Preventive Maintenance of Steam Turbine used in Thermal Power Plant by Reliability Investigation and FMEA

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Abstract: ***The fault method of steam turbine parts, unbalance of pivoting components, misalignment of turbine shaft, rotor breakdown, oil film flimsiness of bearing and so on are responsible for problematic and unverifiable failure of energy plant. Experience of administrators, support arrangement execution of maintenance group and utilizing norms codes of good practices by designers and makers are diminishing the potential failure methods of the system. This work researches the reliability of steam turbines introduced in a thermal power plant. reliability estimation depends on a most recent five year verifiable failure database of two turbines of 210 MW, both are introduced and authorized in the meantime. The technique for reliability assessment depends on ideas of system reliability, for example, failure mode and impacts examination (FMEA) to order basic segments in light of an authentic failure database to enhance the system reliability. It is important to enhance the reliability records of the power plant by taking a few measures, for example, very much arranged and routine maintenance of types of assets and also preparing and retraining of specialized technical human resources of the major equipment.***

Keywords: Reliability, RCM, MTBF, MTTR, FMEA

1. Introduction

Failure mode and effects analysis (FMEA) is a broadly utilized building method for characterizing, recognizing and dispensing with known for potential Failures, issues, blunders et cetera from framework, outline, process, and service before they come to the customer, **Stamatis et al. [1]**. While applying FMEA, a cross functional and multidisciplinary group recognizes Failure modes, estimate their dangers and organizes them with the goal that proper remedial moves can be made. A Failure mode in one part can fill in as the reason for a failure mode in another segment. A Failure cause is characterized as a plan shortcoming that may bring about a Failure. For every Failure mode distinguished, the FMEA group ought to figure out what a definitive impact of Failure will be. A Failure impact is characterized as the consequence of a Failure mode on the capacity of the item or process as apparent by the client, **Kwai-Sang Chin et al. [2]**. FMEA ends up being one of the most essential early protection activities in system, plan, process or administration which will keep failures and blunders from happening and achieving the client, **Pillay et al. [3]**. Steam turbine generator set is a key gadget of the power plant. For capable power plant, cost effective generation and long run execution, it is basic to keep up the power plant should run Failure free. Reliability examination have progressively perceived as standard apparatuses for the outlining, booking of task and support of any system. The dependability of energy plant is identified with the likelihood of giving power proficiently and more sparing with a sensible quality affirmation of coherence, **Wang et al. [4]**. A modern power plant framework can be separated into age, transmission and circulation utilitarian territory. The framework can be thought about freely or in blends of every one of the three useful zones. This work is restricted to the assessment of the age dependability. The main aim is to advancement a strategy to enhance the reliability of the steam turbine control plant. In this regard, Reliability centered maintenance ideas are used as a rule for positioning the support arrangement needs of the basic segments of steam turbine. The reliability of the framework can be assigned through the deterministically approach or potentially probabilistic approach. **De Souza et al. [5]** manage the probabilistic part of operational execution of energy plant. In the work, deterministic approach of reliability examination of the asset is utilized to manages seeing how and why a system is unsuccessful, and how it can be intended to keep away from such Failure from happening or re-happening. This incorporates examination, for example, audit of verifiable field Failure reports, understanding logical hypothesis behind the disappointment, the part and level of support policies. **Wang and Billinton [6]** reported that the part of a power plant is to give power, creatively and with a sensible certification of coherence and quality to its shoppers. **Lakhoua [9]** proposed that electric power plant can be partitioned into reasonably subsystems or useful regions, for example, age, transmission and conveyance. Reliability examinations might be done independently or in blends of each of the three utilitarian territories. This work is restricted to the estimation of the age reliability. An advanced power plant is exceptionally immense, multifaceted and exceedingly incorporated, **Gupta and Tewari [7, 8].**

2. Reliability Estimation of Steam Turbine

The most recognized meaning of reliability is the ability of a system, item, framework, and so forth., to work under chosen working conditions for a particular period or number of cycles. Consequently, the reliability is the likelihood of a system to actualize required task for a given time frame with no failure under indicated conditions for which it is foreseen.

