out whenever a failure occurs. The corrective maintenance procedures required immediate action of the maintenance staff with the purpose to restore the machine into operational state. This maintenance policy may include any or all the following steps: recognition, localization and diagnosis (isolation), correction (disassemble, remove, replace, reassemble, adjust), and operation checkout. A total of 858 failures were counted and categorized in seven unit failure modes as shown in Table 1. The unit wise breakdowns are shown in figure 2.The reasons for failures and their percentages are presented in table 2.The fault wise failures are shown in figure 3.The failure frequency of each unit failure mode was evaluated by means of a Pareto chart (see Fig 4). This chart resulted from an analysis of the high rank and

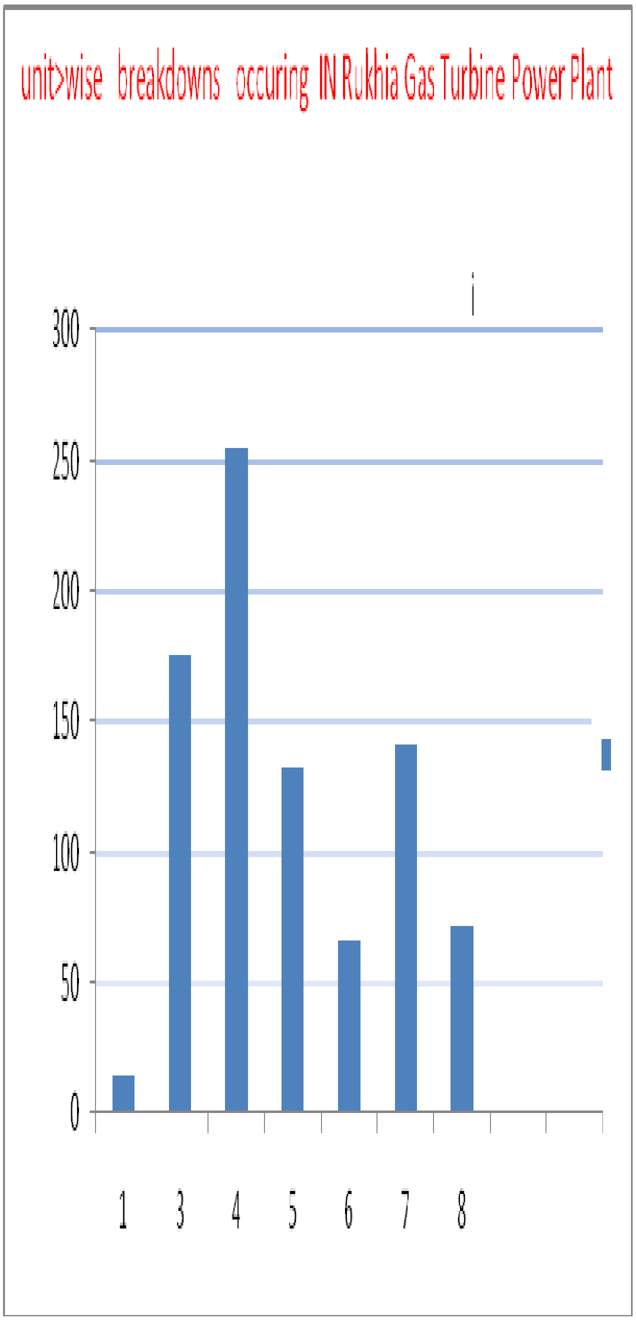

Figure 2 Unitwise Breakdown occurring in Rukhia Gas Turbine Plant

Failure unit	Failure component	Description of failure mode
Unit 1	Turbine	H.P turbine under speed, L.P. over speed, Heavy smoke, Turbine U/S locked, Nozzle Problem, Exhaust overtemp, Low hydraulic pressureServo Problem, Start up problem, Lub oil level low, Lub oil Drain temp high,Lub oil Drain temp high, Lub oil header temp high, Oil leakage,
Unit 2	Generator	P.mg bolt broken, P.m.g. Bush damaged, Not in alignment with the generator
Unit 3	**Combustion chamber**	Loss of Flame, Bearing Drain temp high, Starting and other Problem, Servo valve problems, Nozzle Problems
Unit 4	**Compressor**	Exhaust over temperature, Turbine air inlet differential high, Oil leakage, Compressor bleed valve trouble, Over speed
Unit 5	**Electrical**	De-synchronization, Relay fault under frequency, Synchronization, Feeder fault, Poor demand& shortage of gas, Grid failure

