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DEVELOPMENT OF RISK BASED MAINTENANCE STRATEGY FOR GAS TURBINE POWER SYSTEM

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Abstract: *The unexpected failures, the down time associated with such failures, the loss of production and, the higher maintenance costs are major problems in any power plant. Risk-based maintenance (RBM) approach helps in designing an alternative strategy to minimize the risk resulting from breakdowns or failures. The RBM methodology is comprised of four modules: viz - identification of the scope, risk assessment, risk evaluation, and maintenance planning. Using this methodology, one is able to estimate risk caused by the unexpected failure as a function of the failure probability and the consequences of failure. Critical equipment can be identified based on pre-selected acceptable level of risk. Maintenance of equipment is prioritized based on the risk, which helps in reducing the overall risk of the plant. The case study of a power-generating unit in the Rukhia gas turbine power plant system is used to illustrate the methodology. Results indicate that the methodology is successful in identifying the critical equipment and in reducing the risk of failure of the equipment. Risk reduction is achieved through the adoption of a maintenance plan which not only increases the reliability of the equipment but also reduces the cost of maintenance including the cost of failure.*

Keywords: *Maintenance, Risk based maintenance, failure, preventive maintenance, operation.*

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I. INTRODUCTION

The systems can undergo failures. The failures cause disastrous consequences in human life. The occurrence of failures in manufacturing systems devoted to the production of goods has not so devastating effects but causes, in general, economic losses due to the downtime and the lack of system availability. But in case of process industry the cause of failures are serious.In the case of Gas turbine plant the shut down of critical components will cause serious effect to the loss of human beings and loss of revineues due to shutdown.

Maintenance is crucial to manufacturing operations. In many times the facilities and the production equipment represent the majority of invested capital and deterioration of these facilities and equipment increases production cost and reduce production quality. Managers schedule PM actions to prevent breakdown and equipment deterioration. However to maximize return on their equipment investment manager attempt to identify the risky equipments required time interval between P.M. actions which will balance the costs of P.M. and the cost of breakdowns and equipment deterioration. When possible managers use the equipment's history card to schedule sets of maintenance tasks together. For example managers can minimize down time by scheduling a set of PM actions during the same period and if possible during machine setup. In practice scheduling maintenance activities always involve some risk. Even those firms which know the failure distribution of components still have some probability of component failure before the scheduled PM action.

The Risk based maintenance system identifies the critical equipment on the basis of risk evaluation. An overall equipment and component maintenance plan is carried out to reduce the risk of operation. By pre scheduling the maintenance activities in improved RBM approaches the consequences of failures and down time can be reduced to minimum level for which the criteria considered are set up financial risks and are presented in this paper. An extensive joint probability density function (PDF) of successive failures and the final survival is proposed to estimate the parameters of the failure distribution and maintenance effect. Economic risk criteria are proposed on the basis of maintenance expenditure. A periodic and imperfect PM plan for equipment in high-risk subsystems is established to meet the risk criteria.

II. LITERATURE REVIEW

There has been an increased focus on risk-based maintenance optimization in the offshore industry prompted by the recent functional regulations on risk. Ape land and Aven (1999) presented alternative probabilistic frameworks for this optimization using a Bayesian approach [1]. The American Society of Mechanical Engineers (ASME) recognized the need of risk-based methods and organized a number of multidisciplinary research task forces to study risk-based in-service inspection and testing. A series of ASME publications present this work, which includes both nuclear and industrial applications (ASME,1991).[2].Backlund and Hannu (2002) discussed maintenance decisions based on risk analysis results. An effective use of resources can be achieved by using risk-based maintenance decisions to determine where and when to perform maintenance and proved the need of homogenized quantitative risk analysis [3]

Balkey and Art (1998) developed a methodology, which includes risk-based ranking methods, beginning with the use of plant PRA (Pre Risk Analysis), for the determination of risk-significant and less risk-significant components for inspection and the determination of similar populations for pumps and valves in-service testing. This methodology integrates non-destructive examination data, structural reliability risk assessment results, PRA results, failure data and expert opinions [4]

