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Research Article

Reliability Assessment of Rukhia Gas Turbine Power Plant in Tripura

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Abstract

The reliability indicators of the GTPPS were analyzed based on a five and half -year failure database. Such reliability indicators like failure rate (l), repair rate (µ) and mean time to repair (z) have been estimated. The analyses showed that gas turbine unit (GT4 and GT5) has maximum failure rate (max F) of once in 100 h in 2005 with system availability (Y) of 0. 0.4950 and 0.977 and minimum failure rate (min 1.256) of once in 1000 h in 2005 with Y of 0.983. GT1 has maximum mean time to repair (max z) of 8.091 h in 2005 with Y of 0.98 and minimum mean time to repair (min z) of 1.75h in 2006 with Y of 0.99. For the period under study, GT1 has min Y of 0.98 in the year 2005 and max Y of 0.99 in 2005. The minimum availability (0.299 and 0.314) was observed in the case of unit 7 and unit 8 in the year 2010. Almost all the units showed consistent availability improvement in different years. Measures to improve the reliability (R(t)) indicators of the plant have been suggested such as training and retraining of technical personnel on the major equipment being used and just in time availability of spares.

Keywords: *Gas Turbine Power Plant (GTPP); gas turbines; reliability indicators, maintainability.*

1. Introduction

Reliability analysis techniques have been gradually accepted as standard tools for the planning, design, operation and maintenance of electric power system. The function of an electric power system is to provide electricity to its customers efficiently and with a reasonable assurance of continuity and quality (Adegboye and Ekundayo, 2010; Billinton and Allen, 1992; Kucherov *et al*., 2005). The task of achieving economic efficiency is assigned to system operators or competitive markets, depending on the type of industry structure adopted. On the other hand, the quality of the service is evaluated by the extent to which the supply of electricity is available to customers at a usable voltage and frequency. The reliability of power supply is, therefore, related to the probability of providing customers with continuous service and with a voltage and frequency within prescribed ranges around the nominal values (Wang *et al*., 2002;Wang and Billinton, 2003; Sikos and Klemeš, 2010).

A modern power system is complex, highly integrated and very large. Fortunately, the system can be divided into appropriately subsystems or functional areas that can be analyzed separately (Gupta and Tewari, 2009a, b; Kuo and Zuo, 2003; Lakhoua, 2009). These functional areas are generation, transmission and distribution. Reliability studies are carried out individually and in combinations of the three areas. This work is limited to the evaluation of the generation reliability. Generation system reliability focuses on the reliability of generators in the whole electric power system where electric power is produced from the conversion process of primary energy (fuel) to electricity before transmission. The generation system is an important aspect of electricity supply chain and it is crucial that enough electricity is generated at every moment to meet demand. Generating units will occasionally fail to operate and the system operator has to make sure that enough reserve is available to be operated when this situation arises (Barabady and Kumar, 2007; Caraza and Martha de Souza, 2009; Eti *et al*., 2007; Sukhwinder and Wadhwa, 2004). Reliability of the generation system is divided into adequacy and security (Hooshmand *et al*., 2009; Valdma *et al*., 2007). System adequacy relates to the existence of sufficient generators within the system to satisfy the customer load demand or system operational constraints. System adequacy is associated with static conditions of the system and do not include system disturbances. System security on the other hand relates to the ability of the system to respond to disturbances arising within the system. Therefore, system security is associated with response of the system to whatever perturbation it is subjected to various factors. In this study, the reliability valuations will be focused on the generation system adequacy and will not take into consideration system security. In a generation system study, the total system generation is examined to

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determine its adequacy to meet the total system load requirement. This

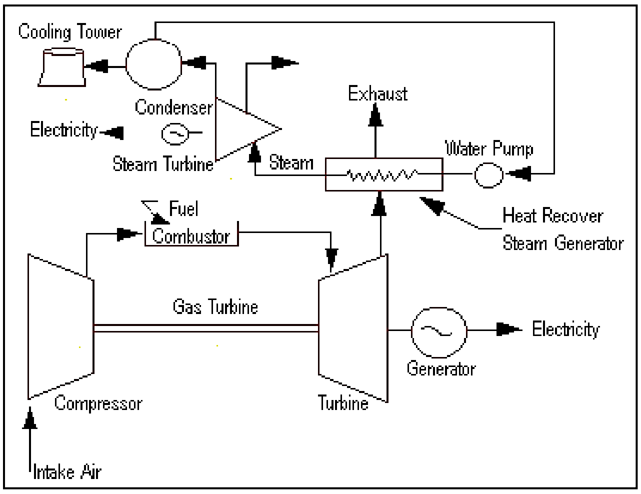


Fig.1 Block diagram of a Gas Turbine Power Plant.

activity is usually termed " generating system adequacy assessment". The transmission system is ignored in generating system adequacy assessment and is treated as a load point (Valdma *et al*., 2007). The main reason of the generating system adequacy assessment is to estimate the generating capacity required to meet the system demand and to have excess capacity to cater for planned and forced outages events.

A failure in a generating unit results in the unit being removed from service in order to be repaired or replaced, this event is known as outage. Such outages can compromise the ability of the system to supply the required load and affect system reliability. An outage may or may not cause an interruption of service depending on the margins of generation provided. Outages also occur when the unit undergoes maintenance or other scheduled work necessary to keep it operating in good condition. A forced outage is an outage that results from emergency conditions, requiring that component be taken out of service immediately. A scheduled or planned outage is an outage that results when a component is deliberately taken out of service, usually for purpose of preventive maintenence or repair.

During the last decade, Tripura has been trying to restructuring her power sector, abondoning the former regulated monopolistic model which ruled the provision of electric energy during most part of this century **(**Obodeh and Isaac, 2011). The new "deregulated" structures are based on free market principles, favouring competition among central government participants and new entrants into the power market such as independent(joint collaboration) power producers (IJPPs) and national integrated power projects (NIPPs) and consumer choice.(Basically Tripura Government runs on socialistic philosophy where deregularization was limited to central sectors, joint sectors and Private participators are very few entrants in power generation.) In this new environment, each generating company should provide its reliability and associated price to ensure customer satisfaction and personal preference. One such organisation that generate power for its use and the state is Gas Turbine Power Plant company of Rukhia (GTPPSR). It is one of the subsidiaries of Tripura state electricity power corporation (TSEPCL). Like many organisational setups involved in production, the scheduled working time contribute to the productive capacity of the company. It is important therefore to ensure that equipment usage is maximised to save time and money. Again, production managers are demanding strict guaranteed performance to meet production targets. Continuous power supply is necessary for the achievement of these targets. In Tripura, power supply to many consumers has over the years been done by the Tripura state electricity power corporation (TSEPCL). but this supply has always been unreliable, with its many power outages. Due to the unreliability of power supply from BTPPS (Barmura thermal Power plant station, another subsidiary unit of TSEPCL), TSEPCL management established another thermal power station in the year 1992. The station consists of: gas turbine with total capacity of 82 MW(actual generation capacity =74 M.W.,one unit of 8 M.W. is kept as standby).It has 7 generating units (Unit no -1(8 M.W.) , Unit no -3 (8 M.W.), Unit no -4(8 M.W.), Unit no -5(8 M.W.), Unit no -6(8 M.W.), Unit no -7(21 M.W.), Unit no -8 (21 M.W.) a combined cycle unit of one 20 M.W, unit for utilization of the exhaust gases are in the pipeline for major expansion. The different units are represented as GT1,GT3, GT4,GT5 .GT6, GT7, GT8 The study herein covers GT1 GT1,GT3, GT4,GT5.GT6, GT7 and GT8 units.The theoretical basis of deregulation in the electricity industry are not completely developed yet and the practical experience with electricity markets is still limited (Kucherov *et al*., 2005; Prisyazhniuk, 2008; Wang and Billinton, 2003) and it is fully depended on Government initiatives in Tripura.. In effect, the restructuring processes have brought about new problems and many open questions, especially regarding the introduction of competitive or market-based mechanisms and their effect on the reliability of power supply. However, it is becoming increasingly necessary to guarantee plant reliability and economic efficiency in order to improve plant utilization (Kucherov *et al*., 2005).