Table 1: Categorization of failures units in Gas Turbine unit Plant

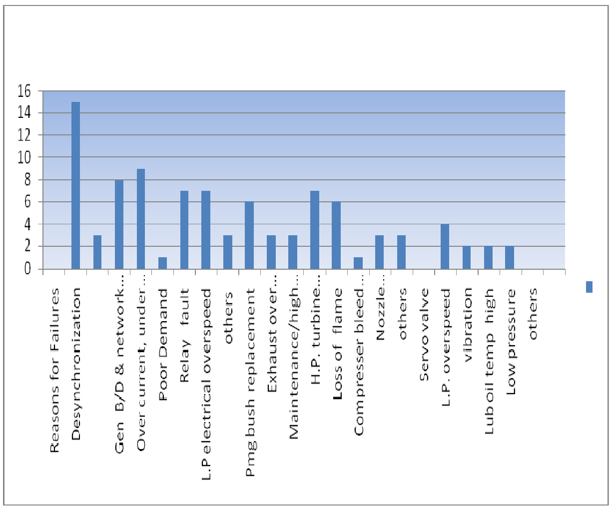

Figure 3 Fault wise failure percentages

Reasons for Failures	Percentage of failures
Desynchronization	15
Feeder fault	3
Gen B/D & network transformer punctured	8
Over current, under frequency	9
Poor Demand	1
Relay fault	7
L.P electrical overspeed	7
others	3
Pmg bush replacement	6
Exhaust over temperature/overspeed/oil leakage	3
Maintenance/high vibration	3
H.P. turbine underspeed	7
Loss of flame	6
Compresser bleed valve trouble	1
Nozzle problem, Turbine air inlet differential high	3
Others	3
Servo valve	1
L.P. overspeed	4
Vibration	2
Lub oil temp high	2
Low pressure	2
Others	4