Dey (2001) presented a risk-based model for inspection and maintenance of a cross-country petroleum pipeline that reduces the amount of time spent on inspection. This model does not only reduce the cost of the pipeline maintenance; but also suggests efficient design and operational philosophies, construction methodology, and logical insurance plans. The risk-based model uses an analytical hierarchy process and a multiple attribute decision-making technique to identify the factors that influence the failure of a specific pipeline segment. This method could be used to prioritize the inspection and maintenance of pipeline segments. [5]

Industries worldwide spend a huge amount of money on maintenance of production machinery. Each year US industry spends well over $300 billion on plant maintenance and operation (Dhillion, 2002).[6] Furthermore, it is estimated that approximately 80%of the industry dollars are spent to address chronic failures of the equipment and injury to people. An operating cost reduction of about 40–60% can be achieved through effective maintenance strategies (Dhillion, 2002) [6]. Dadson developed a failure model based on the Weibull probability distribution which established the optimum interval between PM actions as a function of the Weibull scale parameter(θ).[7].Hagemeijer and Kerkveld (1998) developed a methodology for risk-based inspection of pressurized systems. The methodology is based on the determination of risk by evaluating the consequences and the likelihood of equipment failure. Likelihood of equipment failure is assessed, by means of extrapolation, at the future planned maintenance campaign to identify the necessary corrective work. The study aimed to optimize the inspection and maintenance

efforts and to minimize the risk in a petroleum plant in Brunei.[8]. Harnly (1998) developed a risk ranked inspection recommendation procedure that is used in one of Exxon's chemical plants to prioritize repairs that have been identified during equipment inspection. The equipment are prioritized based on the severity index, which is failure potential combined with consequences of failure. The reduction in the overall risk of the plant is accomplished by working high risk items first. Making decisions concerning a selection of a maintenance strategy using a risk-based approach is essential to develop cost effective maintenance polices for mechanized and automated systems because in this approach the technical features (such as reliability and maintainability characteristics) are analyzed considering economic and safety consequences [9]

Studies by Khan and Abbasi (1998), views the major challenge for a maintenance engineer is to implement a maintenance strategy, which maximizes availability and efficiency of the equipment; controls the rate of equipment deterioration; ensures a safe and environmentally friendly operation; and minimizes the total cost of the operation. This can only be achieved by adopting a structured approach to the study of equipment [10, 11]. Recently, Khan and Haddara (2003) proposed a new and comprehensive methodology for risk-based inspection and maintenance. The application of methodology was illustrated using a particular system as a case study. The methodology integrates quantitative risk assessment and evaluation with proven reliability analysis techniques. The equipment is prioritized based on total risk (economic, safety and environmental). A maintenance plan to reduce unacceptable risk is developed [12]

The methodology was also applied to an ethylene oxide production plant (Khan and Haddara, 2004).Dey (2001) presented a risk-based model for inspection and maintenance of a cross-country petroleum pipeline that reduces the amount of time spent on inspection. This model does not only reduce the cost of the pipeline maintenance; but also suggests efficient design and operational philosophies, construction methodology, and logical insurance plans [13] . Kletz (1994), and Kumar (1998) show a strong relationship between maintenance practices and the occurrence of major accidents. Profitability is closely related to the availability and reliability of the equipment [14].(Kumar, 1998). provides a holistic view of the various decision scenarios concerning the selection of a maintenance strategy where cost consequences of every possible solution can be assessed quantitatively. Risk-based maintenance strategies can also be used to improve the existing maintenance policies through optimal decision procedures in different phases of the risk cycle of a system. Unexpected failures usually have adverse effects on the environment and may result in major accidents [15]. Misewicz, Smith, Nessim, and Playdon (2002) developed a risk-based integrity project ranking approach for natural gas and CO2 pipelines. The approach is based on a benefit cost ratio, defined as the expected risk reduction in dollars per mile over the project useful life, divided by the total project cost. Risk reduction is estimated using a quantitative risk analysis approach. The benefit cost ratio results can be used as a tool to justify the maintenance budget.[16]. A holistic, risk-based approach to asset integrity management was discussed by Montgomery and Serratela (2002). It is based on proven risk assessment and reliability analysis methodologies, as well as the need to have appropriate management systems. Combining risk assessment and risk-based decision-making tools provides operators with a realistic way to achieve corporate and regulators objectives. The review of the literature indicates that there is a trend to use risk as a criterion to plan maintenance tasks. However, most of the previous studies focused on a particular system and were either quantitative or semi quantitative. [17]