The increasing electricity demand, the increasingly competitive environment and the recent deregulation of Tripura's electricity supply sector will result in increased competition among the IJPPs. To survive, suppliers must reduce maintenance costs, prioritize maintenance actions and raise reliability. The aim of this study is to find ways to increase equipment reliability and extend the equipment's life through cost-effective maintenance using GTPPSR as a case study.

2. Materials and methods

The records of failure frequency of installations, containing the description and analysis of the failure and other materials filed by the operation monitoring services constitute the basic source of information on the failure frequency and range of repairs of generating devices of the power units. The reliability was calculated considering a five and half year operational database. In processing the data, mean time between failures (m), mean time to repair (availability () and reliability (*Rt* were obtained. Mean time between failures (m) is a measure of how long, on average, an equipment will perform as specified before an unplanned failure will occur.

$$m = 1/\lambda \qquad \text{------ (1)}$$

Where λ = Expected no of failure

$$\lambda = \Phi_n/\beta_t \qquad \text{------ (2)}$$

Where Φ_n = no of failure between maintenance , β_t = total operating time between maintenance, Mean time to repair (ζ) is a measure of how long on average it will take to bring the equipment back to normal serviceability when it does fail.

$$\zeta = \psi_i / \Phi_n \qquad \text{------ (3)}$$

When ψ_i = total outage hours per year., Φ_n= number of failures per year and $\zeta = 1/\mu$ ------ (4)

Where μ = expected repair rate.

Availability (ψ) is a measure of the percentage of time that an equipment is capable of producing its end product at some specified acceptable level. In the case of a turbine in a power plant, availability is a measure of the fraction of time that it is generating the nominal power output.

$$\Psi = \frac{\mu}{\mu+\lambda} \qquad \text{--------(5)}$$

$$\text{or} \quad \psi = \frac{1}{(1+\lambda\zeta)} \qquad \text{--------(6)}$$

Using equations (1) and (4) in equation (6), we have: $\psi =$

$$\frac{m}{(m+\zeta)} \qquad \text{------- (7)}$$

Reliability ($R(t)$) is regarded as the ability of an equipment to perform its required function satisfactory under stated conditions during a given period of time (Ireson *et al*., 1996; Smith and Hinchcliffe, 2004). In order words, reliability is a probability that the equipment is operating without failure in the time period *t*.

$$R(t) = e^{-t/m} \qquad \text{--------(8)}$$

Using equation (1) in equation (8) yields

$$R(t) = e^{-\lambda t} \qquad \text{--------(9)}$$

Where, *t* = specified period of failure-free operation.

3. Evaluation of MTTF and MTBF

Table 1 Failures over the years

Failures in years	2005	2006	2007	2008	2009	2010	Summary of Running hours
Unit 1	11	4					Total breakdown =15, Hours =96 ,Running hours=1 year=365 days=8760 hours
Unit 3	0	26	36	37	65	13	Total no of failures are 176 Break down=305 hours, Running hours:-4 years 3 month=1550 days =37200 hours
Unit 4	91	51	22	28	55	8	Total no. of Breakdown= 255 , Running hours:- five and half years= 2007.5 days=13152 hours, Total repair hours =467 hours
Unit 5	91	42	nil				Total Breakdown numbers are 131, Running hours:- 17520 hours. Break down hours:-269 hours
Unit 6	67						Total failures:-67, Hours:-133,Total Running Hours:- 6 months, 180 days=4320 hours
Unit 7	61	0	19	14	41	8	Total breakdown=141,Breakdown hours=282 hours, Total Running hours=47544
Unit 8	0	16	16	13	21	6	Total Breakdown=76,Breakdown hours=173 hours, Total hours 37920 hours

Since Datas are not recorded according to our choices So it is taken as one year running time between maintenance = 365 days = 8760 hours. Here one error is that Units are assumed of running over the years. In the year 2010 we have taken 7 months as running months instead of 12 months. =210 days=5040 hours.

Table 2 Calculation of Failure rate over the years

Failures in years	2005	$\lambda 5$	2006	$\lambda 6$	2007	$\lambda 7$	2008	$\lambda 8$	2009	$\lambda 9$	2010	$\lambda 10$
Unit 1	11	1.256×10^{-3}	4	4.5662×10^{-4}		nil		nil		nil		nil
Unit 3	0	nil	26	2.968×10^{-3}	36	4.11×10^{-3}	37	4.224×10^{-3}	65	7.42×10^{-3}	13	2.5794×10^{-3}
Unit 4	91	**0.0104**	51	5.822×10^{-3}	22	2.5114×10^{-3}	28	3.196×10^{-3}	55	6.278×10^{-3}	8	1.587×10^{-3}
Unit 5	91	0.0104	42	4.794×10^{-3}	nil	nil	nil	nil	nil	nil	nil	Nil
Unit 6	67	0.00765		nil	nil	nil	nil	nil	nil	nil	nil	Nil
Unit 7	61	0.00696	0	nil	19	2.1689×10^{-3}	14	1.5982×10^{-3}	41	4.680×10^{-3}	8	1.587×10^{-3}
Unit 8	0	nil	16	1.826×10^{-3}	16	1.826×10^{-3}	13	1.484×10^{-3}	21	2.397×10^{-3}	6	**1.1905×10^{-3}**

As the product matures, the weaker units fail, the failure rate becomes nearly constant, and devices have entered what is considered the normal life period. This period is characterized by a relatively constant failure rate. The length of this period is also referred to as the "system life" of a product or component. It is during this period of time that the lowest failure rate occurs. The useful life period is the most common time frame for making reliability prediction.

