Electric grid equipment operational risks assessment: special aspects

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Abstract: - The paper presents a new approach to analyze the risks on the electric grid equipment operation based on the developed data mining system for assessing its technical state. Within the framework of this research, the author approach to the development of a system for assessing the risks of electric grid equipment, principles and algorithms for its construction and operation in the tasks of managing the production assets of energy enterprises is described. As an approval of the developed model, a calculation example of an assessment of the transformer operation risks based on operational data and technical diagnostics data was performed.

Key-Words: - risk analysis, technical state assessment, transformer, probabilistic approach, equipment life cycle.

1 Introduction

Today, the management of production assets for power enterprises (grid companies, large industrial enterprises, owning electrical equipment) becomes not only a priority issue of the economic nature in terms of investment programs, but also, among other things, the issue of maintenance and repair programs improvement, which is aimed at optimizing the life cycle of substation equipment.

Such a duality of tasks does not allow one to solve them one-sided, excluding one or the other component. Therefore, it is only possible to get an effective system for production assets management of the power system utilities, when the blocks of power equipment technical state assessment and risks management are operated simultaneously. It should be noted, that this interconnection should not be consistent, as it is implemented in most of the existing systems, such as [1,2,3], but parallel with the possibility of the feedback link implementation. In other words, the asset management system should be sensitive not only to the changes in technical state assessment block, but also to the changes in economic indicators and the risks.

Therefore, the main problem facing power system utilities today is the problem of optimizing their own limited technical and economic resources and creating such a mathematical model for assets management system implementation, that will allow a comprehensive assessment and prediction of the state and corresponding risks of power network equipment, while providing on its' basis precise and qualitative solutions, both in the case of technical parameters of power equipment unit, and economic internal and external indicators and parameters.

2 The Main Aspects of Power Equipment Risks Assessment

Production assets management of any enterprise, according to [4], is management in conditions of uncertainty, which means that it requires special attention to risks accounting. When taking into account risks, it is necessary to consider a risk as a complex value, consisting of risk analysis, risk assessment and management. Each of the components has its own problems in term of identification and analysis.

2.1 Risk analysis problem

In most modern power systems, the first stage of risk analysis is the formulation of power equipment technical state estimation, and then, on its basis, the analysis of its operational risks. It is obvious that the analysis of the risks depends on the accuracy and quality of technical state identification of the power network equipment. Thus, no matter how qualitatively the risk identification process has been done, if the evaluation of the technical state of the power equipment is not accurate enough, then the analysis, and, subsequently, the risk assessment will only worsen the quality of the forecast, increasing the identification error by several times. This is due to the fact, that in real operational conditions of the power equipment it is practically impossible to obtain a definite estimation of the technical state. This is only possible if the state is close to a normal one and all the parameters are within the permissible values. But, obviously, the normally operated equipment unit has minimal risks.

It is much more difficult to predict the risks, when technical state assessment of the power equipment unit does not meet technical requirements, or cannot be correctly identified. The main problem is the lack of statistical data, on the basis of which it would be possible to identify and assess the possible risks.

Within the framework of this study, the analysis was carried out for the main substation equipment of a large grid company, owning 106 substations of 35-500 kV. One of the main tasks of the research was to identify on the basis of the results of technical diagnostics and testing, the equipment units, that do not comply with technical documentation requirements.

Table 1. Power equipment units that do not meet technical documentation requirements

Equipment	Total 2015, units	Total 2016, units
Power transformers	103	145
Current transform.	10	18
Voltage transform.	40	28
Circuit breakers	100	86

It can be seen from Table 1, that the total number of equipment units, that do not comply with standard and technical requirements ranges from about 10% to 20%. Within the present research work there is no division by voltage ratings of power equipment, or by type - this is generalized data. The annual statistics of substation equipment technical state confirms that typically no more than 2-5% of the total number of power equipment units of different types do not comply with standard and technical documentation. Such small sample can hardly be used for risk identification.

Within the framework of other studies [5,6] the author proved, that in order to build a reliable forecast, the sample size should not be less than 75 values for each type of power equipment units, otherwise the forecast is considered to be unreliable.