Murty and Naikan suggest a complicated method for designing condition monitoring measurement intervals for all types of machines by considering interval availability, economic factors and four different stages of machine life. A different method of determining the measurement interval is utilized in each of the four different stages. The method is based on the limiting value of the ratio of the repair rate and failure rate, They suggest that much of the information can be obtained from Data collection in the first year of machine life [18]. **Shore** improved the failure model based on the Weibull probability distribution model with a solution method that required only partial distribution information. However neither Research considered the inherent probability of the early breakdowns. Many of the existing models are difficult to use [19]. Vesely, Belhadj, and Rezos (1993) used probabilistic risk assessment (PRA) as a tool for maintenance prioritization.. The minimal cutset contribution and the risk reduction importance are the two measures that were calculated. Using minimal cutsets and the risk reduction importance, the basic events and their associated maintenance were prioritized. Moreover, basic events having low risk and unimportant maintenances were ignored [20]. Krishnasamy L *et al* developed a riskbased maintenance strategy for power generating plant.They presented a case study in which they carried out risk assessment, risk evaluation and developed fault tree to identify the high risk component. Finally they suggested the maintenance procedure for the risky components [21]. The contributions by others in maintenance field are as follows:- Least-cost strategies for asset management (operation, maintenance and capital expenditures) are essential for increasing the revenues of power-generating plants. The risk-centered approach as used in this study helps in making decisions regarding the prioritization of the equipment for maintenance and in determining an appropriate maintenance interval. The present work describes the application of a risk-based maintenance policy for developing a maintenance plan for a gas turbine plant in Rukhia of India.

III. RISK BASED MAINTENANCE

Methodology

Risk-based maintenance methodology provides a tool for maintenance planning and decision-making to reduce the probability of failure of equipment and the consequences of failure. The resulting maintenance program maximizes the reliability of the equipment and minimizes the cost of the total maintenance cost. Figure. 2 shows a flow diagram , which depicts the process used to develop this methodology. The following steps are followed.

3.1. Identification of the scope:

The plant is divided into major systems, each system is divided into subsystems and the components of each subsystem are identified. Each system is analyzed one at a time, until the whole plant has been investigated. Data required to analyze the potential failure scenarios for each system are collected. Physical, operational, and logical. Relationships between the components are studied. Figure 1 describes the Block Diagram of Single Shaft Gas Turbine Power Plant

3.2. Risk assessment

Risk assessment starts with the identification of major potential hazards (top events) that each failure scenario may lead to. A fault tree is used to identify the basic events and the intermediate paths that will lead to the top event. Failure data for the basic events of the subsystem are used to estimate the probability of subsystem failure consequence analysis is used to quantify the effect of the occurrence of each failure scenario. This is based on a study of maintenance costs including costs incurred as a result of failure. Finally, a quantitative measure for risk is obtained.

3.3. Risk evaluation:

An acceptable risk criterion is determined and used to decide whether the estimated risk of each failure scenario is acceptable or not. Failure scenarios that produce unacceptable risk are used to determine maintenance policies for the components involved.

3.4. Maintenance planning:

Subsystems that failed to meet the acceptable risk criteria are studied with the objective to designing maintenance program that will reduce the risk. Both the type of maintenance and the maintenance interval should be decided upon at this stage. In this work, we only use the maintenance interval to modify the risk. By modifying the maintenance interval, the probability of failure changes and this will also affect the risk involved. The probability of the top event is decided upon using the acceptable risk criterion. A reverse fault tree analysis is used to estimate the new probability of failure for each basic event. Maintenance intervals which produce the new probability of failure are then calculated. However, one can also look at how maintenance is done with a view to reduce the consequence of failure as well.