$\lambda = \Phi_n/\beta_t$, where Φ_n = no of failure between maintenance β_t = total operating time between maintenance. Total Running Hours of unit: - 6 months, 180 days = 4320 hours.

$\zeta = \psi_i / \Phi_n$------- (3) , when ψ_i = total outage hours per year. Φ_n = number of failures per year and $\zeta = 1/\mu$ = mean time to repair (ζ)mean time between failures (m).

Table 3A Number of Failures and corresponding outage over the years

Failures in year	2005 failures and Outage hours		2006 failures and Outage hours		2007 failures and Outage hours	
Units no	Failure s nos	Outage hours	Failures nos	Outage hours	Failures nos	Outage hours
Unit 1	11	89	4	7	nil	nil
Unit 3	0	0	26	56	36	46
Unit 4	91	173	51	76	22	28
Unit 5	91	208	42	61	nil	nil
Unit 6	67	134	nil	nil	nil	-
Unit 7	61	122	0	nil	19	28
Unit 8	0		16	26	16	29

Table 3B Number of Failures and corresponding outage over the years

Failures in year	2008 failures and Outage hours		2009 failures and Outage hours		2010 failures and Outage hours	
Units no	Failures nos	Outage hours	Failures nos	Outage hours	Failure nos	Outage hours
Unit 1	nil	nil	nil	nil	nil	nil
Unit 3	37	52	65	113	13	38
Unit 4	28	60	55	107	8	23
Unit 5	nil		nil		nil	nil
Unit 6	nil		nil		nil	nil
Unit 7	14	34	41	81	8	17
Unit 8	13	29	21	77	6	11

Table 4 Repair hours over the years

Repair hours in years	2005	2006	2007	2008	2009	2010
Unit 1	89	7	-	-	-	-
Unit 3	0	56	46	52	113	38
Unit 4	173	76	28	60	107	23
Unit 5	208	61	nil	nil	nil	nil
Unit 6	133	nil	nil	nil	nil	nil
Unit 7	122	Nil	28	34	81	17
Unit 8	nil	26	29	29	77	11

Mean time between failures (MTBF) is the predicted elapsed time between inherent failures of a system during operation. MTBF can be calculated as the arithmetic mean (average) time between failures of a system. The MTBF is typically part of a model that assumes the failed system is immediately repaired (MTTR), as a part of a renewal process(9).

Table 5A Calculation of Mean time between failure (m) over the years

M in year	2005 **m5** $m = 1/\lambda$		2006 **m6**		2007 **m7**	
Units no	λ5	**m5**	λ6	**m6**	λ7	**m7**
Unit 1	1.256×10^{-3}	796.2	4.5662×10^{-4}	219	nil	nil
Unit 3	nil	nil	2.968×10^{-3}	336.9	4.11×10^{-3}	243.31
Unit 4	0.0104	76.56	5.822×10^{-3}	171.76	2.5114×10^{-3}	398.3
Unit 5	0.0104	76.56	4.794×10^{-3}	208.6	nil	nil
Unit 6	0.00765	130.7	nil	Nil	nil	nil
Unit 7	0.00696	143.7	nil	nil	2.1689×10^{-3}	461
Unit 8	nil		1.826×10^{-3}	547.6	1.826×10^{-3}	547.7

Table 5B Calculation of Mean time between failure (m) over the years

M in year	2008 **m 8**		2009 **m9**		2010 **m10**	
Units no	λ8	**m8**	λ9	**m9**	λ10	**m10**
Unit 1	nil	nil	nil	nil	nil	nil
Unit 3	4.224×10^{-3}	236.74	7.42×10^{-3}	134.77	2.5794×10^{-3}	387.7
Unit 4	3.196×10^{-3}	312.9	6.278×10^{-3}	159.3	1.587×10^{-3}	630.2
Unit 5	nil	nil	nil	nil	Nil	nil
Unit 6	nil	nil	nil	nil	Nil	nil
Unit 7	1.5982×10^{-3}	625.7	4.680×10^{-3}	213.7	1.587×10^{-3}	630.2
Unit 8	1.484×10^{-3}	673.85	2.397×10^{-3}	417.2	1.1905×10^{-3}	839.98

This is in contrast to the MTTF, which measures average time to failures with the modeling assumption that the failed system is not repaired (infinite repair rate). There are many variations of MTBF, such as mean time between system aborts (MTBSA) or mean time between critical failures (MTBCF) or mean time between unit replacement (MTBUR). Such nomenclature is used when it is desirable to differentiate among types of failures, such as critical and non-critical failures. In the opening sentence, MTBF is the mean (average) time between failures of a system, the reciprocal of the failure rate, while in the formal definition of MTBF is the sum of the MTTF and MTTR). The MTTF is simply the reciprocal of the failure rate. Table 5A and 5B shows the MTBFs of the GTPP for the period 2005 to 2010 for 8 units

Table 6A Calculation of Mean time to repair over the years

Failures in year	2005 $\zeta 5$ $\zeta = \psi_i / \Phi_n$			2006 $\zeta 6$			2007 $\zeta 7$		
Units no	Φ_n	ψ_i	$\zeta 5$	Φ_n	ψ_i	$\zeta 6$	Φ_n	ψ_i	$\zeta 7$
Unit1	11	89	8.091	4	7	1.75	nil	nil	nil
Unit3	0	0	0	26	56	2.153	36	46	1.277
Unit4	91	173	1.90	51	76	1.490	22	28	1.272
Unit5	91	208	2.286	42	61	1.452	nil	nil	nil
Unit6	67	134	2	nil	nil	nil	nil	nil	nil
Unit7	61	122	2	0	nil	nil	19	28	1.473
Unit8	0			16	26	1.625	16	29	1.812

Table 6B Calculation of Mean time to repair over the years

Failures in year	2008 $\zeta 8$			2009 $\zeta 9$			2010 $\zeta 10$		
Units no	Φ_n	ψ_i	$\zeta 8$	Φ_n	ψ_i	$\zeta 9$	Φ_n	ψ_i	$\zeta 10$
Unit1	nil	nil	nil	nil	nil	nil	nil	nil	nil
Unit3	37	52	1.405	65	113	1.74	13	38	2.92
Unit4	28	60	2.143	55	107	1.945	8	23	2.875
Unit5	nil		nil	nil	nil	nil	nil	nil	nil
Unit6	nil		nil	nil	nil	nil	nil	nil	nil
Unit7	14	34	2.43	41	81	1.976	8	17	2.125
Unit8	13	29	2.230	21	77	3.66	6	11	1.833

Table 6A and 6B shows the calculation of the mean time to repair of the system over the years from 2005 t0 2010 for all the 8 units.