The measure for reliability estimation of non-repairable asset/system is Mean Time to Failure (MTTF) and for repairable framework is Mean Time between Failure (MTBF). Numerically, reliability of a part/component for given period t can be represented as,

$$R(t) = e^{-\lambda t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$\text{Where, } \lambda \text{ (mean time to failure)} = \frac{\text{(Total number of failure/Turbine population)}}{\text{(Operating Periods in years)}}$$

The reliability of steam turbine has ascertained based most recent five years historical failure database of two turbines of 210 MW, both are installed and commissioned at the same time. The reliability count is appeared in Table-01. Mean time between failures (m), mean time to repair (ζ) and reliability is assessed by preparing the historical fault data available.

Mean time between failures (m) is a ratio of aggregate working time between maintenance every year to the quantity of failure every year. It is the measure of number arithmetic mean (average) time, in which period the asset will execute a predetermined task before an unplanned failure will occur. Consequently it is the reciprocal of the failure rate,

$$\lambda = \Phi n/\beta t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$m = 1/\lambda \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where, λ = Expected no of failure, Φn = no of failures per year and βt = total operating time between maintenance in the year.

Mean time to repair (ζ) is a ratio of total outage hours per year to number of failures per year. It is an inverse of expected repair rate. Hence, mean time to repair is quantified the average outage hours; the equipment can bring back to normal operating condition when it does fail.

$$\zeta = \psi i/\Phi n = 1/\mu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where, ψi = total outage hours per year, Φn = number of failures per year and μ = expected repair rate.

It is expected that failed system is quickly repaired, when we compute the mean time between failures (MTBF). Therefore, mean time to repair (MTTR) or repair rate is zero, in real framework this is inconceivable; along these lines. MTBF is considered as sum of the MTTF and MTTR. In contrast with MTBF, mean time to failure (MTTF) is a measure of average time to failures with the demonstrating speculation that the failed system can't be repaired. The MTTF is essentially the reciprocal of the failure rate.

Reliability R(t) is viewed as the ability of a asset to execute its required function reasonably under given conditions amid an expressed time frame [Ireson et al. (1996), and Smith and Hinchcliffe (2004)]. Accordingly, reliability is a probability that the equipment is operating without failure in the specific time t.

$$R(t) = e^{-t/m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

$$\text{Therefore, } (t) = e^{-\lambda t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

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

Table 1: Calculation of MTBF, MTTR and Reliability for "Turbine-01" of the year 2013-2017

Year	Φn	βt	$\lambda=\Phi n/\beta t$	$m=1/\lambda$	ψi	$\zeta=\psi i/\Phi n$	$\mu=1/\zeta$	t	$R(t) = e^{-\lambda t}$
2013	12	7213	0.00166	602.41	71	5.92	0.1689	241	0.670
2014	24	6187	0.00387	258.39	75	3.12	0.3200	227	0.415
2015	17	7287	0.00233	429.18	63	3.70	0.2702	183	0.653
2016	21	6552	0.00320	312.50	52	2.48	0.4032	243	0.459
2017	23	7640	0.00301	332.25	58	2.25	0.4444	264	0.452

Table 2: Calculation of MTBF, MTTR and Reliability for "Turbine-02" of the year 2013-2017

Year	Φn	βt	$\lambda=\Phi n/\beta t$	$m=1/\lambda$	ψi	$\zeta=\psi i/\Phi n$	$\mu=1/\zeta$	t	$R(t) = e^{-\lambda t}$
2013	8	7818	0.00102	980.39	87	10.87	0.0919	289	0.744
2014	13	8196	0.00158	632.91	41	3.15	0.3174	196	0.734
2015	15	8039	0.00186	537.63	36	2.40	0.4166	213	0.672
2016	11	7726	0.00142	704.22	43	3.90	0.2564	179	0.775
2017	9	8411	0.00107	934.57	47	5.22	0.1915	162	0.840

The investigation shows that steam turbine-01 has maximum failure rate and minimum reliability in comparison to turbine-02. Reliability of the steam turbine can be enhanced considerably by reviewing maintenance practices. Routine preventive maintenance should be given additional attention to improve the performance of power plant.

3. Reliability Analysis of Steam Turbine

The failure criterion of any component of steam turbine is lack of ability of creating the ostensible power output. The reliability investigation is executed for two steam turbines introduced in the power plant, submitted to same appointing procedure and beginning to work at the same time. Time to failure information has utilized for reliability investigation of a system. Mean time to failure (MTTF) is for the most part utilized parameter to describe reliability of a system. The mean time to failure is given by,

$$MTTF = \int R(t), [0 \text{ to } \infty] \ldots\ldots\ldots\ldots \text{(7)}$$

Where, $R(t)$ = reliability at time t and t = time period (hours)

In the reliability investigation the Bath-Tub Curve (Figure-1) is extensively utilized for time subordinate failure rate of segments. Bath-Tub has three distinct regions: early life period, useful life period, and wear out period. A decreasing curve between day and age t0 to t1 of the bath tub speaks to the early life time frame (otherwise called newborn child mortality period) of the system.