It follows from all of the above, that in order to avoid the problem of inaccurate assessment and forecasting of risks, it is necessary to begin the development of risk assessment system with the adjustment of the technical state identification system.

2.2 Risk assessment issues

First of all, the problem of risk assessment is connected with the technical state assessment sub-system. The fact is that modern systems for technical state assessment are based on the principle of unambiguous conclusion formulation, which briefly describes current technical state of the power equipment unit, for example, "normal" or "faulty, but operable".

According to the author’s vision, such an approach - obtaining a single solution is not the optimal one, since in this case the level of conformance of technical state assessment and real technical state of the object it is not clear. From the point of view of operation experience, the same equipment unit can be referred to different technical states, having the same characteristic values, especially if these are boundary values between one and the other state. Thus, the inaccuracy in risk assessment of risks comes precisely from the inaccuracy of technical state assessment.

The possible solution to the problem is the application of membership functions. Depending on the type of the object under consideration, the type of limiting values (one-sided or two-sided range), the diagnostic method, etc., the type and number of membership functions can be different. Determination of the optimal type and number of membership functions is a separate task for technical state assessment of electrical equipment. Selection of a number and type of membership functions for the power transformer technical state assessment problem is presented in the case study in [7].

When the result is obtained as a numerical characteristic of belonging to each of the specified states, it will be possible to increase the accuracy of risk assessment and, in addition, to make the risk assessment procedure a probabilistic one, which will also give the possibility to consider all additional factors, that can affect the result.

2.3 Risk management issues

The developed risk system is integral to the model of the analytical system for managing the life cycle of electric grid equipment. The risk assessment system is included to the ***data processing*** subsystem, consisting of three blocks as shown in Fig. 1, and is a set of three consecutive steps: "data mining on the equipment state", then on its basis "risks data mining" (technological and technical risks are meant), and on the basis of the last block "solutions data mining".

Data mining is implemented based on the method of gradient boosted decision trees, which allows obtaining an aggregated differential estimation of the state of the electric grid objects, its risks and possible solutions. In the course of data mining, the state is evaluated by the principle "from particulars to generals" - based on hierarchical decomposition.

The complexity of power grid objects forces the object to be divided into a set of subobjects, which are in turn divided into a set of elements since there are various interrelated processes in each subobject, which makes it very difficult to determine the technical state of the electric grid equipment when the problem is solved brute-force. In turn, each of the elements of the set is characterized by a certain data set. Similarly, an assessment of risks and possible solutions is performed according to the principle of decomposition.

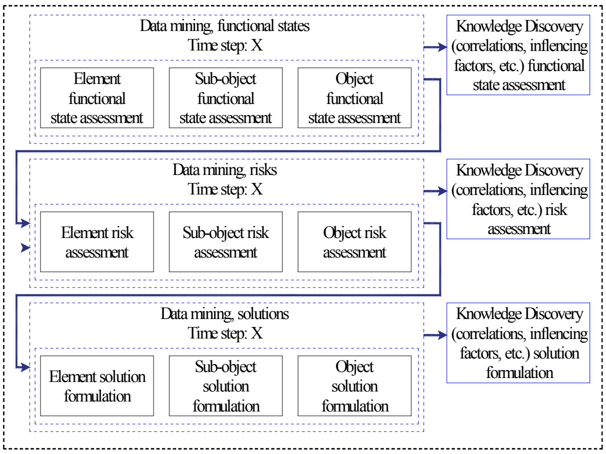

Fig.1. Fragment of the system of grid equipment life-cycle management

An analysis is performed to identify possible patterns, useful knowledge, dependencies and influencing factors after each stage of data mining (assessment of the state, risks and possible solutions).

The problem of risk management in the same way depends on technical state assessment of the object under consideration. Risk management is practically the second stage of the system for technical state assessment of the power network equipment. It can be classified as a fuzzy multi-criteria problem for analysing a set of particular solutions $Y=\{y_1, y_2, ..., y_n\}$, containing n elements (groups of parameters), obtained in the first stage.

Thus, in this case, the implementation of the decision-support system can be treated as determining the optimal solution (taking into account the ranking of possible solutions) for the further operation of the power network equipment, based on the assessment of its technical state, calculated based on available aggregate information about the object.