Table 2 Percentage wise failure modes of Gas turbine Power plant

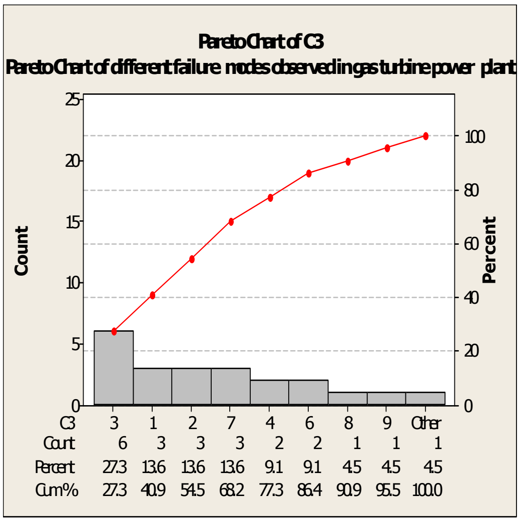

Fig. 4: Pareto chart for all failure modes of the Gas turbine Power Plant

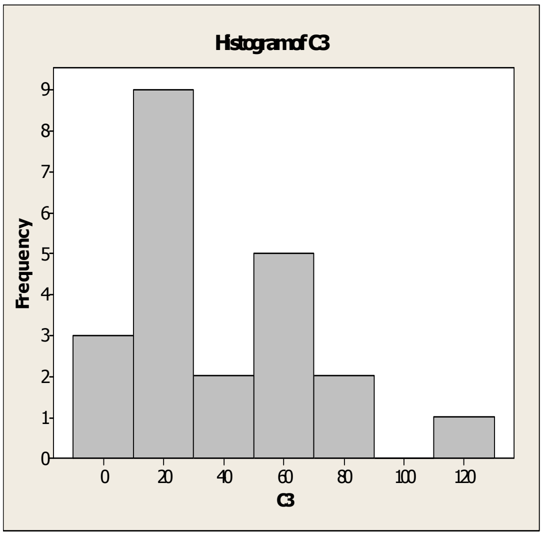

Figure 5 Histogram of Failure Distribution

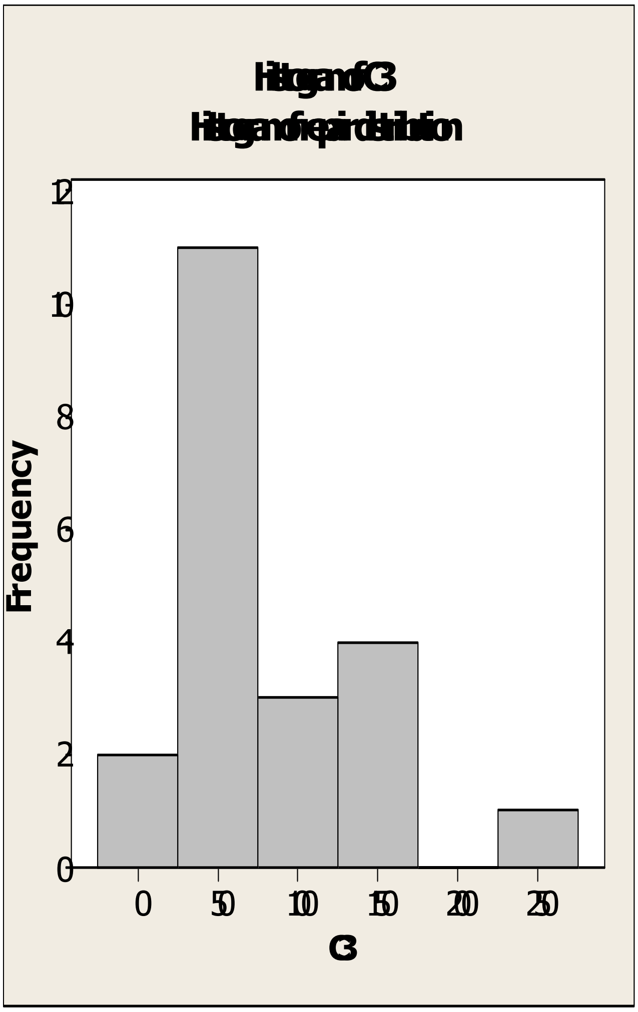

Figure 6: Histogram of Repair Distribution

Failure unit	Failure nos	% of total	Repair hours	Running hours	% of downtime	Equivalent to
Unit 1	15	2	96	8760	1.1%	1%
Unit 3	176	20	303	37200	0.81%	1%
Unit 4	255	30	469	13152	3.64%	4%
Unit 5	131	15	240	17520	1.37%	1%
Unit 6	67	8	133	4320	3.1%	3%
Unit 7	141	16	282	47544	0.6%	1%
Unit 8	76	9	173	37920	0.46%	0.5%
Total	861	100	1696	166416	1.02%	1%

Table 3: Unit wise failure hours running hours, repair hours and percentage of down time

occurrence of failures, indicating the number of failure occurrences per unit failure mode of the total failure occurrence.

The unit wise failure hours running hours .repair hours and percentage of downtimes are presented in table 3.

The most frequent failure mode are the unit 4 failures (unit 4) amounting to 29 % of all the failures.

The second frequent failure mode are unit 3 failures (Unit 3) standing for 20 % of all the failures; whereas the unit 7 failures (unit 7) are ranked in the third position with 16 .4 % of all the failures and unit 5 contributes15% of total failures.

In Fig. 5 and 6, the histograms of failure and repair data for TBF and TTR, respectively, of the gas turbine plant are displayed.

The histograms arise from grouping the failure and repair times into classes and plotting the frequency of observations per class versus the interval times of each class.

The histograms of TBF and TTR exhibit the near symmetrical distribution and as a result the normal or a Weibull (with a shape parameter between 3 and 4) distribution will be investigated in order to identify the one providing the best fit.

4.0 Statistical analysis of field failure data:

In order to obtain qualitative and quantitative analysis of the failure data for the gas turbine plant, the descriptive statistics of the basic features of the failure and repair data for TBF, and TTR are presented in Table 4.

Statistical analysis plays a key role in decision making as viewed by Ching-Chih Tseng [18].

Thus, it is possible to extract the minimum and the maximum value of the sample, mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis of the failure data at failure modes, and the machine level. The SD of the random variable is defined as the square root of the variance, and is often used in place of the variance to describe the distribution spread.

Since the CV of a random variable is defined as the ratio of the standard deviation over the mean of the random variable, and is a dimensionless measure of the variability of the random variable.

Skewness and kurtosis are statistics that characterize the shape and symmetry of the distribution.

Skewness is a measure of the degree of asymmetry of a distribution while kurtosis is a measure of whether the data appear as peaks or are flat.

A normal distribution will have kurtosis and skewness values equal to zero. From Table 4 the following observations can be made: (a) in the Gas turbine power plant system for every 62.2 hours there is a failure that ranging between 1 and 3521hours.

The CV at machine level is more than one, thereby indicating that the TBF has high variability. (b) The TBF is more than zero skewed which mean that the TBF may approximate exponential or webull distribution. (c) All the units

TTR had CVs more than1 less than one, and therefore low variability. (d)

The mean TTR for the gas turbine power plant unit is 1.66 h to6.40 hours that ranges between one hour to the entire continuous operation or 98 h, with low variability because the CV of the TTR is less than one or slightly more than one.

