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THE MAINTENANCE STRATEGY SELECTION OF A GAS TURBINE POWER PLANT SYSTEM

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Abstract-This paper describes an application for selecting the best maintenance strategy for an important Gas turbine Power plant system in Tripura. Five possible alternatives are considered: preventive, predictive, condition-based, corrective and opportunistic maintenance. The best maintenance policy must be selected for each unit of the plant (about eight units and forty components in total). The machines are clustered in three homogeneous groups after a criticality analysis based on internal procedures of the plant. With the critical analysis technique, several aspects, which characterize each of the above-mentioned maintenance strategies, are arranged in a hierarchic structure and evaluated using only a series of pair wise judgments. To improve the effectiveness of the methodology the several factors are taken for criticality analysis calculations. The findings in summary are (1)best maintenance strategy for each components (2)identification of most critical components in the plant(3) determination of priority to all the components and fixing up the group.
Keywords: Maintenance; gas turbine plant; F.M.E.C.A; consequences, strategy

INTRODUCTION

Many companies think of maintenance as an inevitable source of cost. For these companies maintenance operations have a corrective function and are only executed in emergency conditions. Today, this form of intervention is no longer acceptable because of certain critical elements such as product quality, plant safety, and the increase in maintenance department costs which can represent from 15 to 70% of total production costs. The managers have to select the best maintenance policy for each piece of equipment or system from a set of possible alternatives. For example, corrective, preventive, opportunistic, condition-based and predictive maintenance policies are considered in this paper.It is particularly difficult to choose the best mix of maintenance policies when this choice is based on preventive elements, i.e. during the plant design phase. This is the situation in the case examined in this paper, that of an gas turbine plant generating power by the use of natural gas which is being built by Bharat heavy electricals limited of India. This plant have about 8 power unit with 40 components like compressors, combustion chamber, Turbine and generators catering the thirst of Power of the State of Tripura., and the management must decide on the maintenance approach for the different machines. These decisions will have significant consequences in the short-medium term for matters such as resources (i.e. budget) allocation, technological choices, managerial and organizational procedures, etc. At this level of selection, it is only necessary to define the best maintenance strategy to adopt for each machine, bearing in mind budget constraints. It is not necessary to identify the best solution from among the alternatives that this approach presents. The maintenance manager only wants to recognize the most critical machines for a pre- allocation of the budget maintenance resources, without entering into the details of the actual final choice. This final choice would, in any case, be impossible because the plant is not yet operating and, as a consequence, total knowledge of the reliability aspects of the plant machines is not yet available. In other words, the problem is not whether it is better to control the temperature or the vibration of a certain facility under analysis, but only to decide if it is better to adopt a condition-based type of maintenance approach rather than another type. The second level of decision making concerns a fine tuned selection of the alternative maintenance approaches (i.e. definition of the optimal maintenance frequencies, thresholds for condition-based intervention, etc.). This level must be postponed until data from the operating production system becomes available. Several attributes must be taken into account at this first level when selecting the type of maintenance. This selection involves several aspects such as the investment required, safety and environmental problems, failure costs, reliability Mean Time to Repair (MTTR) of the facility, etc. Several of these factors are not easy to evaluate because of their intangible and complex nature .Besides, the nature of the weights of importance that the maintenance staff must give to these factors during the selection process is highly subjective.Finally,bearing in mind that the plant is still in the construction phase, some tangible aspects such as MTBF and MTTR can be only estimated from failure data concerning machines working in other plants (in this case gas turbine plant) under more or less similar operating conditions. Furthermore, they will affect each single facility analyzed in a particular way and, as a consequence, the final maintenance policy selection. It is therefore clear that the analysis and justification of maintenance strategy selection is a critical and complex task due to the great number of attributes to be considered, many of which are intangible. As an aid to the resolution of this problem, some multi-criteria decision making (MCDM) approaches are proposed in the literature.

