FMECA Use for the Equipment Reliability Analysis in Hydro-Power Engineering

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Abstract. It is proposed to use FMECA analysis for collection and compilation of statistical information concerning failures of the main hydro-power equipment. An algorithm of FMECA analysis for hydro-power industry has been developed. In the article authors give an example of the analysis for the hydroelectric power station of the Angara-Yenisei cascade.

1. Introduction

Today hydro-power engineering is considered to be one of the most effective areas of the electric power industry and one of the most important sources of energy supply. The growing interest in the hydro-power industry is raising the issue of ensuring the reliability of the main equipment.

In the Russian Federation the majority of hydroelectric power stations are at stable maintenance stage, therefore the study of the reliability can be constructed on quantitative methods of an assessment of failures.

As quantitative methods are based on stable maintenance stage statistics on failures that raised the issue for hydroelectric power stations - how equipment database on failure must be collected and systematized in order to provide its effective planning and projections.

One of the standardized methods used by modern engineering for analysis of industrial equipment failures named as Failure Mode Effect and Criticality Analysis (hereafter called FMECA) [1]. FMECA combines quality component – description of consequences of the failure, and quantitative component – calculation of its probability of occurrence.

MIL-STD-1629 is most widely used (basic) standard of FMECA, drafted by THE United States Department of Defense. Generally, the standard describes the failure detection process, rating scales and formulas for failure rate calculating.

As FMECA has been used by various industries such as automotive, aviation and nuclear for almost 40 years, special standards have been developed for its use [3-4].

In this regard, it is important to note that specials standards, basically, describe unified FMECA process and the main difference is to modify industry-specific rating scale and organization forms of database on failures.

As far as FMECA technology requires failure database, the following section will deal with recommendations of database formation for companies of hydro-power industry as well as tables for the qualitative analysis of consequence of the failure.
2. FMECA for hydro-power industry

The analysis of the information on failures has shown the inefficiency of the existing statistical information forms, therefore FMECA-form for hydroelectric power stations has been suggested. (Table 1).

As FMECA-form is being completed for each subsystem of the main equipment, so initially the company needs to determine the system and its structure; to identify the boundaries of the system, which parts of the system, should be taken into account, and which should not; to highlight the main functions for the system; to divide the system into components.

Usually there are functional elements such as subsystems and elements in the structure of the system, the further decomposition of which depends on the objectives of the analysis.

Once the system and its main subsystems have been identified, completion of the form could be initiated by the following principle.

A. **Elements of construction structure**
   Each subsystem element with an identification number is defined.

B. **The Function**
   All functions performed by each of the subsystem elements are specified. Specific number is supposed to be assigned to each function.

| Code | Description | Code | Description |
|------|-------------|------|-------------|
|      |             | 1    |             |
|      |             | 2    |             |
|      |             | 3    |             |
|      |             | 4    |             |
|      |             | 5    |             |
|      |             | 6    |             |

C. **Possible types of functional failures**

It is identification of possible types of functional failures for each function/element.

D. **Failure Rate (1).**

| Probability of occurrence of failure | Reasons for refusal | Types of corrective actions | Subsystem Level | Level of the System | Degree of the consequences of failures | Risk Index | Responsible unit |
|--------------------------------------|---------------------|-----------------------------|-----------------|---------------------|----------------------------------------|------------|-----------------|
| 5                                    | 6                   | 7                           | 8               | 9                   | 10                                     | 11         | 12              |
The failure rate is the conditional density of the probability of occurrence of failure of the object [5].

\[ \Lambda(t) = \frac{n(t)}{Nrt} \Delta t = \frac{n(t)}{N-n(t)} \Delta t = \frac{f(t)}{P(t)} \]  

(1)

where, \( f(t) \) - is the time to (first) failure distribution (i.e. the failure density function); \( P(t) \) - the probability of no failure before time \( t \)

**E. Probability of occurrence of failure (2)**

It is common to use the following levels of failure probability: Frequent failure (a) - the probability range of failure 0.2; Probable failure (B) - the probability range of failure (from 0.1 to 0.2]; Possible failure (C) – the probability range of failure (from 0.01 to 0.1]; Rare failure (D) - the probability of failure (from 0.001 to 0.01]; Unlikely failure (E) - the probability of failure < 0.001 [6].

\[ P(X=k) = \frac{(\lambda t)^k}{k!}e^{-\lambda t} \]  

(2)

where, \( \lambda \) -the failure rate during the period under review; \( k \) - the number of failures (1, 2, 3, etc.);

\( P(k) \) - the probability of occurrence of \( k \) failures for the period under review.

**F. Reasons for refusal**

The following classification of reasons for refusal has been proposed.

- **Faults in construction/installation (FC).** This category includes actions and decisions taken during the design, manufacture, and installation of components process.
- **The human dimension /Mistakes made by staff (HD).** A number of reasons related to errors or omissions of station personnel are determined in this part. An example is non-compliance in rules of procedure.
- **The external environment (EE).** It describes a number of reasons related to severe external conditions that have not been taken into account in technical regulation at the design stage.
- **Internal causes (IC).** Failures are related to internal components malfunction due to such phenomena as normal wear or others.
- **Other causes (OC).** This category includes reasons for rejection related to malfunction of the other paired node of the system.
- **Unidentified causes (UC).** It is used in case of inability to identify the cause of failure of the element.

**G. Types of corrective actions**

Measures specified by the regulation (technical maintenance and repairs) for each type of refusal are reflected in this paragraph.