4. Estimation of availability and repair rate

Availability (ψ) $\Psi = \frac{\mu}{\mu+\lambda}$ -----------(10)

Table 7A Calculation of expected repair rate over the years

Repair rate in years	2005 $\mu 5$ $\zeta = 1/\mu$, $\mu = 1/\zeta$		2006 $\mu 6$		2007 $\mu 7$	
Units	$\zeta 5$	$\mu 5$	$\zeta 6$	$\mu 6$	$\zeta 7$	$\mu 7$
Unit 1	8.091	0.1236	1.75	0.57143	nil	nil
Unit 3	0	0	2.153	0.465	1.277	0.7831
Unit 4	1.90	0.5263	1.490	0.671	1.272	0.7862
Unit 5	2.286	0.437	1.452	0.704	nil	nil
Unit 6	2	0.5	nil	nil	nil	nil
Unit 7	2	0.5	nil	nil	1.473	0.6788
Unit 8	0	0	1.625	0.6154	1.812	0.5518

Table 7B Calculation of expected repair rate over the years

Repair rate in years	2008 μ 8		2009 μ 9		2010 μ 10	
Units	$\zeta 8$	$\mu 8$	$\zeta 9$	$\mu 9$	$\zeta 10$	$\mu 10$
Unit 1	nil	nil	nil	nil	nil	nil
Unit 3	1.405	0.712	1.74	0.5747	2.92	0.3425
Unit 4	2.143	0.4666	1.945	0.51414	2.875	0.3478
Unit 5	nil	nil	nil	nil	nil	nil
Unit 6	nil	nil	nil	nil	nil	nil
Unit 7	2.43	0.4115	1.976	0.5061	2.125	0.3478
Unit 8	2.230	0.448	3.66	0.2732	1.833	0.54554

or $\psi = \frac{1}{(1+\lambda\zeta)}$ ---------- (11)

m = 1/λ ---------- (12)

Table 8A Calculation of Availability over the years

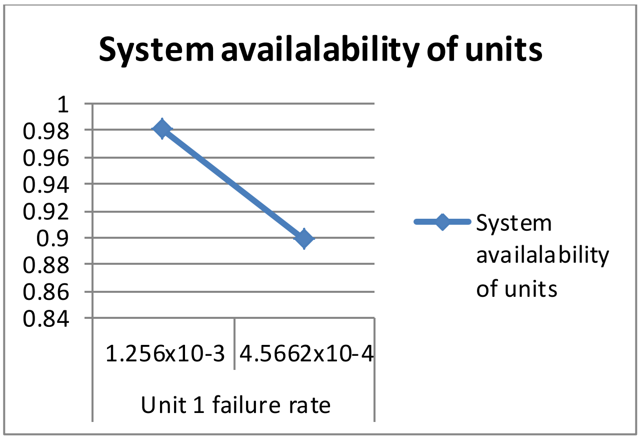
Availability in years	2005 Ψ 5 ψ = 1/(1+λζ)			2006 Ψ 6		
Units no	λ5	ζ5	Ψ 5	λ6	ζ6	Ψ 6
Unit 1	$1.256\text{x}10^{-3}$	8.091	0.88	$4.5662\text{x}10^{-4}$	1.75	0.999
Unit 3	nil	0	0	$2.968\ \text{x}10^{-3}$	2.153	0.993
Unit 4	0.0104	101	0.495 0	$5.822\ \text{x}10^{-3}$	1.490	0.999
Unit 5	0.0104	2.286	0.977	$4.794\ \text{x}10^{-3}$	1.452	0.993
Unit 6	0.00765	2	0.985	nil	nil	nil
Unit 7	0.00696	2	0.985	nil	nil	nil
Unit 8	nil	0	0	$1.826\text{x}10^{-3}$	1.625	0.997

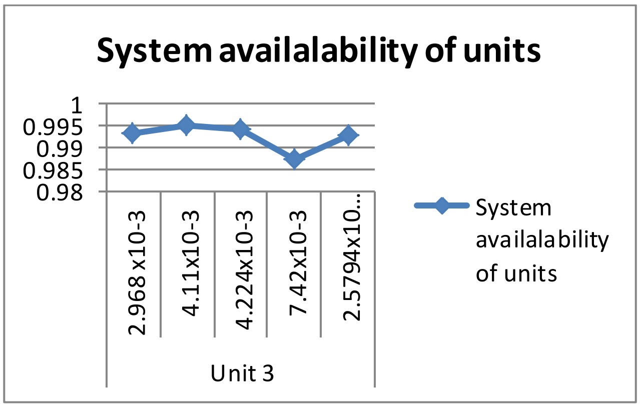
Table 8B Calculation of Availability over the years

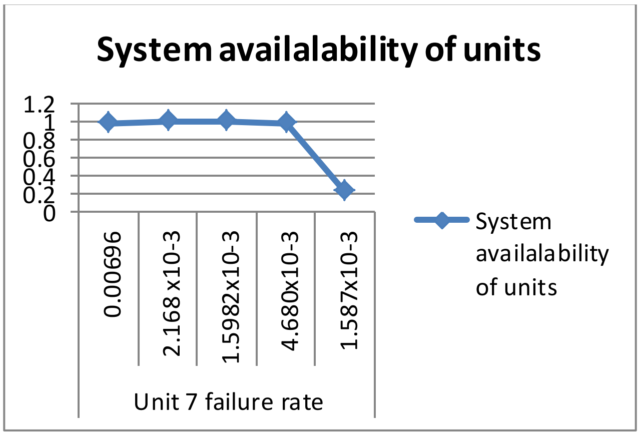
Availability in years	2007 Ψ 7			2008 Ψ 8		
Units no	λ7	ζ7	Ψ 7	λ8	ζ8	Ψ 8
Unit 1	nil	nil	nil	nil	nil	nil
Unit 3	$4.11\text{x}10^{-3}$	1.277	0.9948	$4.224\text{x}10^{-3}$	1.405	0.994
Unit 4	$2.5114\text{x}10^{-3}$	1.272	0.99	$3.196\ \text{x}10^{-3}$	2.143	0.9930
Unit 5	nil	nil	nil	nil	nil	nil
Unit 6	nil	nil	nil	nil	nil	nil
Unit 7	$2.168\ \text{x}10^{-3}$	1.473	0.9968	$1.5982\text{x}10^{-3}$	2.43	0.9960
Unit 8	$1.826\text{x}10^{-3}$	1.812	0.9970	$1.484\text{x}10^{-3}$	2.230	0.996

Table 8C Calculation of Availability over the years

Availability in years	2009 Ψ 9			2010 Ψ 10		
Units numbers	λ9	ζ9	Ψ 9	λ10	ζ10	Ψ 10
Unit 1	nil	nil	nil	nil	nil	nil
Unit 3	$7.42\text{x}10^{-3}$	1.74	0.987	$2.5794\text{x}10^{-3}$	2.92	0.9025
Unit 4	$16.278\ \text{x}10^{-3}$	1.945	0.96	$1.587\text{x}10^{-3}$	2.875	0.996
Unit 5	nil	nil	nil	Nil	nil	nil
Unit 6	nil	nil	nil	Nil	nil	nil
Unit 7	$4.680\text{x}10^{-3}$	1.976	0.99	$1.587\text{x}10^{-3}$	2.125	0.229
Unit 8	$2.397\text{x}10^{-3}$	3.66	0.99	$1.1905\text{x}10^{-3}$	1.833	0.3144