Literature review

Almeida and Bohoris[1] discuss the application of decision making theory to maintenance with particular attention to multi-attribute utility theory. Triantaphyllou et al.[2] suggest the use of Analytical Hierarchy Process (AHP) considering only four maintenance criteria: cost, reparability, reliability and availability. The Reliability Centered Maintenance (RCM) methodology (Ref.[3]) is probably the most widely used technique. RCM represents a method for preserving functional integrity and is designed to minimize maintenance costs by balancing the higher cost of corrective maintenance against the cost of preventive maintenance, taking into account the loss of potential life of the unit in question [4]. One of the tools more frequently adopted by the companies to categorize the machines in several groups of risk is Based on the concepts of failure mode effect and criticality, analysis technique (FMECA).This methodology has been Proposed in different possible variants, in terms of relevant Criteria considered and /or risk priority number formulation [5]. Using this approach ,the selection of a maintenance Policy is performed through the analysis of obtained priority Risk number .An example of this approach has also been This information will then be updated using the data Acquired during the working life of the plant. The analysis system has been structured in a rational way so as to keep the update process as objective as possible. This has been accomplished through the use of a charting procedure, using well-understood evaluations of different parameters and a simple and clear analysis of corrective interventions. The maintenance plan developed for the machines of the IGCC plant is based on the well-known FMECA technique[6,7]. The analysis results have provided a criticality index for Every machine ,allowing the best maintenance policy to be selected. The formal tool used during the hierarchy structure definition was the Interpretive Structural Modeling (IMS) [8,9]approach .IMS is a well-established interactive Learning process for identifying and summarizing relationships among specific factors of a multi-criteria decision. As the decision information given by decision-makers is often imprecise or uncertain due to a lack of data, time pressure, or the decision-makers' limited attention and information processing capabilities, research pertaining to multi-criteria decision analysis (MCDA) problems has most often been performed in a fuzzy environment viewed by Ting-YuChen [10] Making problem, and provides an efficient means by Which a group of decision-makers can impose order on the complexity of the problem This fact is probably due to some Important aspects of AHP such as[11]:(1)the possibility to Measure the consistency in the decision maker's judgment: Each criterion can be characterized by an important degree of sensitivity , i.e. the ranking of all strategies changes dramatically over the entire Weight range [12].The problem is to check whether a few Changes in the judgment evaluations can lead to significant modifications in the priority final ranking. At the 2002 IETC, Linnhoff March presented an overview of spreadsheet-based software packages to rigorously model site utility systems [13]. Such models allow the user to plan future scenarios that might impact system operation (energy saving projects, production changes, new equipment, future energy tariffs, etc.). Decision analysis is used when a decision maker wishes to evaluate the performance of a number of alternative solutions for a given problem. Often an alternative may be superior in terms of one or some of the criteria, but inferior in terms of some other criteria. The objective of using an analytic hierarchy process (AHP) is to identify the preferred alternative and also determine a complete ranking of the alternatives when all the criteria are considered simultaneously (14).(M. C. CARNERO, 2006). The analytic hierarchy process (AHP) provides a framework for coping with situations involving multiple criteria for supplier selection. This framework reduces complex decisions to a series of pair wise comparisons and then synthesizes the results viewed by Pei-Chun Lin and Kung-Yu

Lin.[15] AHP assumes that multiple-criteria problems can be completely expressed in a hierarchical structure. The data acquired from the decision-makers are compared pairwise with respect to the relative importance of each of the criteria, or the degree of preference of one factor to another with respect to each criterion viewed by Ching-Chow Yang and Bai-Sheng Chen[16]

Possible alternative maintenance strategies

Five alternative maintenance policies are evaluated in this case study. Briefly, they are the following.

Corrective maintenance. The main feature of corrective maintenance is that actions are only performed when a machine breakdown. There is no intervention until a failure has occurred.

Preventive maintenance: Preventive maintenance is based on component reliability characteristics. This data makes it possible to analyze the behavior of the element in question and allows the maintenance engineer to define a periodic maintenance program for the machine. The preventive maintenance policy tries to determine a series of checks, replacements and/or component revisions with a frequency related to the failure rate. In other words, preventive (periodic) maintenances is effective in overcoming the problems associated with the wearing of components. It is evident that, after a check ,it is not always necessary to substitute the component :maintenance is often sufficient.

Opportunistic maintenance.: The possibility of using opportunistic maintenance is determined by the nearness or concurrence of control or substitution times for different components on the same machine or plant. This type of maintenance can lead to the whole plant being shut down at set times to perform all relevant maintenance interventions at the same time.

Condition-based maintenance. A requisite for the application of condition-based maintenance is the availability of a set of measurements and data acquisition systems to monitor the machine performance in real time. The continuous survey of working conditions can easily and clearly point out an abnormal situation (e. g .the exceeding of a controlled parameter threshold level), allowing the process administrator to punctually perform the necessary controls and, if necessary, stop the machine before a failure can occur.