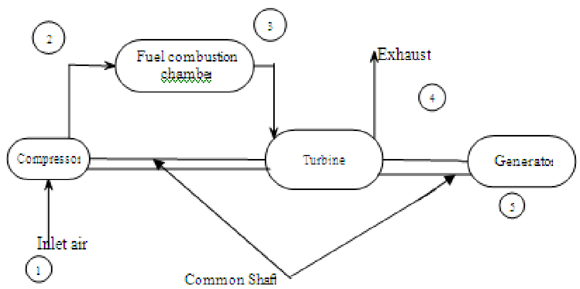

Figure 1: Block Diagram of Single Shaft Gas Turbine Power Plant

IV. CASE STUDY: GAS TURBINE POWER PLANT

A case study is used to illustrate the use of the above mentioned methodology in designing maintenance programs. The case study uses a power-generating unit in an operating steam power plant. A gas turbine power plant is a means for converting the potential chemical energy of fuel into electrical energy. In its simplest form, it consists of a compressor , combustion chamber and two turbine driving an electrical generator. The gas turbine plant is shown in figure 1.

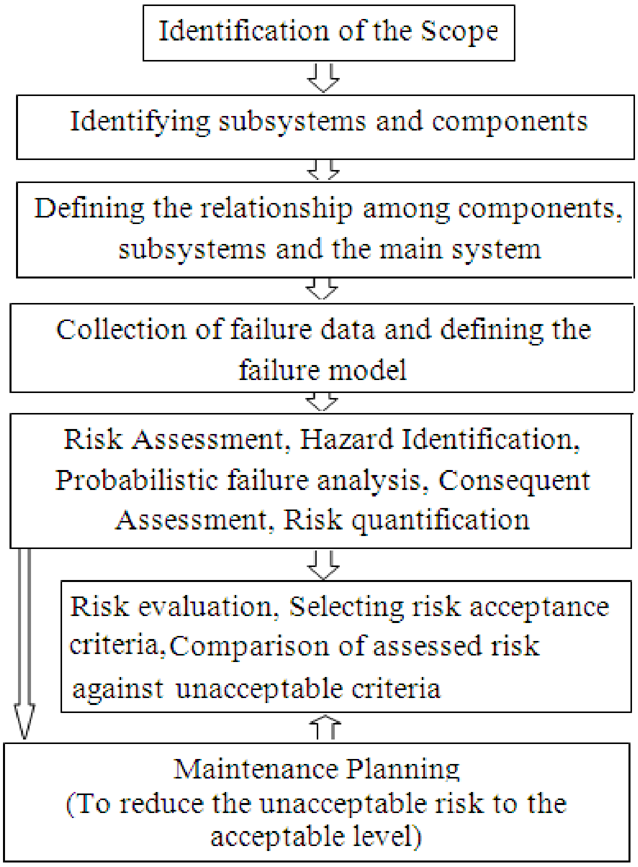

Figure 2 Architecture of R.B.M. Methodology

The Rukhia Gas Turbine power plant started operating in 1989 using five units , sixth, seventh and eighth units are added in 1999. The data used in this work was obtained from the Rukhia Gas Turbine power plant in Rukhia around 25 kilometers from Agartala.. The unit under study is designated here as Unit 4.

V. CONSEQUENCE ANALYSIS

Consequence analysis involves the estimation of maintenance and the production loss cost. The maintenance cost is calculated using the following equation: $MC = C_f + DT.C_v$ where Cf is the fixed cost of failure (cost of spare parts), DT is the down time, and Cv is the variable cost per hour of down time, it includes labor rate and crew size. The cost of spares includes the cost of raw material, internally manufactured parts, the parts sent away for repairs, new spare parts, consumables, small tools, testing equipments, and rent for special equipments. The cost of spares and raw materials is drawn from the plant stock book. For small tools, Rs3.00 is added per man-hour. Special equipments rent cost is derived from plant records. Maintenance down time includes the total amount of time the plant would be out of service as a result of failure, from the moment it fails until the moment it is fully operational again. The repair process itself can be decomposed into a number of different subtasks and delay times as shown in **Figure 3.**

