Fault Liability and Maintenance Cost Modeling of a Steam Turbine

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Abstract - **This paper focuses on modeling of power stations technological equipment reliability. There is described a method of failure model creation, based on failure and repairs data of a particular components, and cost model creation, based on costs specification. At first there is mentioned the data processing procedure, problems of appropriate stochastic parameters inference and total characterization of failure model connected with small number of data and their dependence on operational conditions in concrete. This model should be able to predict the future conditions and to estimate important evaluation indicators. For that reason it is necessary to introduce the software, which is used for simulation, visualization and optimization future development of evaluation indicators possibilities. This work is a part of the joint project of the UWB and Škoda Power company called "Operational availability and maintenance cost optimization with the computer support".**

I. Introduction

One of the basic tasks of management in operational reliability control area is planning and making the strategic decisions. It is important especially in energetic, where an effect of maintenance prove at fault liability and expensiveness of potential consequences. Planned and preventive maintenance activities are instruments for technological equipment lifetime raising and for contractual power supply provision. These activities have decisive effect to total operational cost too. In order to be optimal this service task, it is necessary to make an extended analysis, failure causes and effects calculations with respect to task effect and production progress strategy.

The aim of this paper is to bring out the problem of processing the information from steam turbine operation to proper form for effective maintenance planning especially based on cost evaluation of outage risk and maintenance.

The principle is the creation of the probability model of operational condition from historical data. This model should be able to predict the future conditions and to estimate important evaluation indicators. With the aid of input conditions and simulation parameters changes it is possible to make sensitivity analysis of indicators in reliability interval, iterative optimizations and finding of the best strategic solution according to given criteria e.g.

II. Data Processing

A. Data processing basic themes

Model design stem from demand after the components fault liability character of steam turbine realization in accordance to component failure and repairs data, obtained from Škoda Power (producer). The main aim is time development monitoring of technological unit fault liability. According the analysis there was find out, that the fundamental problem is finding so-called 'hidden failure model' of components without planned maintenance execution (left scheme) based on failure data of components at real operation without applying the planned maintenance (right scheme), see fig. 1.

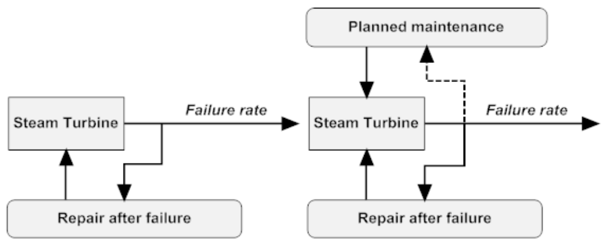

Figure 1. Scheme of failure model with and without planned maintenance

Reduction of planned maintenance effect is possible to solve with expert based adjustment of failure data set or model parameters. To components, which was called for repair at planned maintenance, is attached a failure. Further way is to take a presumption, that failure rate will be rise after the time of planned maintenance interval. The modified model has more pessimistic character then the original, but it is more realistic.

Other problem is definitely small number of failure data of selected component with the low or zero observed fault liability and high technical lifetime. In the case, it is not possible to approximate more complicated stochastic functions by ordinary way. Therefore complex data processing must be used with respect to knowledge based presumptions.

These presumptions are:

a) time progression of components failure rate matches to bathtube curve,
b) mean failure rate can be determined from designed technical lifetime.

According to the assumptions is possible to set a shape of the estimation parametric function curve or to extend a statistical failure data.

B. Statistical analysis

For stochastic probability distribution of failure origination special parameters must be defined. These can be taken from producer of components or from some reliable database (only if there was guaranteed an identical form of definition, comparable construction and components properties). However, mostly this information is not available. Then it is necessary to use a standard statistical solution ([1],[2],[3]). According to the historical data about time duration between failures and repair duration it is possible to estimate needful parameters by data analysis. For statistical parameters estimation it is necessary to have a sufficient number of correct values obtained by many realizations. It follows, that the sparse data is necessary to put together for resultant estimation credibility. For compounding of components is used a bunching algorithm repeatedly, orientated firstly to similarity of particular components failure frequency histogram and then to mean time of repair. McQueen bunching algorithm (so-called k-means) is used for implementation. After data compounding it is already possible to estimate standardized group parameters of failure characteristics, which can be later linear recalculate for particular component parameters (with using predefine particular mean time between failure).