The TTR has a marginal positive skew value, meaning that the TTR presented borderline mode < median < mean.

Variable	N	Mean	SD	Covc	Minim	Maxm	Skewness	Kurtosis
TBF Unit1	15	605	1712	2.82	25	6764	3.8123	14.655
TBF Unit3	175	231.7	407.0	1.75	6	2777.0	4.5102	22.80
TBF Unit4	252	175.6	373.8	2.11	1.0	4369	7.8156	78.384
TBF Unit5	131	102.6	141.1	1.382	7.0	1032.0	3.4508	16.2386
TBF Unit6	66	62.2	92.7	1,47	2.0	572	3.8467	17.09
TBF Unit7	140	243.7	367.2	1.50	1.0	2308	3.2893	13.1130
TBF Unit8	76	441.5	670.9	1.51	7.0	3521.0	3.2577	11.5012
TTR Unit1	15	6.40	8.57	1.33	1.0	30.00	1.93630	3.30267
TTR Unit3	175	1.666	1.881	1.13	1.00	12.00	3.8437	16.1955
TTR Unit4	252	1.840	1.742	0.946	1.0	10.0	2.6390	6.88293
TTR	131	2.153	2.824	1.21	1.00	15.00	3.14802	9.98612

Unit5								
TTR Unit6	66	2.0	1.867	0.933	1.0	9.0	2.0886	3.68247
TTR Unit7	140	2.7	2.665	0.987	1.00	98.0	9.898	107.27
TTR Unit8	76	2.289	3.586	1.566	1.00	23.00	4.0193	17.8538

Table:4 : Descriptive statistics:of GTPPS , the minimum and the maximum value of the sample (N), mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis of the failure data at failure modes, and the machine level.

6. Reliability and maintainability analysis

Reliability is the probability that a system (machine or component) will perform a required function, under stated operating conditions, for a given period of time t.

T defines the TBF of the system. If $T \geq 0$, then the reliability can be expressed as (Ebeling, 1997)[6], $R(t) = P(T \geq t)$.. The un-reliability function is defined as, Q(t), which is the probability of failure in t, $Q(t) = 1-R(t)=P(T\leq t)$ In reliability theory, the hazard or failure rate function is denoted as, $\lambda(t) = f(t)/R(t)$where f(t) is the probability density function(pdf) of the failure distribution.

Maintainability is the probability that a failed machine or component will be restored to operational effectiveness within a period of time when the repairs are performed in accordance to the prescribed procedures. In other words, it is the probability of repairs in a given time. The repair time includes access time, diagnosis time, spare part supply, replacement time, checkout time, and alignment time.

The Gas Turbine plant as mentioned above exhibits availability reaching 94%.Given that the gas turbine the plant consists of several generating units in series and the entire reliability of the plant is given by equation 2

R(Line) = $\prod_{i=1}^{k} R_i$(t) =$R_{1(t)}$* R_2 (t)*----------- R_k(t)-- -(2)

where k is the total number of the machines. When the reliability of the gas turbine power plant is not suitable, it must be optimized.

The low level of the reliability may be attributed to the com-plexity and the full automation of the machine that contains a numerous number of components (mechanicals, electrical, pneumatics, complexity with different failure modes (Tsarouhtsis and Nazlis,2006)[16].

Therefore, the gas turbine plant unit is characterized by the maintenance staff as the 'neuralgic point' of` line. To avoid the inadequate operation of the machine with frequent discontinuations and high repair times, the target is to reduce the failure frequency and the failure duration. These approaches are determined by good operation practice (GOP) and must be applied at the same time. Both approaches were considered as necessary steps towards overall system improvement. Our objective was focused on reducing the downtimes of machine by prolonging the TBF and minimizing the repair time. To predict reliability and maintainability for gas turbine plant unit , one must analyze the failure and repair data by estimating the failure and repair distribution. The TBF and TTR distributions were investigated by means of histograms and descriptive statistics for fitting several candidate theoretical distributions. The maximum likelihood estimation method was used per candidate distribution and assessed its parameters by applying a goodness- of-fit test – Anderson–Darling.