Predictive maintenance. Unlike the condition-based maintenance policy, in predictive maintenance the Acquired controlled parameters data are analyzed to find a possible temporal trend. This makes it possible to predict when the controlled quantity value will reach or exceed the threshold values. The maintenance staff will then be able to plan when, depending on the operating conditions, the component substitution or revision is really unavoidable.

Methodology used for the maintenance strategy selection of the Gas Turbine Power Plant system.

The internal methodology developed by the company to solve the maintenance strategy selection problem for the Gas Turbine Power Plant system is based on a "criticality analysis "which may be considered as an extension of the FMECA technique. This analysis takes into account the following six parameters:

- safeties;
- machine importance for the process;
- maintenance costs;
- failure frequency;
- downtime length;
- operating conditions;
- With an additional evaluation for the
- machine access difficulty.

< Take in Table 1>

Note that, the six parameters presented below derived from an accurate pre-analysis to select all of the relevant parameters that can contribute to the machine criticality .As reported by the maintenance manager,12 criteria have initially been considered:

a. Safety. Consi dering the safety of personnel, equipment, the buildings and environment in the event of a failure.

b. Machine importance for the process. The importance of the machine for the correct operation of the plant. For instance, the presence of an inter-operational buffer to stock the products can reduce the machine criticality since the maintenance intervention could be performed without a plant shutdown.

c. Spare machine availability. Machines that do not have spares available are the most critical.

d. Spare parts availability. The shortage of spare parts increases the machine criticality and requires a replenish-ment order to be issued after a failure has occurred.

e. Maintenance cost. This parameter is based on manpower and spare parts costs.

f. Access difficulty. The maintenance intervention can be difficult for machines arranged in a compact manner placed in a restrict area because they are dangerous, or situated at a great height (for example, some agitators electric motors and air-cooler banks).The machine access difficulty increases the length of down time and, moreover ,increases the probability of a failure owing to the fact that inspection teams cannot easily detect incipient failures.

g. Failure frequency. This parameter is linked to the mean time between failures (MTBF) of the machine.

h. Downtime length. This parameter is linked to the mean time to repair (MTTR) of the machine.

i. Machine type. A higher criticality level must be assigned to the machines which are of more complex construction. These machines are also characterized by higher maintenance costs (material and manpower)and longer repair times.

l. Operating conditions. Operating conditions in the presence of wear cause a higher degree of machine criticality.
m. Propagation effect. The propagation effect takes into account the possible consequences of a machine failure on the adjacent equipment (domino effect).
n. Production loss cost. The higher the machine importance for the process the higher the machine criticality due to a loss of production. To restrict the complexity (and the costs)of the analysis to be performed ,the number of evaluation parameters is reduced by grouping together those that are similar and by removing the less meaningful ones .An increase in the number of parameters does not imply a higher degree of analysis accuracy .With a large number of parameters the analysis becomes much more onerous in terms of data required and elaboration time. Besides, the quantitative evaluation of the factors described is complex and subject risk of in correct estimates. The following “clusters” were created. The “spare machine availability ”mainly affects the uninterrupted duration o f the production process and can there-be linked to the “machine importance for the process” and the “production loss cost” .In terms of spare parts, the “maintenance cost ”can include the “machine type ”factor, The manpower contribution to the maintenance cost can be clustered with the “down time length ” attribute. System “safety ”,“failure frequency”, “access difficulty” and “operating conditions” are considered to be stand- alone factors by the maintenance staff.
For every analyzed machine of the Gas Turbine Power Plant system, a subjective numerical evaluation is given adopting a scale From 1 to 100. Finally, the factors taken into consideration are linked to gether in the following criticality index CI:
CI =[(SX1.5)+(IP X 2.5) + (MCX2) + (FFX1)+ (DL X 1.5) +(OCX1)]X AD …------------(1)
Where S = safety,
IP=ˆ machine importance for the process,
MC= maintenance costs,
FF = failure frequency,
DL =downtime length ,
OC =ˆ operating conditions,
AD = machine access difficulty
In the index ,the machine “access difficulty ” has been considered by the management to be an aggravating aspect as far as the equipment criticality is concerned. It is there-fore suitable to evaluate the effect of the machine “access difficulty” as an “a posteriori “factor. For this reason with this approach the machine criticality index has been multi-plied by the machine “access difficulty”.
A rational quantification of the seven factors has been defined and based on a set of tables .In particular, every relevant factor is divided into several classes that are assigned a different score (in the range from 1 to 100) to take into account the different criticality levels. For the sake of brevity, only the evaluation of the “machine importance For the process ”attribute is reported
< Take in Table 2>
The weighted values assigned by the maintenance staff to the different parameters are shown in Table 1. The weight assigned to safety is not the highest because in an gas turbine plant danger is intrinsic to the process.The operating conditions are weighted equal to one in accordance with the hypothesis of a correct facility selection as a function of the required service . The breakdown frequency is weighted equal to one in virtue of the fact that failure Rates are currently estimated values only. The CI index has been used to classify about 40 Machines of the plant (pumps, compressors, generators, etc.) Into the different groups corresponding to three different maintenance strategies, as shown in Table2.
Note that only corrective , preventive and predictive maintenance strategies have been taken into account by the Gas Turbine Power Plant system maintenance management.
The main features of the three groups are the following:
Group1. A failure of group1 machines can lead to Serious consequences in terms of workers' safety, plant and environmental damages , production losses, etc. .Significant savings can be obtained by reducing the failure frequency and the downtime length .A careful Maintenance (i.e., predictive) can lead to good levels maintenance (i.e. predictive)can lead to good levels of company added-value. In this case, savings in Maintenance investments are not advisable .This group contains about the 70% of the Gas Turbine Power Plant system examined.
Group2. The damages derived from a failure can be serious but ,in general ,they do not affect the external Environment. A medium cost reduction can be obtained with an effective but expensive maintenances. Then an appropriate cost /benefit analysis must be conducted to limit the maintenance investments (i.e. Inspection, diagnostic, etc.)for this type of facilities (about the 25% of the machines).For this Reason a preventive maintenance is preferable to a more expensive predictive policy.
Group3. The failures are not relevant. Spare parts Are not expensive and, as a consequence, low levels of savings can be obtained through a reduction of Spare stocks and failure frequencies. With a tight Budget the maintenance investments for these types Of facilities should be reduced, also because the added- value derived from a maintenance plan is negligible. The cheapest corrective