For fault liability of mechanical parts definition it is most often applied Tri-weibull stochastic function [2]:

$$l(x) = \frac{b_1 x^{b_1 - 1}}{h_1^{b_1}} + \frac{b_2 x^{b_2 - 1}}{h_2^{b_2}} + \frac{b_3 x^{b_3 - 1}}{h_3^{b_3}}. \qquad (1)$$

It takes into account time progression of failure rate because of aging very well (otherwise bathtube curve). Module Weibull analysis of Availability Workbench (AWB) software by company Isograph is used to bathtube curve forming. Needful parameters β' a η' characterizing the interlay curve are obtained by cumulative probability graph after particular data groups import.

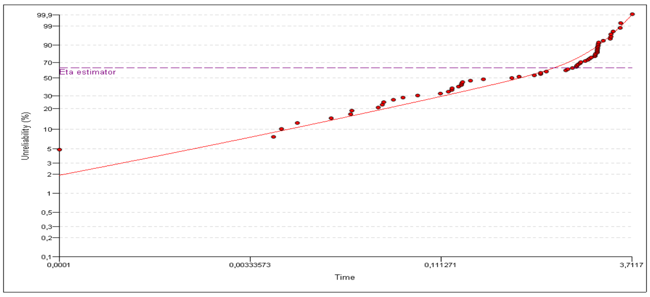

Figure 2. Example of Cumulative probability graph

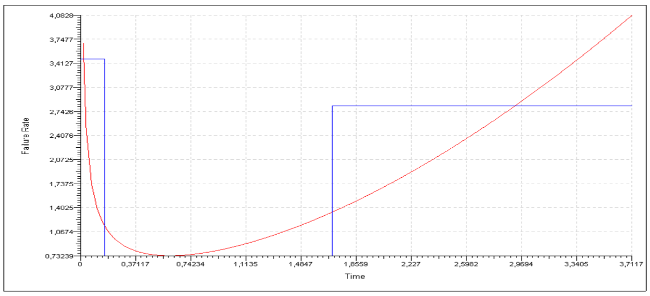

Figure 3. Example of Failure rate graph

On the figures 2 and 3 is displayed a standardized progression of given group failure rate. The results of automatic parameters estimation for particular groups need not to be always satisfactory, that is why it is necessary to adjust them by hand for proper form of failure rate curve (according to expert estimations). After standardized parameters recalculation into particular components parameters is obtained sufficient information for components failure rate progression modeling. For recalculation there is used the time transformation. The basic criteria for this transformation is the curve shape conservation and its proportional expansion to real values of mean time between failures computed from data. The time transformation is applied to Tri-weibull distribution parameters of each component:

$$\begin{aligned} b &= b' \\ h &= h' \cdot MTTF \end{aligned}, \qquad (2)$$

where β' and η' are original parameters of standardized distribution for component groups and *MTTF* is mean time to failure of particular component.

III. Availability and Cost Model

A.. *Model creation*

One of the basic efficiency indicators of steam turbine energy operation is availability, from which is possible to calculate specific technical fault liability. Time progress can be obtained by simulation according to real operation behavior. For implementation of availability model there is used module AvSim of software Availability Workbench.

This module offers the tools for definition and editing of stochastic models string data structure in a several most widespread formalisms and hierarchical structured levels of components characterization to the component cause of failure level.

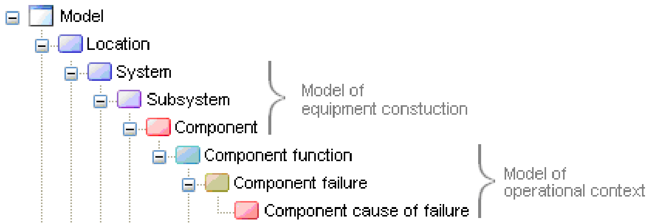

Figure 4. Hierarchical structured levels of components

In model structure point of view, there is used serial sequence principle of selected critical components reliability blocks (the particular components operational probability multiply themselves). Decisive aspect is certainly failure cause and effect ([4]).

To model there can be assigned a various additional information and operational conditions including of costs specification, which are fundamental for cost model. This model is created in other module of AWB called RCMCost.

Simulation is proceeded by Monte-Carlo ([5]) method. There are discerned between the operational and failure condition. Availability is determine as relative ratio of operation duration and total time in view. A number of realizations of random processes are generated and resultant condition is computed as the mean.

B. *Planned maintenance effects on fault liability modeling*

For every component there exists parameters set, which represents failure origin probability distribution in Tri-weibull function form. Appropriate failure rate function representation is the best way how to characterize the risk progress of failure origin in time on similar conditions and presumptions, under them was the function derived from real failure data.

Due to the information of the major part of the components technical lifetime the parameter estimation is achieved, which eliminates planned maintenance effect from data (at least in part). This effect can be modeled independently (in the various times).