The Anderson–Darling statistics of several theoretical distributions for TBF and TTR based on failure data of the machine and failure modes level were summarized in Table 5. A smaller statistic value indicates that the distribution fits the data better. The TBF at failure modes level for unit 3 and unit 8 followed lognormal distribution, the unit 5 follows the lognormal distribution. the unit 1 a log logistic distribution, the unit4 and 6 followed weibull distribution, and the unit7 a exponential distribution and are the best fit. The TTR at unit 5 of the exponential distribution is the best fit, and the weibull is valid for unit 3. Meanwhile, unit 6,7 and unit 4 follow the exponential distribution and the unit 1 is characterized by the lognormal distribution, whereas unit 8 is loglogistically distributed. Unit wise distributions are presented in table 5 and the best fit distribution is presented in table 6. Although in reliability theory the Weibull distribution is often the representative one for describing the failure data; in the case of gas turbine power plant the Weibull distribution is not appropriate. The gas turbine power plant unit1 follows the log logistic distribution and the lognormal distribution for TBF and TTR, respectively. The probability density functions, survival functions, probability plot, and hazard functions for a selected distribution of TBF, TTR for the gas turbine power plant were shown in Fig. 7.The survival plot is separately shown in figure 8. Similarly for TTR of Unit 5 are shown in figure 9 and 10. The hazard rate functions at machine level for both TBF and TTR display a pick: (a) the TBF has continuous increasing failure rate, meaning that the machine has drastically higher probability to fail in the long run. In other words the current corrective maintenance policy requires urgent revision. (b) The TTR initially shows increasing repair rate up to 98 h and then constant repair rate, implying that the probability to repair a failure increases with time up to the first 98 h. However, should a repair process not have been completed within the first 98 h and going on for a rather long time, then the probability to repair a failure in the next time is constant.

7. Determination of reliability and hazard rate models for the gas turbine power plant

The gas turbine power plant consists of several components in series with a common transfer mechanism and fully automated control system. The gas turbine power plant will function if and only if all its components are properly functioning. Should a component of the machine fail then the machine stops, and as a result the production line stops too.

The machine, as mentioned above, is following the normal failure flow, and it is fair to indicate T as the continuous random variable representing the time between to failure, then the probability density function (pdf) of normal distribution is (Kececioglu, 2002)[9]

$\frac{1}{\sqrt{2\pi\sigma}}\exp\left[\frac{-1}{2}\frac{(logt-\mu)^2}{\sigma^2}\right]$ and Reliability can be expressed as

$\frac{1}{\sqrt{2\pi\sigma}}\int_{logt}^{\infty}\exp\left[\frac{-1}{2}\frac{(x-\mu)^2}{\sigma^2}\right]I\,dx$ Where the

parameters μ and σ are the mean and the standard deviation of the distribution, respectively expressed both in hours. The mean is called the location parameter, the larger the μ the larger the average life of the machine.

The second parameter σ is called scale parameter; as σ decreases the pdf becomes narrower and taller, implying the pdf pushed towards the mean.. The opposite occurs if σ increases. In case of standardized normal probability, the density function with a mean of zero and standard deviation of one, the pdf of z is given as: $\Phi(t) = \frac{1}{\sqrt{2\pi}}\exp[-z^2/2]$--------[4]

where $z = (\frac{t-\mu}{\sigma}$Therefore the reliability and the un-reliability of the gas turbine unit are respectively

$R(t) = Pr(T \geq t) = (1-\Phi(\frac{t-\mu}{\sigma}))$---------------------[5]

$F(t) = \Phi(\frac{t-\mu}{\sigma})$---[6]

Where Φ(t) is the cumulative probabilities of the standardized normal distribution. The hazard or failure rate function of the machine is given by $\lambda(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1-\Phi(\frac{t-\mu}{\sigma})}$---[7]

where μ and σ stand for TBF are 99.4860 and 142.8766, respectively (see Fig. 7).

Consequently, the Eqs. (5)–(7) are used to calculate the reliability, un-reliability, and the failure rate of the gas turbine power plant machine, based on lognormal distribution per time t. Thus, these models were used to indicate the operational behavior as performance evaluation of the machine. The formula for calculating the Reliability, probability density function and hazard rate are shown in Table 7. The following conclusions were derived for gas turbine power plant machine TBF based on lognormal distribution (see Table 8): (a) the time within which the 25% of the failures (first quartile, Q1) are expected to occur, amounts to 28.0196 of operating hours, the time within which the 75% of the failures (third quartile, Q3) are expected to occur, is 115.374 of operating hours, whereas the time.