Random failures are spoken to by the exponential probability function for expressing reliability phenomena. The failure modes in the beginning of the operational life of steam turbine are not are not generally random thusly it can't be spoken to by an exponential reliability distribution. The early failure mode of the steam turbine relies on designing, manufacturing, commissioning, operational method, misalignment between cylinder and rotor, uneven radial clearance caused by improper installation and support and even on natural conditions.

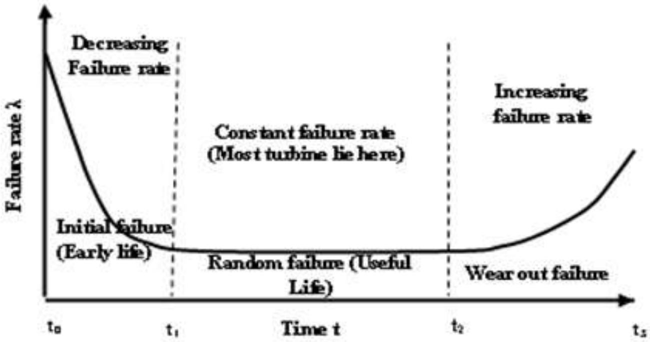

Figure 1: Bath-Tub Curve

The failure rate stays steady will stay consistent amid the valuable life time of any system however failure will happen haphazardly. This is appeared on the diagram for era t1 to t2. Wrong usage, human blunders, and unsatisfactory design margins might be some of the source for failure in this time of life. These failures can be condensed by consolidating repetition in the system. During wear out period (between t2 to t3) the likelihood of failure rate has increments. In this period the failure happens because of maturing, misalignment, crawl, contact, limited existence of segments and less preventive support. These failures can be diminished by usage of effective preventive maintenance policies and substitution of harmed parts. At the point when the maturing impact (time related failures) and early failures are exhibited then the reliability of steam turbine is generally assessed by Weibull probability distribution.

4. Fault Mode Analysis of Steam Turbine Based on Fmea Metho

Failure Modes and Effect Analysis (FMEA) is known to be a systematic procedure for the analysis of a system to identify the potential failure modes, their causes and effects on system performance. FMEA is applicable at various levels of system decomposition from the highest level of block diagram down to the functions of discrete components. FMEA is an analysis method faced to system specific physical unit. Failure mode analysis uses the bottom-up method. Based on the basic failure mode of system unit, potential fault reasons will be found out. Analyzing the effect by fault reasons, some actions are took to reduce and prevent the impact of fault on the system [10]. The process for carrying out an FMEA can be divided into several steps which are briefly explained here [3].

1) Develop a good understanding of what the system is supposed to do when it is operating properly.
2) Determine the system analytic hierarchy. Divide the system into sub-systems and assemblies in order to localize the search for components.
3) Structure system reliability block diagram. Use blue prints, schematics and flow charts to identify components and relations among components.
4) Determine failure modes of each component and the effects of failure modes on assemblies, sub-systems, and the entire system.
5) Evaluation the impact on the system caused by failure mode.
6) Categorize the hazard level (severity) of each failure mode (several qualitative systems have been developed for this purpose).
7) Estimate the probability and calculate the Risk Priority Number (RPN).
8) Develop recommendations to enhance the system performance. This fall into two categories:
    a) Preventive actions: avoiding a failure situation.
    b) Compensatory actions: minimizing losses in the event that a failure occurs.
9) Summarize the analysis: this can be accomplished in a tabular form.

Generally, an FMEA table will have a major row for each component. As these components may have multiple failure modes, the major row is sometimes divided into sub-rows where each sub-row summarizes a specific failure mode. The table is organized into the following columns: Component, Component Function, Potential Failure mode, Potential Cause(s) of Failure, Potential Effects of Failure, Probability (Occurrence), Hazard level (severity), Detection, RPN (O*S*D) [11-15].

According to the above method, the FMEA table of steam turbine was shown in table-03. By using FMEA, we will at least get the fault symptoms, fault consequence and effect, fault reason, preventive actions and other information of steam turbine.