Effect of planned maintenance to the failure rate development is so-called age reduction from probability aspect, which developed a reduction of effective lifetime of every component and whole modeled equipment.

The failure rate progress is changed by the planned maintenance implementation to the model in accordance to the original data. The simulation results should agree with the real data.

Figure 5 shows the example of common component failure rate progress in calendar time – without planned maintenance, when failure rate curve follows up the bathtube curve and with planned maintenance, which is made every 5 years.

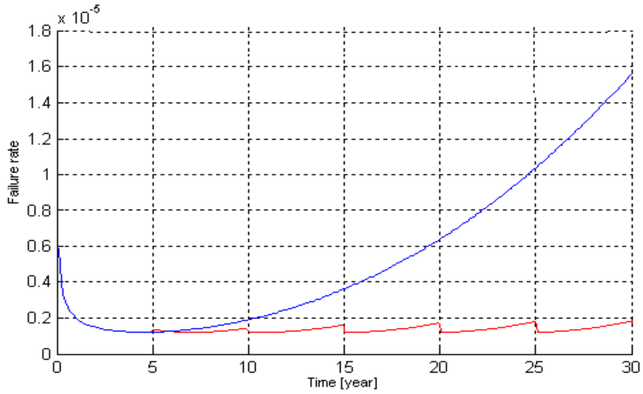

Figure 5. Example of common component failure rate

C. *Model verification*

Because of small number of data reliable the stochastic distribution parameters estimations aren't fully. That's why it is not possible to consider the result of first simulations to be the final result. It is important to set up the common model so that the simulations results could be comparable with real condition of concrete equipment.

Due to presumptions and hypothesis it is necessary to specify the model according to some stable characteristic of fault liability, which can be analyzed from data. Mean of year's availability relating to whole monitored operational term is chosen as the verification characteristic. By the ratio of real availability (calculated from data) and simulation availability (estimated by model on the same conditions) the fault coefficient is determined. This fault coefficient is used for proportional optimization of the correction coefficient in accordance to statistical relevancy of number of data.

D. *Model correction*

The aim of correction is the linear reduction of the failure rate function value. Coefficient of correction depends on number of data for each component and it can be computed in accordance to formula:

$$K = \frac{Q+N}{1+N}, \qquad (3)$$

where Q is optimization parameter, which is changed by ΔQ in every iteration, and N is real failure number of data, from which is estimated given parameter set. This computation is based on presumption, that unavailability increase because of added components failures is necessary for unavailability reduction compensation, especially for components from small number of data.

Model parameters correction is based on transformation of stochastic distribution coefficients. In the case of exponential distribution the simplest way is multiplying by one parameter K – mean time to failure with correction:

$$l^*(x) = \frac{l(x)}{K} = \frac{1}{K \cdot MTTF}, \qquad (4)$$

In the case of Tri-weibull distribution the situation is more complicated. It is necessary to multiply every term denominator, then total failure rate become reduced independently from time and curve form is saved. It is appropriate to make correction just for η coefficients in denominator. Calculation is made in accordance to formula:

$$l^*(x) = \frac{b_1 x^{b_1-1}}{(K^{b_1^{-1}} \cdot h_1^{b_1})^{b_1}} + \frac{b_2 x^{b_2-1}}{(K^{b_2^{-1}} \cdot h_2^{b_2})^{b_2}} + \frac{b_3 x^{b_3-1}}{(K^{b_3^{-1}} \cdot h_3^{b_3})^{b_3}}, \qquad (5)$$

Result of iterative optimization is parameters of particular components failure model set correction.

IV. Availability and Cost Simulation, Optimization

For getting the close results after model correction and verification it is necessary to correct and completely characterize the availability and cost model from all perspectives (labour, spares, equipment, failure effects, prices etc.). Used software AWB has strictly defined needed resources and functionalities. The scheme of resources and functionalities can be seen on the figure 6.

Simulations made by AWB are focused on fault liability indicator development location. There are randomly generated failure events in defined time horizon and number of realizations according to the required parameters.