Within which, the half of the failures (inter quartile range: IQR = Q3 _ Q1) are anticipated to take place, equals to 87.36 of operating hours. (b) From the percentiles with 95% confidence interval, it is evident that the time within which, the 5% of the failures are anticipated to occur, amounts to 10.21 h. (c) From the survival probabilities with 95% confidence interval, it was found out that after an hour of operation the probability of properly functioning of the machine is 97.40%. After an operation shift (8 h), the probability of properly functioning of the machine is 96.05%, As regards to Table 9, the conclusions derived for machine TTR, based on logistic distribution, are as follows: (a) the 25% of the failures (first quartile, Q1) will be repaired within the first 1 h, the 75% of the failures (third quartile, Q3) will be repaired in 3 h, whereas half of the failures (interquartile range: IQR = Q3 _ Q1) will be repaired in 2 h, (b) from the percentiles with 95% confidence interval, one can perceive that 10% of the failures will be repaired within 0.226 h, and (c) from the survival probabilities with 95% confidence interval, the probability to repair the machine in less than an hour is 1 - 0.8738 = 0.1262. The probability to repair the machine in less than 3 h is 1 - 0.6620 = 0.338, and the probability to repair the machine in less than 6 h is 1 - 0.2274 = 0.7726.

Distribution	Unit1 failure	Unit 3 failure	Unit4 failure	Unit5 failure	Unit6 failure	Unit7 failure	Unit8 failure
TBF							
Weibull	4.429	6.008	0.571	7.192	2.060	4.436	1.380
Lognormal	1.417	0.466	6.087	0.920		13.532	0.594
Normal	6.714	21.224	30.026	14.514		15.373	9.574
Logistic	5,178	19.675	29.258	13.724	7.773	14.0079	8.118
Smallest extreme value		39.745	53.894	37.527		32.540	17.965
Log logistic	1.284	0.706	1.124	1.393		1.706	0.778
Exponential	9.980	12.824	31.879	6.908	3.591	1.010	5.975
TTR							
Distribution	Unit1 failure	Unit3 failure	Unit 4 failure	Unit5 failure	Unit6failure	Unit7 failure	Unit8failure
Weibull	2.791	11.282	136.802	83.026	36.022	59.603	43.655
Lognormal	1.510	48.134	49.763	31.568	12.594	27.796	17.739
Normal		48.339	53.252	34.057	13.658	33.414	20.697
Logistic	2.651	48.349	51.796	31.724	13.289	31.416	19.368
Smallest extreme value		89.688	121.246	66.497	34.065	52.978	35.066
Log logistic	1.530	48.541	52.896	32.215	13.157	28.522	17.562
Exponential	2.356	35.075	40.669	23.562	9.585	24.794	15.925

Table: 5 The Anderson–Darling statistics for time-between-failure (TBF), time-to-repair (TTR) for failure and machine level. The smaller the statistic value, the better the model fitting

Failure of Units	Best fit Distribution	
	TBF	TTR
Unit 1	Log logistic	Lognormal
Unit 3	Lognormal	Weibull
Unit 4	Weibull	Exponential
Unit 5	Lognormal	Exponential
Unit 6	Weibull	Exponential
Unit 7	Exponential	Exponential
Unit 8	Lognormal	Log logistic