The estimation of the probability of each decision, based on the assessment of the technical state of the system, is carried out by quantitative analysis of the significance and contributions of the final event into the total risk (probability). The decision regarding the necessity of the most significant events' probabilities adjustment and allocation of the resources, required to change the probabilities of this events, is made based on the calculation results, obtained at the previous stage.

3 Power Network Equipment Risk Assessment System

3.1 Technical state assessment

In this paper, the author presents an approach for power network equipment risk assessment and describes the basic principles of construction and functioning of the system within the framework of energy enterprises' assets management. Nowadays such reversibility (bi-directionality) of the processes in production assets management systems can be achieved by using artificial intelligence methods.

A computational example of the risk assessment was carried out for the oil-filled power transformer TDTN-110/35/10 kV, using retrospective operation dataset in April-May 2011. The analysis of power transformer technical state was carried out using available diagnostic data, presented in Table 2.

Table 2. Power transformer initial dataset

<table>
<tr><td colspan="8">Chromatographic gas analysis</td></tr>
<tr><td>Gas</td><td>H_2</td><td>CH_4</td><td>C_2H_4</td><td>C_2H_6</td><td>C_2H_2</td><td colspan="2">Date</td></tr>
<tr><td>% vol.</td><td>0,000304</td><td>0,000395</td><td>0,00167</td><td>0,0000548</td><td>0,00391</td><td colspan="2">12.04</td></tr>
<tr><td>% vol.</td><td>0,000376</td><td>0,00044</td><td>0,00183</td><td>0,0000574</td><td>0,00454</td><td colspan="2">27.04</td></tr>
<tr><td>% vol.</td><td>0,000546</td><td>0,000501</td><td>0,00193</td><td>0,0000566</td><td>0,00498</td><td colspan="2">03.05</td></tr>
<tr><td colspan="8">Open-circuit losses</td></tr>
<tr><td></td><td colspan="3">Commissioning</td><td colspan="3">Last measurements</td><td rowspan="2">Date</td></tr>
<tr><td>Phase</td><td>AB</td><td>BC</td><td>CA</td><td>AB</td><td>BC</td><td>CA</td></tr>
<tr><td>ΔP_{xx}, W</td><td>9,2</td><td>9,3</td><td>11,4</td><td>10,5</td><td>11,0</td><td>15,5</td><td>27.04</td></tr>
<tr><td colspan="8">Insulation resistance</td></tr>
<tr><td>Circuit</td><td colspan="3">Commissioning</td><td colspan="3">Last measurement</td><td>Date</td></tr>
</table>

	HV-MV+LV+C	MW-LV+HV+C	LV-HV+MV+C	HV-MV+LV+C	MW-LV+HV+C	LV-HV+MV+C	
R_{60}, Ohm	3000	2500	3000	4600	4100	3900	27.04
R_{60}, Ohm	3000	2500	3000	2400	2100	3300	03.05
Commis. date	1993						
Capital repair date	2008						

The results of calculations for a power transformer TDTN-110/35/10 kV according to the proposed methodology of technical state assessment are presented in Table 3. The software package MATLAB was used as a modeling tool. The state of the transformer TDTN-110/35/10 can be characterized as “faulty, but operable” with a probability of 74.4%, and as “emergency” - with a probability of 26.6%. Based on the results of the technical state assessment of the power transformer TDTN-110/35/10 kV, the following decisions can be made on the basis of the membership functions:

• carry out repairs (the probability of making this decision is 88.3%);

• decommissioning (the probability of making this decision is 11.7%).