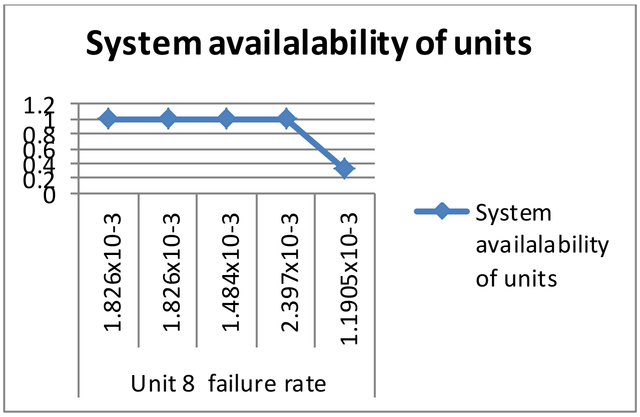
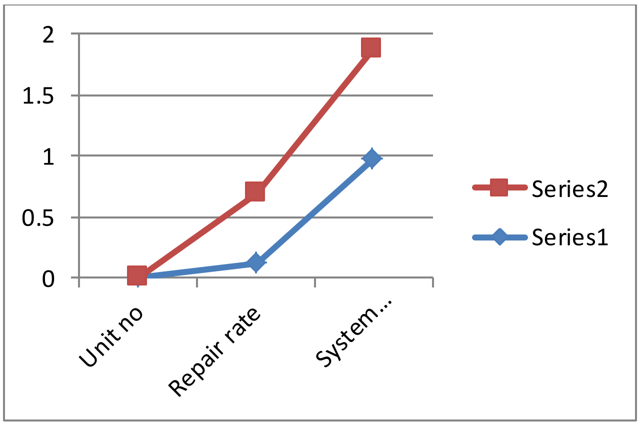
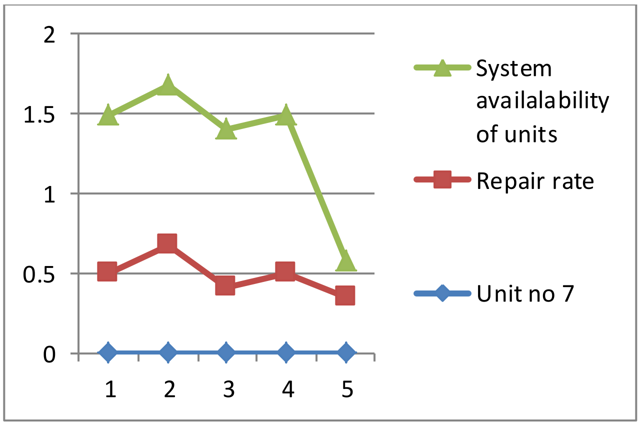
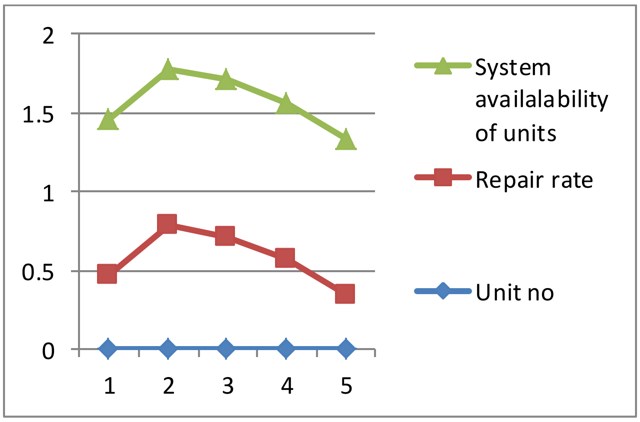
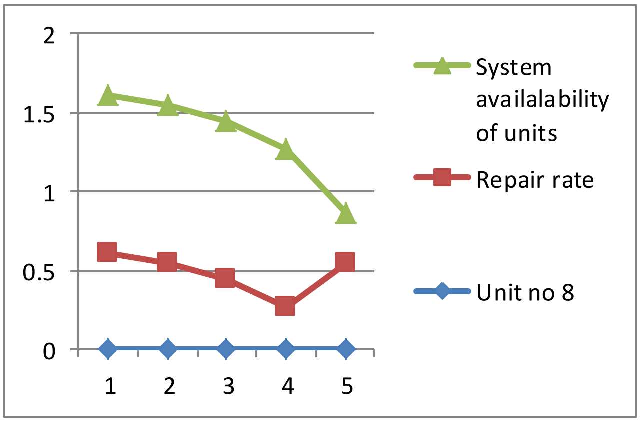


Figure 2 Effect of failure rate on the system availability









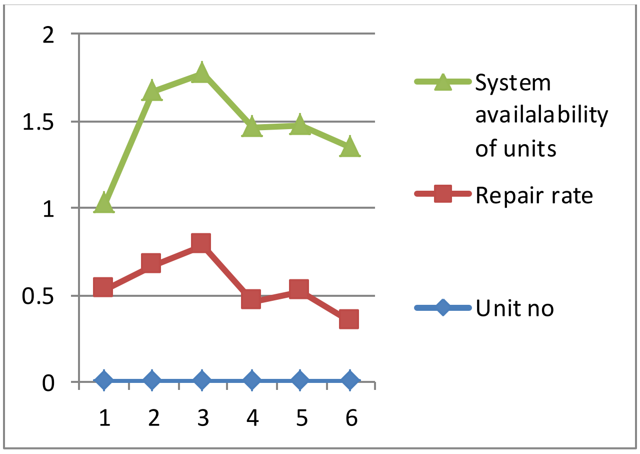
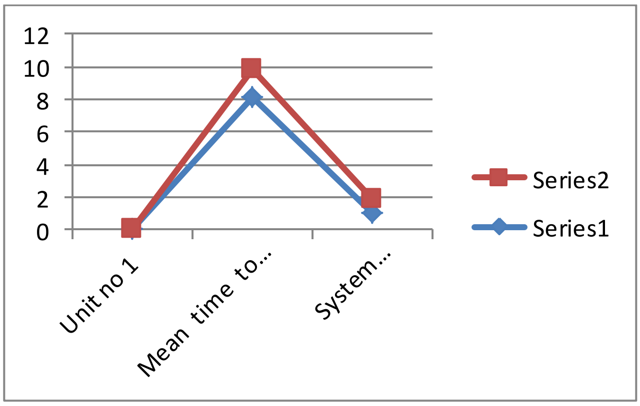
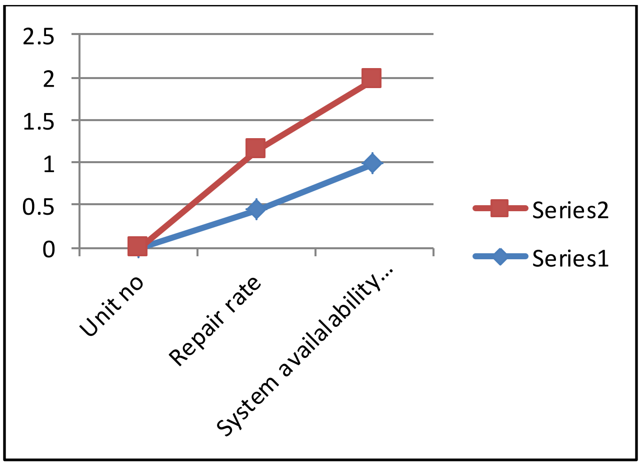
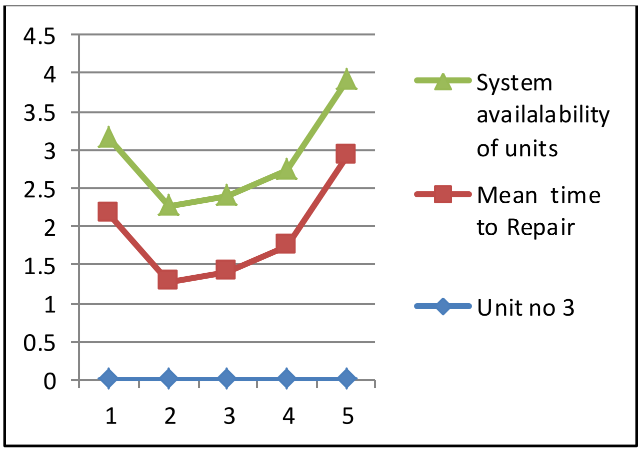