Table 3: FMEA scale for Probability of Occurrence (O), Severity (S) and Detectability (D)

Probability of occurrence (O)	*Rating*	*Severity (S)*	*Rating*	*Detectability (D)*	*Rating*
Failure occurs every 8 years	1	Negligible or no effect.	1	Design controls almost certain to detect a potential cause and subsequent failure mode.	1
Failure occurs every 4 years	2	Operator will experience minor negative impact on the process.	2	High chance that designing controls will detect a potential cause and subsequent failure mode.	2
Failure occurs every 2 years	3	Turbine operable and safe but performance degraded.	3	100% visual inspection with visual standards.	3

Failure occurs every years	4	Performance can be severely degraded and maintenance will be needed within next few months.	4	Periodic Non Destructive Testing (NDT).	4
Failure occurs every 6 months	5	Turbine inoperable, immediate shutdown is needed major financial impact.	5	Very remote chance that design or machinery controls will detect a potential cause and subsequent failure mode.	5

Table 4: Result from the FMEA

Component	Component Function	Potential Failure Mode	Potential Causes of Failure	(O)	Potential Effects of Failure	(S)	(D)	RPN
Labyrinth seals	Mechanical Sealing	Erosion	• Solid particles in the steam • Formation of Droplets in the steam	3	• Performance drop • Leakage	2	2	12
		Corrosion	• Expos ion to corrosive substances in the steam	1	• Performance drop • Leakage	1	3	3
		Rubbing	• Misalignment of rotor	1	• High wear rate	2	2	4
Diaphragm	Convert thermal energy to kinetic energy by accelerating steam	Erosion	• Penetration of solid particles & droplets from steam	3	• High wear rate, vibration, fractures, breaking of nozzles	4	3	36
		Scaling	• Too dry steam • High amount of substances in steam	2	• Efficiency drop, vibration, clogging of steam path	3	3	18
		Corrosion	• Exposure to corrosive substances in the steam	1	• Wear	2	3	6
Rotor Blades	Convert kinetic energy to mechanical energy	Erosion	• Penetration of solid particles & droplets from the steam	2	• Vibration, fracture, high wear rate,	4	3	24
		Cracking	• Fatigue, Vibration	1	• Breaking of blades	5	4	20
		Scaling	• Too dry steam • High amount of substances in steam	2	• Efficiency drop, mass flow drop, vibration, clogging of steam	3	2	12
Bearings	Support the rotor	Wear	Aging	1	• Vibration	2	1	2
		Fracture formation	• Fatigue • Vibration	1	• Damage to bearings	2	4	8
Rotor	Transfer mechanical energy to generator	Erosion	• Penetration of solid particles & droplets from the steam	3	• High wear rate, Vibration, • Unbalanced rotor,	2	3	18
		Corrosion	• Exposure to corrosive substances in the steam	2	• Wear	2	3	12
		Misalignme-nt of rotor	• Generator & Turbine supports are skewed	1	• Vibration	4	2	8
		Fatigue	• Aging	1	• Fracture of blade attachments	2	4	8
Casing	Protects the rotor and forms the steam path	Erosion	• Penetration of solid particles & droplets from the steam	4	• High wear rate of diaphragms and drain holes	2	3	24
		Scaling	• High amount of substances in the steam, Too dry steam	3	• Clogging of drain holes	2	3	18
		Corrosion	• Exposure to corrosive substances in the steam	2	• wear of casing	1	3	6

From the above table-04, the maintenance personals will attain the turbine component first, which has maximum RPN and will follow it by decreasing order. So when the preventive maintenance/overhauling will be taken place by the maintenance personals, they will attain diaphragm first. And Labyrinth seals will be attained last.

5. Conclusion

The reliability characteristics of any overwhelming obligation steam turbine relies on the different factor, for example, on on-site installation process, skills of operators, training of maintenance team, natural factors and steam quality. The proposed strategy can characterizes quantitatively the system reliability and accessibility. The system reliability can be inspected through utilizing of time to failure and time to repair database. The examination depends on the most recent five year operational data base. The advancement of chronicled database with extra failure and repair information amid future operational years will allow more solid estimation of the turbines reliability. Preparing and retraining of technical human resources on the major equipments, well planning and more regular scheduled maintenance can enhance the reliability files of the plant. Meanwhile, in light of the FMEA method, fault method of steam turbine components was examined in detail. Some profitable conclusions were achieved, including the fault symptoms, fault consequence and impact, fault causes, preventive activities and other data of steam turbine.

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