Table: 6

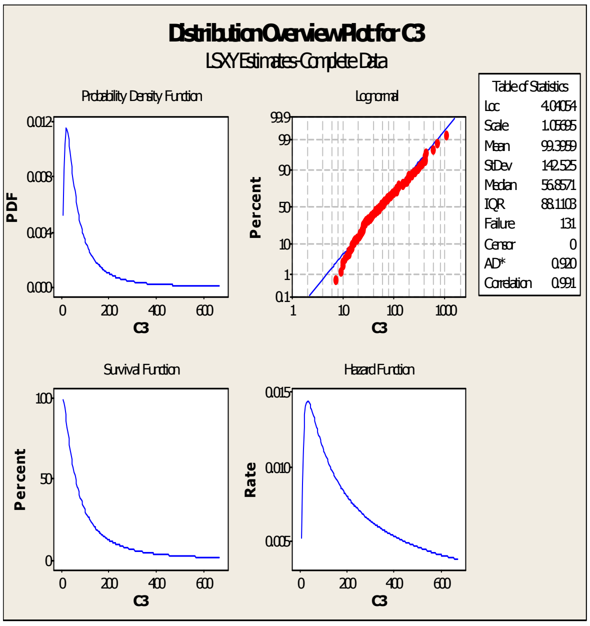

Figure: 7 Distribution overview of TBF failure Data of unit no5

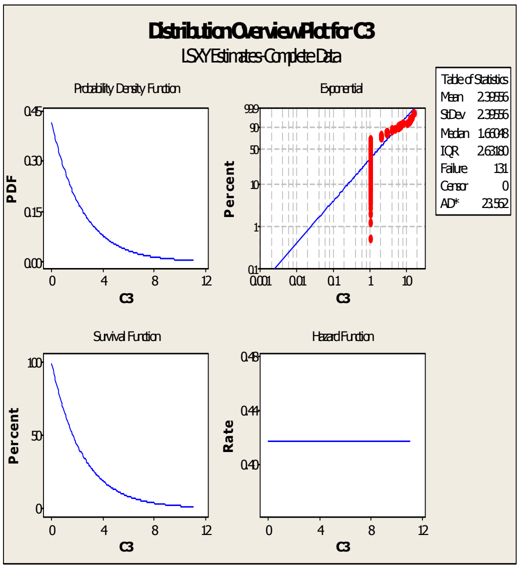

Figure: 9: Distribution overview of TTR Data of unit no5

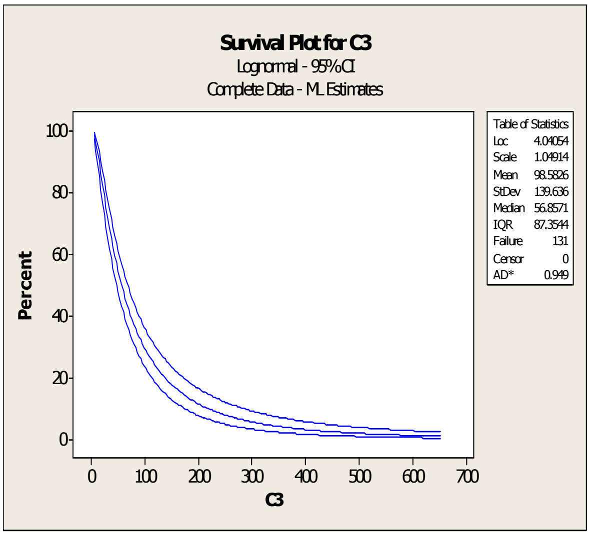

Figure 8 :Survival failure data of unit no5 failure Data

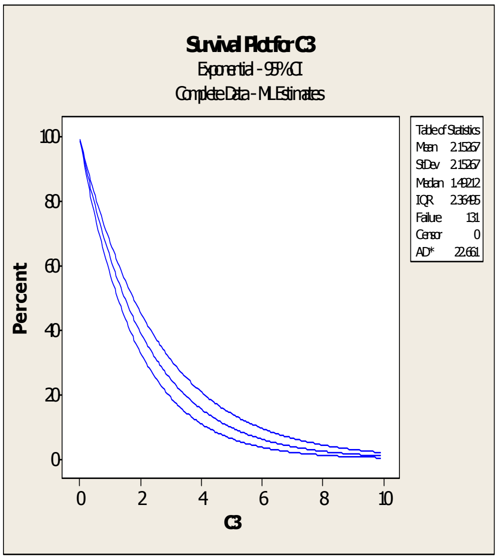

Figure 10: Survival data of unit no5 failure Data

Distribution	Hazardfunc	Probab density function	Reliability
log logistic	$\frac{\alpha t^{\alpha-1}}{[(1+(t}$	$\frac{\alpha t^{\alpha-1}\rho^{\alpha}}{[(1+(t\rho)^{\alpha}]^2}$	$\frac{1}{(1+(t\rho)^{\alpha}}$
Weibull	$\alpha\frac{t^{\alpha-1}}{\beta}$	$\alpha\frac{t^{\alpha-1}}{\beta}$ exp($-\frac{t^{\beta}}{\beta}$)	exp($-\frac{t^{\beta}}{\beta}$)
Exponential	Λ	$\lambda e^{-\lambda t}$	$e^{-\lambda t}$ exp (-λt)
Lognormal	$\frac{f(t)}{1-F(t}$	$\frac{1}{\sqrt{2\pi\sigma}}\exp[\frac{-1}{2}\frac{(logt-}{\sigma^2}$	$\frac{1}{\sqrt{2\pi\sigma}}\int_{logt}^{\infty}\exp[\frac{-1}{2}(x$
Normal	$\frac{f(t)}{1-F(t}$	$\frac{1}{\sqrt{2\pi\sigma}}\exp[\frac{-(t-}{2\sigma^2}$	$\frac{1}{\sqrt{2\pi\sigma}}\int_{t}^{\infty}\exp[\frac{-1}{2}\frac{(t-}{\sigma}$
Logistic			

Table: 7 Formula for calculating reliability, hazard rate fubction and Probability distribution functi on