Fig. 3 Effect of repair rate on system availability







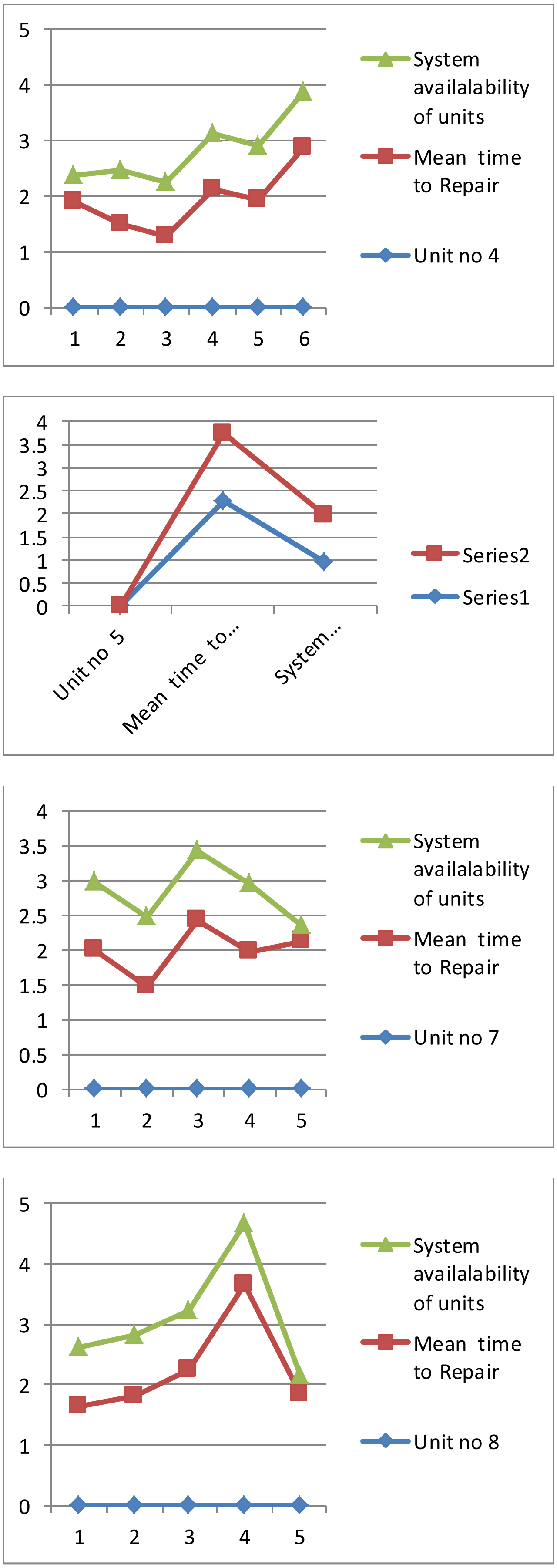


Fig. 4 Effect of mean time to repair on system availability

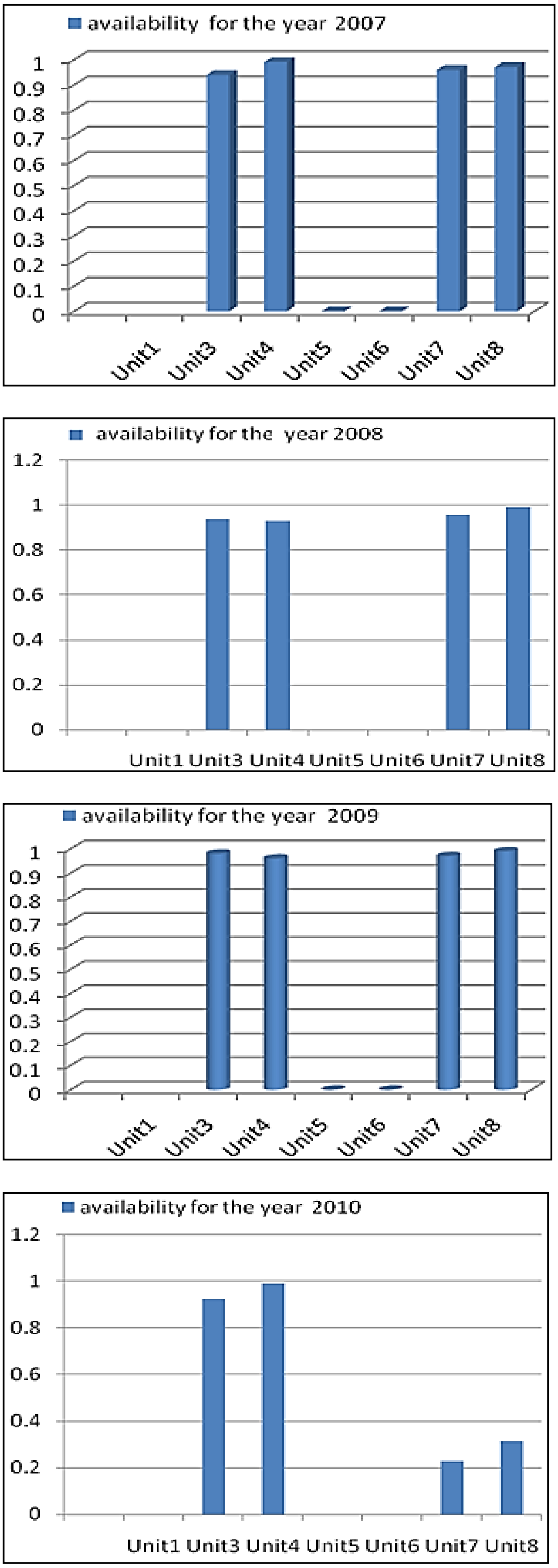


Fig.5 Variation of system availability with year

5. Evaluation of reliability

Reliability is defined as the probability that a device will perform its intended function during a specified period of time under stated conditions. Reliability may be improved by clarity of expression, lengthening the measure, and other informal means. However, formal psychometric analysis, called item analysis, is considered the most effective way to increase reliability.