maintenance is, therefore, the best choice. Group3 contains 5% of the machines.

Results

The Machine wise weights assigned to the gas turbine plant are given below. Where S = safety, IP=ˆ machine importance for the process, MC= maintenance costs, FF = failure frequency, DL =downtime length , OC =ˆ operating conditions, AD = machine access difficulty In the index

CI =[(SX1.5)+(IP X 2.5) + (MCX2) + (FFX1)+ (DL X 1.5) +(OCX1)]X AD.

Using the formula the Criticality Index is carried out and are as follows in table no 3

< Take in Table 3 >

Similarly Criticality Index of Components are derived as follows in table no 4

< Take in Table 4 >

Discussion and analysis

It has been shown from the table that the Units operating in the gas turbine plant are of mixture of high critical and medium critical and of Low critical items. The units are segregated according to criticality indexes and maintenance policy derived with the consultation with the Plant personnel. The demarcation of High value, medium value and low value are categorized as follows

High value Critical numbers for Units: Criticality Index ≥ 700

Medium value Critical numbers for Units: Criticality Index 1000 ≥ C.I. ≥600

And High value Critical numbers for Units: Criticality Index 600 ≥ C.I.

The analysis shows that Unit 1 is high critical items or high Criticality Index and Unit 3,4,5 are medium criticality unit or medium criticality index. And Unit 6,7,8 are low criticality items or low criticality indexes. The maintenance Policy recommended are as follows: -

< Take in Table 5 >

And it covers all the Units in the plant. The high critical value machines are placed in category group 1 and Medium category machines are placed in category group 2 and low critical value machines are placed in group3. Similarly analyses of the components are carried out as follows: The reason of this analysis is to find out critical components and 100% satisfied maintenance policy. So that Plant can run very safely and less number of outages or breakdown occurs.

The demarcation of High value, medium value and low value are categorized as follows

High value Critical numbers for Components: Criticality Index ≥ 1000

Medium value Critical numbers for Components: Criticality Index 1000 ≥ C.I. ≥600

And Low value Critical numbers for Components: Criticality Index 600 ≥ C.I.

12 items are found in high critical category. These items are as follows :

2ndstage nozzle, Bearing header, Bearing 2 and 4 of L.P. turbine

Bearing 2, Aux hydraulic pump, Lp turbine (back side of H.P. turbine),. Servo valve, Turbine housing and Bearing 2 of H.P. turbine.

2nd stage Nozzle, Bearing 2, of Combustion chamber.,

Bearing of Compressor,

and P.m g. shaft of Generator.