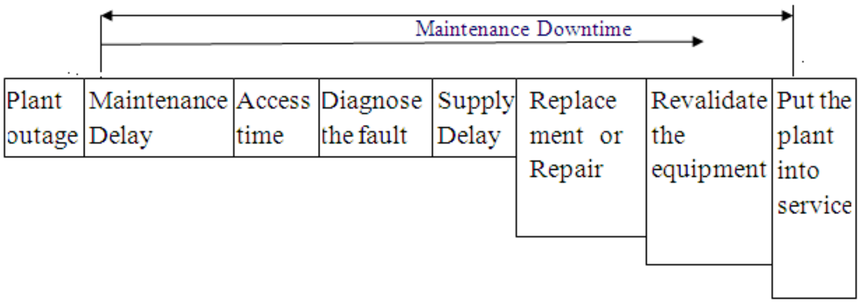

Figure 3 : Analysis of Downtime

5.1 Estimation of Production loss cost : The production loss cost is estimated using the following formula PLC =DT.PL.SP, Where DT = downtime, PL = production loss in Megawatt (1 Megawatt = 10^6 watt, one watt is the rate at which work is done when one ampere (A) of current flows through an electrical potential difference of one volt (V) and in terms of classical mechanics, one watt is the rate at which work is done when an object's velocity is held constant at one meter per second against constant opposing force of one newton)

SP is the selling price of generated electricity. The cost of labor is an important component of the maintenance cost. This is based on the hourly rate for various trades and the information is drawn from the plant documentation (Table 1 represents the rates used in the present study). Down time associated with forced outage and forced de-rating state is estimated from the failure data collected for the GTPPS. Owing to the lack of data, the down time and the number of maintenance personnel involved in repair is estimated by interviewing the maintenance personnel.

5.2 Estimation of Probability of failure : Down time associated with forced outage and forced de-rating state is estimated from the failure data collected for the GTPPS. Owing to the lack of data, the down time and the number of maintenance personnel involved in repair is estimated by interviewing the maintenance personnel. The probability of failure of different components and subcomponents are given in table 2,3,4,5,6,7 respectively collecting from the plant Data. Production loss in Mega Watt hour was computed from the failure data. A price for fuel was estimated at Rs 45.00 per cubic centimeter. The price was derived from the cost of the Gases collected from GAIL. This price includes overheads, the combination of production loss cost and the maintenance cost gives the consequence of the failure in Rupees. Risk is calculated using the results of the previous two steps, by multiplying the probability and the consequence of failure.

Table 1 Labor Rates of Different categories

Trade	Description	Hourly Rate
Boiler maker $	General foreman	Rs 46.21/-
	Foreman	44.90
	Fitter/welder	41.26/-
	Apprentice 3	38.04
	Apprentice 2	32.81
	Apprentice 1	27.64
	Helper	38.04
Pipe fitter	Foreman	45.49
	Welder/journeyman	42.64
Mill wright	Foreman	41.47
	Welder/journeyman	40.22
	Apprentice	38.60
	Journey	34.64
	Electrician	25.00

Table 2: Summary values of failures in Generator

Component	Name of the Problem	Total failure observed	Total repair time taken	λ value
P.m.g. bolt	P.m.g. bolt broken	6	6	6.1896×10^{-04}
P.m.g. bush	P.m.g. bush changed	40	44	4.1264×10^{-03}
P.m.g. shaft	Bush not in alignment of the generator	4	20	4.1264×10^{-04}

5.3 Risk evaluation: An acceptable risk criterion was determined based on the yearly maintenance expenditure of Unit 4. (found from records as Rs 2,000,000 per year) The estimated risk for each individual subsystem was compared against the acceptable risk criterion. Subsystems whose estimated risk exceeded the acceptance criteria were identified. These are the units whose maintenance plan had to be modified in order to lower their risk. To facilitate this comparison, a risk index was calculated. The risk index is the actual risk divided by the acceptable risk. The risk indexes and probability of failures and consequences of different components are described in table 8 and 9.

Component	Name of the Problem	Reliability $= e^{-\lambda t}$ T= 12000	Probability of failure $1 - e^{-\lambda t}$	Failure probability of the system
P.m.g. bolt	P.m.g bolt broken	0.000593	0.999407	0.9974
P.m.g bush	P.m.g bush changed	0.000318	1	
P.m.g shaft	Bush not in alignment of the generator	0.00708	0.9928	

Table 3: Summary value of failures of other systems (electrical system)