Table 9A Calculation of Reliability over the years

Failures in year	2005 failures free operations and Reliability		2006 failures free operations and Reliability		2007 failures free operations and Reliability	
Units no	Failures free in hrs	Reliability	Failures free	Reliability	Failures free	Reliability
Unit 1	552	0.4992	96	0.645	nil	nil
Unit 3	nil	nil	93x24=2232	0.00133	109x24=2616	0.00022
Unit 4	24x24=576	0.025	21x24=504	0.053	182x24=4368	0.0017
Unit 5	43days=1032 hours	0.0022	72 hours	0.7080	nil	nil
Unit 6	552 hours	0.015	nil	nil	nil	nil
Unit 7	44x24=1056	o.0064	365x24=8760	1.0	87x24=2088	0.011
Unit 8	nil	nil	93x24=2232	0.0177	143x24=3432	0.0191

This analysis consists of computation of item difficulties and item discrimination indices, the latter index involving computation of correlations between the items and sum of the item scores of the entire test.

Table 9B Calculation of Reliability over the years

Failures in year	2008 failures free operations and Reliability		2009 failures free operations and Reliability		2010 failures free operations and Reliability	
Units no	Failures free	Reliability	Failures free	Reliability	Failures free	Reliability
Unit 1	nil	nil	nil	nil	nil	nil
Unit 3	57x24=1368	0.0032	48 hrs	0.69	29x24=696	0.78
Unit 4	125x24=3000	0.00685	25x24=600	0.0232	25x24=600	0.386
Unit 5	nil	nil	nil	nil	nil	nil
Unit 6	nil	nil	nil	nil	nil	nil
Unit 7	84x24=2016	0.04	144 hrs	0.509	97x24hrs =2328	0.024
Unit 8	150x24=3600	0.0478	133x24 =3192	0.0476	58x24=1392	0.466

Table 10 Reliability indicator of unit 1

Year / Parameter	2005	2006	2007	2008	2009	2010
	GT 1	GT 1	GT 1	GT 1	GT 1	GT 1
Nos of failures	11	4				
Downtime hours	89	7	nil	nil	nil	nil
ζ (h)	8.091	1.75	nil	nil	nil	nil
M(h)	796.2	219	nil	nil	nil	nil
ψ	0.98	0.9992	nil	nil	nil	nil
R(t)	0.4992	0.645	nil	nil	nil	nil

If items that are too difficult, too easy, and/or have near-zero or negative discrimination are replaced with better items, the reliability of the measure will increase. $R(t) = 1 - F(t)$ and $R(t) = \exp(-\lambda t)$. (where λ is the failure rate).

$$R(t) = e^{\lambda t} = e^{-t/m} \qquad \text{----------(13)}$$

Where, t = specified period of failure-free operation. In unit no 1 in the year 2005 the first 552 hours have run without failures and in the year 2006 the first 96 hours had run without failures. So we have taken this hour free operation as reliability calculation.

23.01.05	15.00 hrs
03.01.06	14.53 hrs

So reliability for the year 2005 is as $R_{2005} = e^{-1.256x10-3x552} = 0.4992$. Similarly $R_{2006} = e^{-4.5662x10-4x96} = 0.645$.

Table 11 Reliability indicator unit 3

Year / Parameter	2005	2006	2007	2008	2009	2010
	GT 3	GT 3	GT 3	GT 3	GT 3	GT 3
No of failures	0	26	36	37	65	13
Downtime hours	0	56	46	52	113	38
ζ (h)	nil	2.153	1.277	1.405	1.74	2.92
M(h)	nil	336.9	243.31	236.74	134.77	387.7
ψ	nil	0.993	0.9948	0.994	0.987	0.99255
R(t)	nil	0.00133	0.00022	0.0032	0.69	0.78

Table 12 Reliability indicator unit 4

Year Parameter	2005	2006	2007	2008	2009	2010
	GT 4	GT 4	GT 4	GT 4	GT 4	GT 4
No of failures	91	51	22	28	55	8
Downtime hours	173	76	28	60	107	23
ζ (h)	1.90	1.490	1.272	2.143	1.945	2.875
M(h)	76.56	171.76	398.3	312.9	159.3	630.2
ψ	0.4950	0.999	0.995	0.992	0.96	0.996
R(t)	0.025	0.053	0.0017	0.00685	0.0232	0.386

Table 13 Reliability indicator unit 5

Year Parameter	2005	2006	2007	2008	2009	2010
	GT 5	GT 5	GT 5	GT 5	GT 5	GT 5
No of failures	91	42	-	-	-	-
Downtime hours	208	61	nil	nil	nil	nil
ζ (h)	2.286	1.452	nil	nil	nil	nil
M(h)	76.56	208.6	nil	nil	nil	nil
ψ	0.977	0.993	nil	nil	nil	nil
R(t)	0.0022	0.7080	nil	nil	nil	nil

Table 14 Reliability indicator unit 6

Year Parameter	2005	2006	2007	2008	2009	2010
	GT 6	GT 6	GT 6	GT 6	GT 6	GT 6
No of failures	67					
Downtime hours	134	nil	nil	nil	nil	nil
ζ (h)	2	nil	nil	nil	nil	nil
M(h)	130.7	nil	Nil	nil	nil	nil
ψ	0.985	nil	nil	nil	nil	nil
R(t)	0.015	nil	nil	nil	nil	nil

Table 10 to 16 shows the reliability indicator of each unit for the years 2005 to 2010.