**H. The consequences of failure**

The impacts on the subsystem which may occur in case of failure of the element (column "Subsystem Level") are listed, as well as impacts on the system (column "Level of the System»)

**I. Degree of the consequences of failures**

Classification of the consequences of failure is carried out for all types of failure, for each element in accordance with the categories. It is commonly divided into 9 categories of degree of consequences in compliance with the standard SAE ARP 5580 “Recommended failure modes and effects analysis (FMECA) practices for non-automobile applications” [3].

We propose to generalize these categories to three groups, which will be applicable to the objects of hydro-power industry.

- **Resource-determining (catastrophic) failure (I).** Severe damage to the operation. The inability to fulfill all the objectives. High degree of complexity in reactivating.
- **Medium failure (II).** The average damage to the operation. Some tasks cannot be performed. The average degree of difficulty in reactivating.
- **Partial failure (III).** The average damage to the operation. Some tasks cannot be performed. The working process might need to be stopped; some tasks can be operated only after finalization.

**J. Risk Index**

The Risk Index column is determined by a combination of the probability of occurrence of failure and degree of the consequences of failures [7]. Thus, this column is written: I-a, I - D, II-C, III-D, etc.

**K. Responsible unit**
The unit responsible for addressing deficiencies is entered in the next column. It can be such units as: technical and automatic-control department (TACD); operation and maintenance department (OMD); turbines shop (TS); electric power shop (EPS) and etc. [8].

Therefore, having filled all the data in a FMECA-from, it is possible to prioritize the consequences of failures using a matrix (Figure 1) that combines degree of consequences of failures (three levels) and probability of occurrence of failure (five level), according to FMECA-form for hydro-power engineering.

| Probability level of occurrence of failure | Degree of the consequences of failure |
|------------------------------------------|-------------------------------------|
| A                                        | I                                   |
| B                                        | II                                  |
| C                                        | III                                 |
| D                                        |                                     |
| E                                        |                                     |

Elements located in the third zone should be strictly controlled and be explored their failure, because they can lead to rejection of the whole system.

Elements of the second zone can lead to disruption of the subsystem; therefore, it is necessary to develop a monitoring system during operation.

Elements of the third zone are characterized by rare failures that have insignificant impact on the subsystem, therefore, the priority in planning this category of failures is not high [7].

3. Experiment

It is proposed to consider the hydroelectric power station of the Angara-Yenisei cascade as an object of study for a better understanding of the technology for completing the FMECA-form. The main hydro power equipment of the hydroelectric power plant includes 12 hydro units with a total capacity of 6000 MWt.

Analyzing the failure statistics of the existing hydroelectric power station, the following data were obtained (Table 2).

| The reason for capacity reduction | Number of incidents | Capacity reduction, MWt |
|----------------------------------|---------------------|------------------------|
| The failure of initiating system (IS), taking into account: | 17                  | 122,253                |
| Overheating IS                   | 1                   | 20,256                 |
| Control failure                  | 1                   | 4,88                   |
| Defect of exciting wire          | 1                   |                        |
| Thyristore replacement           | 2                   |                        |
| Thyristore cooler replacement    | 1                   |                        |
| Insulation replacement           | 2                   | 75,198                 |
| Fuse replacement                 | 14                  | 50,466                 |

Failures associated with the fuse replacement can be an independent failure or the cause of the failure of the initiation system (Figure 2).
Figure 2. Functional diagram of the initiating system with types of functional failures.

We need to fill the FMECA-form for fuses of type 3NE7637-1C (Table 3) consistent with the approach suggested in chapter II above.

Fuse failure can be categorized as the second area of the criticality matrix and characterized by the following indicators:

- The refusal is classified as partial (III). It might delay the task and decrease efficiency, but provides no risks to human health or the environment.
- The level of probability of failure is in category E (unlikely failure), since the probability of occurrence of one event in the period under review (5 years) is 0.000012, lower than 0.001

According to GOST 27.310-95 “Reliability in engineering. Analysis of species, consequences and criticality of failures. Framework” for elements whose failures get into the 2nd priority group the following corrective actions are recommended: to assess the need for the development of monitoring systems, signaling and compensation for failure; to replace the elements in order to increase the reliability of the entire system; to conduct a comprehensive FMECA [9].

4. Conclusion

In-depth analysis of failures is a key element in ensuring the reliability of the main hydro power equipment. Therefore it is necessary to create an appropriate database of failures.

Table 3. An example of executing form «failure mode effect and criticality analysis».

| Code | Design element | Function | Failure Rate | Probability of occurrence of failure | Reasons for refusal | Types of corrective actions | Consequences of failure | Degree of consequences of failure | Code | Risk Index | Description | Responsible unit |
|------|----------------|----------|--------------|-------------------------------------|--------------------|---------------------------|------------------------|-----------------------------|------|-------------|--------------|------------------|
| 1    | Fuse 3ne7637-1C| Overcurrent protection | 2, 8 | 0.00001 | I | C | Partial failure | IS | No | III | E-III | OMD |

The proposed form "Failure Mode Effect and Criticality Analysis (FMECA)" characterizes not only the stages of the analysis itself, but also create a standard for working with information on failures. Specificity of hydro-power industry was taken into consideration in this form. Also degree of
the consequences of failure and level of probability of occurrence of failure specific to hydroelectric power stations were formed. This form can serve as a platform for forecasting failures and developing the maintenance and logistic support in the future.

5. References

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