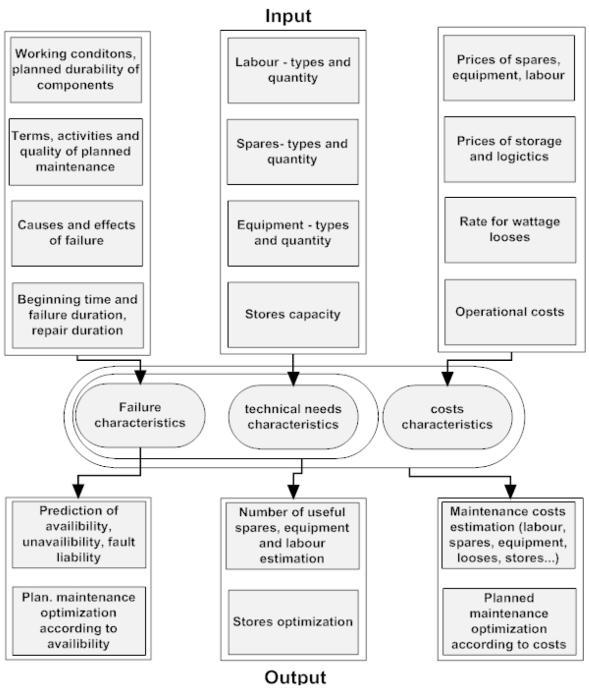

Figure 6. Scheme of needful resources and functionalities of AWB

The simulation results are mean values of availability in every particular period (1 year e.g.) in simulation horizon. According to project assignment the attention is concentrated on simulation of the history and prediction of availability and specific technical fault liability. Many parameters are set up or adjusted according to the expert estimations. On the figure 7 there is shown running of the specific technical fault liability in history.

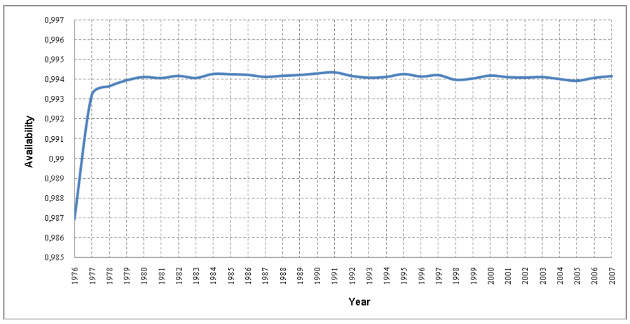

Figure 7. Common steam turbine availability simulation (history)

Cost simulations and planned maintenance interval optimizations are made in RCMCost. Parameters of failure origin probability distribution for cost model are imported from AvSim module and additionally there are rated by cost every maintenance units and failure effects. Software enables the optimal interval calculation from the cost and from the availability perspective.

Simulations are aimed at general and ordinary maintenance interval cost optimization. Optimal interval is a compromise between maintenance costs and costs to repair after failure (see fig. 8).

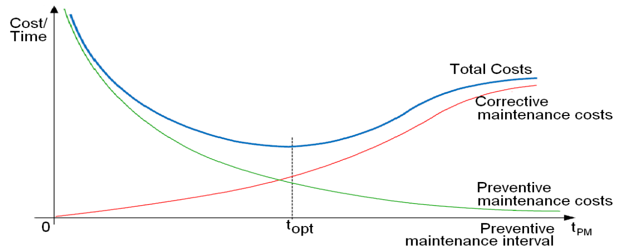

Figure 8. Principal of cost optimization

It is very important to execute the sensitivity analysis, which can show the potential range of resultant characteristics for selected availability parameters estimation interval. Sensitivity analysis can be taken for relative change of mean time to failure of particular components, mean time of repair or for age reduction factor (it characterizes the quality of repair) changes – see fig.9.

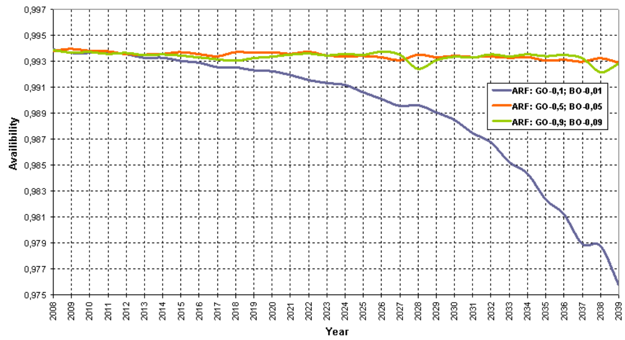

Figure 9. Sensitivity analysis of age reduction factor (ARF)

V. Conclusion

Fault liability modeling and simulations of condensing steam turbine described above is focused on availability and cost prediction (with the option to change the operational condition, particular terms and planned maintenance range). As the results it can be computed for example expected operational availability values, which could be used for power supply provision guarantee or as recommendation for planned maintenance optimal time and range. These resultant technical-economic indicators are useful for turbine producers, which must guarantee the failure-free operation and service, and for users (energy companies), which can predict their own management conditions and the expansion planning.

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