Table 15 Reliability indicator unit 7

Year Parameter	2005	2006	2007	2008	2009	2010
	GT 7	GT 7	GT 7	GT 7	GT 7	GT 7
No of failures	61	0	19	14	41	8
Downtime hours	122	nil	28	34	81	17
ζ (h)	2	nil	1.473	2.43	1.976	2.125
M(h)	143.7	nil	461	625.7	213.7	630.2
ψ	0.985	nil	0.9968	0.9960	0.97	0.229
R(t)	o.0064	1.0	0.011	0.04	0.509	0.024

Table 16 Reliability indicator unit 8

Year Parameter	2005	2006	2007	2008	2009	2010
	GT8	GT8	GT8	GT8	GT8	GT8
No of failures	0	16	16	13	21	6
Downtime hours	nil	26	29	29	77	11
ζ (h)	nil	1.625	1.812	2.230	3.66	1.833
M(h)	nil	547.6	547.7	673.85	417.2	839.98
ψ	nil	0.997	0.997	0.996	0.99	0.3144
R(t)	nil	0.0177	0.0191	0.0478	0.0476	0.466

6. Results and discussions

Table 10 -16 presents reliability indices for the gas turbine thermal generation units from 2005to 2010. Most of the failures were related to high temperature in combustors or excessive vibration on the bearings. In the years 2005 and 2010, GT1 experienced more failures due to high temperature in the exhaust collector caused by combustor failure. In the year 2006, GT3 experienced twenty six failures. Most of these failures were related to calibration problems of pressure gauges located at the exhaust collector and the other three were related to fuel filters premature cleaning due to premature clogging caused by poor natural gas quality. In the year 2005, the main problems with GT4 were related to the lubrication oil system, mainly the oil feeding pressure. These failures can be reduced if the maintenance procedure tasks involve periodical inspection and replacement of parts, that were subjected to very high temperature and located in the hot gas paths (combustion chamber and turbine). However, sensors were installed in the oil pump to allow the use of a monitoring system. to check oil pump vibration and oil temperature and flow. But a bi-monthly oil analysis should be implemented in order to check for the presence of metallic particles in the fluid that could be an indication of possible bearings parts wear. The failure rate is a reasonable measure for durability of generating devices and indication for economical effectiveness of repairs. Effect of failure rate on the system availability is revealed in Figure 1. Failure rate of GT1 peaked at $1.256\text{x}10^{-3}$ (once in 1000 h) in 2005 with system availability (Y) of 0. 98 and its lowest value of 4.566 (four in 1000 h) was attained in 2005 with Y of 0.899 . While for GT3, maximum value of $7.42\text{x}10^{-3}$ was obtained in 2007 with Y of 0.987 and minimum value of $2.5794\text{x}10^{-3}$ in 2010 with Y of 0.992. The forth going observations show that increase in failure rate results in decrease in Y . However, effective maintenance management is essential in reducing the adverse effect of equipment failure.

This can be accomplished by accurately predicting the equipment failure such that appropriate actions can be planned and taken in order to minimize the impact of equipment failure to operation. Also continuous use of operating unit exhibiting partial failure should be discouraged so as to avoid degradation or catastrophic failure. The effect of repair rate (μ) on Y is depicted in Figure 2. It showed that GT1 has a maximum repair rate (max μ) of (0.57143) in 2006 with Y of 0.999 and minimum repair rate (min μ) of *0.1236* in 2005 with Y of 0.88. In the other hand, GT 3 has max μ of 0.7831 in 2007 with Y of 0.9948 and min μ of 0.3425 in 2010with Y of 0.9052. The aforementioned analysis show that Y increases with increase in μ . Figure 3 represents variation of mean time to repair (z)with year. GT1 has maximum mean time to repair (max z) of 8.091 h in 2006 with Y of 0.98 and minimum mean time to repair (min z) of 1.75 h in 2005 with Y of 0.9992. Similarly, GT2 has max z of 2.92 h in 2010 with Y of 0.925 and min z of 1.277 h in 2007 with Y of 0.9948.. From the forth going, it can be deduce that Y decreases with increase in z . The operational consequences of failure can be reduced by taking steps to shorten the downtime, most often by reducing the time to get hold of spare parts. The Y over the period of study is shown in Figure 4. GT4 has min Y in the year 2005.and unit 7 has minimum availability in the year 2010 of 0.0.229 in the year 2010 and max Y of 0.9968 in 2007 while GT3 has min Y of 0.9255 2010 and max Y of 0.9948 in 2007. From the analyses thus far, it is glaring that the measure of reliability $R(t)$ by extension Y of the power plant is determined by indices such as failure rate, μ and z . The Y values of some units for the gas turbine station are lower than the IEEE recommended standard of ASAI which is 0.999 (Bertling and Eriksson, 2005). Availability can be improved significantly by reviewing maintenance practices. Planned maintenance is still essential but more and more, predictive maintenance is becoming the driver for planned outages. It has been reported that plant with availability of 50 to 60% gave 85% and above after it has been refurbished and maintained (Hooshmand *et al*., 2009).

Conclusion

The analyses revealed that gas turbine 4 and 5 (GT4, GT5) has maximum failure rate (max l) of once in 100 h in 2005 with system availability (Y) of 0.495 and ,977 and minimum failure (Obodeh and Esabunor 291) rate ($1.1905\text{x}10^{-3}$) of once in 1000 h in 2010 with Y of 0.3144.for gas turbine unit no 8 GT8. While for gas turbine 3 (GT 3), max $7.42\text{x}10^{-3}$ of seven in 1000 h was obtained in 2009 with Y of 0.987 and min of twice in 1000 h($2.5794\text{x}10^{-3}$) in 2010 with Y of 0.9025. Increase in failure rate results in decrease in Y. Effective maintenance management is essential in reducing the adverse effect of equipment failure to operation. It was shown that GT1 has a maximum repair rate (max μ) of once in 0.57143 h in 2006 with Y of 0.999 and minimum repair rate (min μ) of once in *0.1236* h in 2005 with Y of *0.1236*. On the other hand, GT3 has max μ of once in 0.7831 h in 2007 with Y of 0.9948. and min μ of once in 0.465 h in 2006 with Y of 0.93. Y increases with increase in μ . GT1 has maximum mean time to repair (max z) of 8.091 h in 2005 with Y of 0.88 and minimum mean time to repair (min z) of 1.75 h in 2006 with Y of 0.993 . Similarly, GT3 has max z of 2.92 h in 2010 with Y of 0.9025.and min z of 1.277 h in 2007 with Y of 0.9948. It is possible to reduce the operational consequences of failure by taking steps to shorten the downtime by reducing the time to get hold of spare parts. For the period under study, GT1 has min Y of 0.88 in the year 2005 and max Y of 0.99 in 2006 while GT3 has min Y of 0.9025 in 2010 and max Y of 0.9948 in 2007.The measure of ($R(t)$) of gas turbine station is determined by such indices as failure rate ,and availability can be improved significantly by reviewing maintenance practices. Planned or scheduled maintenance must be given more attention as directed by the unit manufacturer's operation and maintenance manual package, if the unit have to perform properly. In other words, routine preventive maintenance must be well planned and more regular. Measures to improve the ($R(t)$) indices of the plant have been suggested such as training and retraining of technical personnel on the major equipment being used. This will improve their skill and knowledge on the current information and communication technology (ICT) as well as improve their manpower quality.

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