Component	Name of the Problem	Total failure observed	Total repair time taken	λ value
Generator breaker	Desynchronization	33	62	$0.3125\text{x}10^{-03}$
Relay	Relay fault	8	16	$0.1875\text{x}10^{-03}$
Control system	Under frequency	11	14	$0.125\text{x}10^{-03}$
Feeder	Synchronization	10	26	$0.375\text{x}10^{-03}$
Bus bar	Feeder fault	9	10	$0.4783\text{x}10^{-03}$
Gas collecting tank	Poor demand & shortage of Gas	11	39	$0.125\text{x}10^{-03}$
Grid	Grid failure	12	14	$0.1340\text{x}10^{-03}$

Component	Reliability = e-λt T= 20000	Probability of failure 1-e-λt	Failure probability of the system
Generator breaker	0.00193	0.99807	0.9678
Relay	0.0235	0.9765	
Control system	0.0626	0.9374	
Feeder	0.005531	0.994469	
Bus bar	0.00007	0.9993	
Gas collecting tank	0.0626	0.9374	
Grid	0.0685	0.9315	

Table 4: Summary values of failures of compressor systems

Component	Name of the Problem	Total failure observed	Total repair time taken	λ value
Turbine housing	Exhaust over temperature	5	11	$1.6675x10^{-03}$
Servo valve	Servo trouble	3	8	1.005×10^{-03}
bearing	Oil leakage	2	7	0.667×10^{-03}
Air filter module	Turbine air inlet differential high	6	18	2.001×10^{-03}

Component	Reliability = e-λt T= 10000	Probability of failure 1-e-λt	Failure probability of the system
Turbine housing	0.0000057	1	0.9996
Servo valve	0.0000045	1	
bearing	0.001265	0.99871	
Air filter module	0.0000002	0.99998	

VI. MAINTENANCE PLANNING

The strategy that was adopted to lower the risk to meet the acceptable criterion, was to reduce the probability of failure. Based on the evaluation results the components are segregated into three types. High Risk items are high pressure turbine and combustion chamber and medium risk items are Permanent magnet generator bush (pmg), Servo valve, Turbine housing, Air filter module, and generator breaker. The rest 25 components are low Risk equipment. The high risk main equipments (Risk value more than1.0) are high pressure turbine, compressor and combustion chamber and medium risk items are other electrical system and generator. The rest equipments are in Low class category. As a thumb rule without going to the complex equation The maintenance intervals are set as per the following Criteria **::**

High risk items: ----------3 months

Medium risk items: ------- 6 months

and Low risk items are:----- 1 year

Table 5: Summary values of failures of combustion systems

Component	Name of the Problem	Total failure observed	Total repair time taken	λ value
Combustion chamber	Loss of flame	48	79	3.928×10^{-03}
Servo valve	Servo valve problem	4	4	0.327×10^{-03}
2nd stage Nozzle	Nozzle Problem	4	21	0.327×10^{-03}
Bearing 2	Bearing drain temperature high	2	3	0.164×10^{-03}
starter	Starting and electrical problem	5	7	0.4092×10^{-03}

Component	Reliability = e-λt T= 10000	Probability of failure 1-e-λt	Failure probability of the system
Combustion chamber	0.0000002	1.0	0.943
Servo valve	0.38996	0.9619935	
2nd stage Nozzle	0.38996	0.9619935	
Bearing 2	0.19398	0.80602	
starter	0.0167	0.98329	

The modified maintenance interval of main equipments for compensating risk parameters are described. Similarly the maintenance interval of sub components are also prepared for the components (subsystem of equipments) and are as follows::

High risk items: ------------------ 2 months

Medium risk items: -------------- 5 months

and Low risk items are :----------10 months

The modified maintenance interval of sub components for compensating risk parameters are described.

Table 7: Summary values of failures of L.P. Turbine system

Component	Name of the Problem	Total failure observed	Total repair time taken	λ value
L.P. turbine	L. P. over speed	6	15	0.1265×10^{-03}
2nd stage nozzle	Nozzle problem	1	1	0.021×10^{-03}
Diesel engine	Start up problem	2	7	0.021×10^{-03}
Bearing header	Lub oil header temp high	2	9	0.04217×10^{-03}
Bearing 2 and 4	Oil leakage	1	2	0.021×10^{-03}