7 items are found in medium critical category. These items are as follows:

Diesel engine and L.P. turbine of L.P. turbine

Lub oil sump, and Mist eliminator of H.P. turbine

Servo valve of Combustion chamber

Servo valve of Compressor

and P.m.g. bolt of Generator

The rest 13 items are in low critical category.

The maintenance policy is stated as follows. Similarly The high critical value components are placed in category group 1 and Medium category components are placed in category group 2 and low critical value components are placed in group 3. And accordingly the maintenance policy was derived.

< Take in Table 6 >

CONCLUSION

The definition of the most appropriate maintenance policies for a large system such as an gas turbine plant requires the development of the appropriate decision support systems. The maintenance plan selection for each component is very Complex due to the difficulties concerning data collection, The number of factors to be taken into account , their subjectivity, the large number of the plant machines around 8 and 40 components in the case under examination are considered, and the fact that the plant is running. When integrated with the analysis of the facility criticality , the technique adopted has proved to be a valid support. for the selection of the maintenance strategy. The factors incorporated in the analysis are safety, machine importance for the process, maintenance costs, failure frequency, downtime length, operating conditions; machine access difficulty In the index had made the calculation more attractive.

Further Research

The Research can be further extended by incorporating some decision making tool like analytical hierarchy process, TOPSIS in maintenance strategy selection. The order of preferences for the maintenance strategy is not present in this research, which is rather calculation of weights by incorporating some parameters. The research work can also be extentended by incorporating some mathematical tools and mathematical analysis.

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Table 1-Weight values assigned to the relevant parameters considered in FMECA analysis are as follows :

Parameters	weight
Safety	1.5
machine importance for the process;	2.5
Maintenance costs;	2
[2] failure frequency;	1
[2] downtime length;	1.5
Operating condition	1

Table 2-Maintenance policy selection based on criticality index

Criticality Index	Maintenance Policy
>700	Predictive
700- 600	Preventive
<600	Corrective

Table 3: Criticality index of the different units of the Gas turbine Plant

Units no	Running Hours	Nos of Breakdown	Hours in Breakdown	Criticality Index
1	8760	15	96	775
3	37200	176	303	610
4	113152	255	363	675
5	17520	132	290	620
6	4320	67	133	500
7	47544	141	282	458.5
8	37920	72	173	525

Table 4- Criticality analysis of the components of Gas turbine Plant

Rank	Component	Subsystems	Nos of Breakdown	Hours in Breakdown	Running Hours	Criticality Index
1	Generator	P.m.g. bolt	6	6	113152	740
2		P.m.g. bush	40	44	113152	401.5
3		P.m.g. shaft	4	20	113152	1195
4	Electrical and other sub systems	Generator breaker	33	62	113152	538
5		Relay	8	16	113152	480
6		Control system	11	14	113152	416
7		Feeder	10	26	113152	404
8		Bus bar	9	10	113152	391
9		Gas collecting tank	11	39	113152	533
10		Grid	12	14	113152	322
11	Compressor	Turbine housing	5	11	113152	578
12		Servo valve	3	8	113152	623
13		bearing	2	7	113152	1090
14		Air filter module	6	18	113152	717
15	Combustion chamber	Combustion chamber	48	79	113152	432
16		Servo valve	4	4	113152	661
17		2nd stage Nozzle	4	21	113152	1340
18		Bearing 2	2	3	113152	1042
19		starter	5	7	113152	596
20	HP turbine	HP turbine	21	30	113152	425
21		Mist eliminator	2	2	113152	980
22		Lp turbine	1	2	113152	1164
23		Servo valve	1	1	113152	1263
24		Turbine housing	2	3	113152	1219
25		Aux hydraulic pump	2	4	113152	1233
26		Lub oil sump	2	4	113152	878
27		Bearing 2	2	9	113152	1114
28	L.P. turbine	L.P. turbine	6	15	113152	537.2
29		2ndstage nozzle	1	1	113152	1579
30		Diesel engine	2	7	113152	859.5
31		Bearingheader	2	9	113152	1045
32		Bearing 2 and 4	1	2	113152	1579

Table 5-The maintenance Policy selection of the units of Gas turbine plant

Criticality Index	Maintenance Policy	Units coming under the policy
>700	Predictive	Unit 1
600-700	Preventive	Unit 3,4,5
<600	Corrective	Unit 6,7,8

Table 6- Maintenance Policy selection of the components of gas turbine plant

Criticality Index	Maintenance Policy	Group coming under the policy
>1000	Predictive	high critical value components (group 1)
600-1000	Preventive	Medium critical value components (group 2)
<600	Corrective	low critical value components (group 3)