Table 3. Power transformer technical state assessment

№	Transformer element	Data	Tech. state	Rank
1	Transf. oil and general technical state assessment	CADG (electric defect)	0,83	5
		CADG (thermal defect)	0,0	1
2	Magnetic core	Open-circuit losses	0,0	1
3	Solid insulation	Insulation resistance	0,79	5
4	Windings technical state	Ohmic resistance	0,3	3
		Comis. date and capital repair date	0,0	1
Transformer technical state assessment:			0,628	
Quantitative characteristic of the decision:			0,706	

3.2 Risk assessment

In this case, based on the obtained evaluation of the technical state of the power transformer under consideration depending on various decisions the following risks can be identified according to the Figure 1-2. Figures 1-2 show the assessment of the transformer operation risks based on the membership functions analysis according to the assessment of power equipment technical state. In the case of the "emergency" state, with a probability of 26.6%, the risk assessment will be (Fig.1):

• high risk (with a probability of 62%) – an event which requires the normal equipment operation and additional tests and diagnostics to assess the equipment state, as well as carrying out unscheduled repairs and planning the decommissioning process;

• average risk (with a probability of 38%) – an event which requires the normal equipment operation and additional tests or diagnostics to assess the equipment state and replace the most significant at the specified event parts of the equipment.

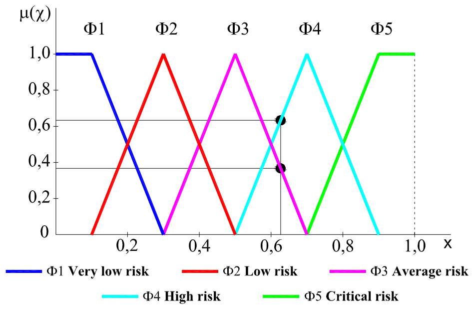

Fig.2. Risk assessment in the "emergency" state

In the case of the "faulty, but operable" state, with a probability of 74.4%, the risk assessment will be (Fig.2):

• very low risk (with a probability of 7.8%) – an event which has little damage to equipment and requires little investment for elimination;

• low risk (with a probability of 22%) – an event which has a minor damage to equipment and requires normal equipment operation.

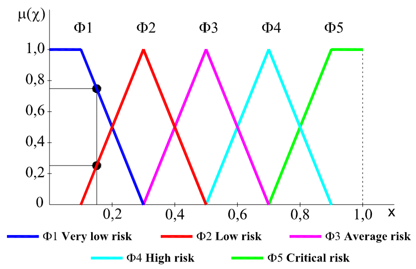

Fig.2. Risk assessment in the "faulty, but operable" state

4 Conclusion

Today, the problem of technical and economic resources optimization forces energy companies to develop mathematical models for the production assets management system, which will give the possibility to comprehensively evaluate and predict the state and risks of power network equipment, while forming precise and qualitative solutions either for technical or economic criteria.

In the developed system, it is suggested to use a scenario-based approach, that takes into account the best (optimistic) and worst (pessimistic) scenario of the system dynamics when making a decision, which is carried out for the purpose of power equipment life cycle optimization. The problems of analysis, evaluation and risk management are also associated primarily with the sub-system power equipment technical state assessment. It is obvious, that before developing a risk management system, it is necessary to improve the system of power equipment technical state assessment. A probabilistic approach will favor the improvement of the accuracy and quality of risk management.

References:

[1] Pritkin B.V. Technical and economic analysis of the production cycle. — M.: UNITI, 2000. – p. 398 (2000) (in Russian).

[2] Dubrov A.M., Lagosha B.A., Hrustalev E.Y. Risk modeling in economy and business. — M.: Finance and Statistics (2000) (in Russian).

[3] Fundamentals of Enterprise Risk Management: How Top Companies Assess Risk, Manage Exposure, and Seize Opportunity. John J. Hampton. Publisher: AMACOM, 320 p. 2009 (in Russian).

[4] Pugach O.V., Orlov A.I. Approaches to general theory of risk. System Analysis. Bauman Moscow state technical university, pp. 49-82 (in Russian).

[5] Khalyasmaa A.I., Dmitriev S.A.. Expert system for engineering assets' management of utility companies. Proceedings 10th edition of the IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives (SDEMPED 2015), pp. 421-427, 2015.

[6] Khalyasmaa A.I., Eroshenko S.A., Training samples construction for energy utilities operational assets management. Lecture Notes in Electrical Engineering. 2018. pp. 229-236

[7] Alexandra I. Khalyasmaa, Stepan A. Dmitriev, Sergey E. Kokin and Daniil A. Glushkov. Defining membership functions in power equipment state assessment problem. 5th International Conference Power Engineering, Energy and Electrical Drives, At Riga, Latvia, Volume: pp.229-233.