Table 6: Summary values of failures of H.P Turbine system

Component	Name of the Problem	Total failure observed	Total repair time taken	λ value
HP turbine	H. P turbine under speed	21	30	$0.442x10^{-03}$
Mist eliminator	Heavy smoke	2	2	$0.04217X 10^{-03}$
	Turbine under speed/ locked	1	2	$0.021x10^{-03}$
Lp turbine	Servo problem	1	1	0.021×10^{-03}
Servo valve	Exhaust over temp	2	3	0.04217X 10
Turbine housing	Low Hydraulic Pressure	2	4	0.04217X 10
Auxiliary hydraulic pump	Lub oil level low	2	4	0.04217X 10
Lub oil sump	Lub oil drain temp High	2	9	0.04217X 10

Component	Reliability $= e^{-\lambda t}$ T= 10000	Probability of failure $1- e^{-\lambda t}$	Failure probability of the system
HP turbine	0.012034	0.987965	0.795
Mist eliminator	0.0012034	0.99879	
	0.81058	0.18942	
Lp turbine	0.81058	0.18942	
Servo valve	0.0012034	0.99879	
Turbine housing	0.0012034	0.99879	
Auxiliary hydraulic pump	0.0012034	0.99879	
Lub oil sump	0.0012034	0.99879	

Component	Reliability = e-λt T= 10000	Probability of failure 1- e-λt	Failure probability of the system
L.P. turbine	0.00000032	0.9999967	0.51340
2nd stage nozzle	0.81058	0.18942	
Diesel engine	0.81058	0.18942	
Bearing header	0.0012034	0.99879	
Bearing 2 and 4	0.81058	0.18942	

Table 8: calculation of Probability of failures and consequences

Rank	Major system	Consequence in millions	Probability of failure over 20 years
1	Combustion chamber	3,678,481	0.943
2	H.P Turbine	2,478,842	0.795
3	Compressor	2,102,023	0.9996
4	Other electrical system	1,634,060	0.9974
5	Generator	11,110,57	0.9974
6	L.P. Turbine	874,745	0.51340

Table 9: calculation of Risk index

Rank	Major system	Risk ($) over 20 years	Risk index considering accepted risk=2000000
1	Combustion chamber	3468807	1.734
2	H.P Turbine	1970679	1.25786
3	Compressor	2093615	1.046
4	Other electrical system	1629811	0.815
5	Generator	1110768	0.5554
6	L.P. Turbine	449094	0.22455

VII. RESULT

Risk assessment results are given in Table 8. Any subsystem whose risk index is greater than 1.0 is considered (see Table 8). Three subsystems were found to violate the risk criterion: the Combustion chamber , H.P Turbine, and the Compressor . A new maintenance schedule had to be developed for these three subsystems. To find out which components contribute more the high-risk levels of these subsystems, a study of the components of the subsystems was carried out.. The components were divided in three categories, high risk (risk index value greater than 0.6), medium risk (risk index value between 0.2 and 0.6), and low risk (risk index value less than 0.2).

VIII. SUMMARY AND CONCLUSION

The paper presents a methodology for designing maintenance programs based on reducing the risk of failure. This approach ensures that not only the reliability of equipment is increased but also that the cost of maintenance including the cost of failure is reduced. This will contribute to the availability of the plant as well as its safe operation. In the present approach, only the maintenance interval was considered. This affects the probability of failure directly, but its effect on the consequence of risk is indirect. In deciding the maintenance interval, we grouped the equipment that would be maintained at the same time together and assigned the minimum length of the maintenance interval for the whole group. This means that some equipment will be over maintained. However, the resulting savings in terms of reducing the down time required to perform the maintenance tasks justify this policy. The study identified the critical equipment based on risk. For example, three Components were found to have unacceptable initial risks. These are the combustion chamber, compressor, high pressure turbine. Reducing the individual risk of each of these components will result in an overall reduction in the risk of the unit. A study of the risk patterns of the components showed that 6% of the items are high risk items.. and 16% of the items followed medium risk items. The remaining 79% of the component are low risk components.

IX. FUTURE SCOPE FOR RESEARCH

(1)The reliability of the component can be improved further if maintenance intervals are estimated mathematically, So scopes for further improvement lies in this topic.

(2) The fault tree analysis can be incorporated for further reducing the risk.

(3) The possibility of incorporating online monitoring system can be incorporated.

(4) Effect of maintenance on failures can be studied specially on high risk equipments

(5) A cost benefit analysis can be done for high and medium risk equipment.

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