Parameter Estimates

Parameter	Estimate	Standard Error	95.0% Normal CI Lower	Upper
Location	4.04054	0.0916642	3.86088	4.22020
Scale	1.04914	0.0648164	0.929497	1.18419

Distribution analysis: TBF FOR turbine compressor Estimation method: Maximum likelihood				
Characteristic of distribution 95.0 % normal CI	Estimate	Standard error	Lower	Upper
Mean(MTTF)	98.5826	11.2516	78.8223	123.297
Standard Deviation	139.636	26.9564	95.6475	203.854
Median	56.8571	5.21177	47.5073	68.0471
First Quartile(Q1)	28.0196	2.84555	22.9624	34.1906
Third Quartile(Q3)	115.374	11.7169	94.5505	140.784
Interquartile Range(IQR)	87.3544	10.1693	69.5333	109.743
Table of percentile: 95.0 % normal c i				
0.1	2.22207	0.489469	1.44298	3.42182
5	10.1234	1.42337	7.68506	13.3354
10	14.8205	1.83332	11.6296	18.8867
20	23.5131	2.50811	19.0772	28.9806
30	32.7981	3.20644	27.0790	39.7250
40	43.5864	4.05891	36.3148	52.3139
50	56.8571	5.21177	47.5073	68.0471
Table of survival prob 95.0 % normal CI	Probability	Lower	Upper	
1	0.974058	0.841139	0.989432	
4	0.968844	0.932481	0.987246	
8	0.960572	0.919408	0.982727	

Table8: Distribution analysis of time-between-failure (TBF), applying the Log normal distribution for beer filling/capping machine, with 95% confidence interval (CI).

Distribution analysis: TTR for turbine compressor of unit 5 Estimation method: Maximum likelihood Distribution: Exponential				
Characteristic of distribution 95.0 % normal CI	Estimate	Standard error	Lower	Upper
Mean TTR in hours	2.15267	0.188080	1.81388	2.55475
Standard deviation	2.15267	0.188080	1.81388	2.55475
Median	1.49212	0.130367	1.25728	1.77081
First Quartile(Q1)	0.619285	0.0541072	0.521820	0.734954
Third Quartile(Q3)	2.98424	0.260734	2.51457	3.54163
Inter quartile range(IQR)	2.36495	0.206627	1.99275	2.80667
Table of percentile: 95.0 % normal c i				
Percent	Percentile	Standard error	Lower	Upper
0.1	0.0021537	0.0001882	0.0018148	0.0025560
5	0.110418	0.0096472	0.0930398	0.131041
10	0.226807	0.0198162	0.191111	0.269169
20	0.480355	0.0419688	0.404755	0.570075
30	0.767804	0.0670834	0.646965	0.911214
40	1.09964	0.0960760	0.926575	1.30503
50	1.49212	0.130367	1.25728	1.77081
Table of survival probabilities 95.0 % normal CI				
Time	Probability	Lower	Upper	
1	0.873867	0.802603	0.921906	
3	0.662018	.0562976	0.748637	
6	0.22474	0.157438	0.316946	

Table 9 :Distribution analysis of time-to-repair (TTR), using the exponential distribution for Gas turbine Power Plant, with 95% confidence interval (CI).

8. Conclusions

The main research findings can be summarized as follows: (a) The availability of the Gas Turbine power plant is 98%, and should be optimized with an adequate operation management. The mean TBF is 73.8766 h whereas the mean TTR is about 4 h. (b) To improve the reliability of the machine efforts, attention should be firstly focused on Unit 4 (mechanical), and secondly on Unit 3. that have the major number of failures. Furthermore, they comprise the 50.3% of all the failures of the machine however for experiment we tried with unit no5 containing 16 % of the failures. (c) The failure times follow the lognormal distribution whereas the time-to-repair (TTR) a failure comply with the logistic distribution. The location parameter μ of the log normal distribution represents the mean time-to-failure of the machine. Therefore, the larger the μ the larger the mean life of the machine, meaning greater productivity. (d) The time-between-failure (TBF) greatly increased probability to fail with time, thus requiring urgently revision of the current corrective maintenance policy. Therefore, the Gas turbine power plant is in wear-out state because of the drastic increase in the failure rate. This is caused by fatigue, aging, corrosion or friction of certain components of the machine. To avoid the inconvenient impact of the failures on the production process, it is strongly recommended to upgrade the operation management i.e. preventive/proactive maintenance programs, parts replacement decisions, training programs for technicians/ operators, spare parts requirement, etc.

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