Electric equipment operation scenarios based on the results of non-destructive condition control

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Abstract. The issues of the developing the scenarios for the electrical equipment effective operation based on information obtained by non-destructive control of its condition were investigated. The problem of equipment condition management was considered in the context of its key technical parameters analysis and its assignment to one or another category of importance. A technique for choosing the electrical equipment operation scenario in accordance with the category of its actual condition was presented, and aspects of the automation of this procedure were considered, taking into account the principles of constructing a hierarchical decisions structure. A practical example of the development of a scenario for the equipment operation based on the results of infrared control of its elements was presented.

1. Introduction

The development of the electric power industry at present and in the future involves the implementation of modern technologies that make it possible to consider an energy facility as a highly automated, adaptive system. Information on the such system condition is a determining factor to form a strategy for its reliable and economical functioning [1-4]. In this regard, the tools for collecting, processing and analyzing such information have an increasingly important role in creating the infrastructure of both a separate power grid complex and a single power system as a whole [1-5].

Operation process of electrical equipment (EE), which is part of such an infrastructure, according to its actual condition, is the most effective strategy for its operability maintaining and is ensured by the functioning of modern non-destructive control systems for electrical installations, individual equipment, its components and assemblies [6-8]. An important point in the such systems operation is not only to collect reliable information about the values of equipment key parameters, but also to analyze it, because it makes it possible to choose a rational scenario for the further object under study operation. We suppose that the formalization of the procedures for development of such scenarios based on the available equipment condition data is a very urgent task focused on efficiency in making timely control decisions [6, 9, 10].

2. The problem of developing the electrical equipment operation scenario

If we assume that the task of non-destructive EE condition control consists in collecting data about the values of its key parameters, comparing them with standard requirements and assessing the presence of defects that worsen its performance, then it can be presented as a function in a simplified form:

\[ K(t) = f(X(t), N, Y) \]
where $X=(x_1, x_2, \ldots, x_n)$ is the vector of EE controlled parameters; $N$ – is the vector of boundary conditions for its operability; $Y=(y_1, y_2, \ldots, y_m)$ is a set of classes of normative or defective conditions. We should note that this task refers to the problem of classifying the EE condition and it can be solved using mathematical modeling methods, in particular, intelligent methods, soft computing methods, machine learning [11, 12].

The task of an effective EE operation scenario forming can be represented in this case by the function $C(t)=f(K(t), S)$, where $S=(s_1, s_2, \ldots, s_m)$ is a set of possible events (control actions). Then the general EE operation process management in accordance with the scenario developing procedure can be considered as a function:

$$TC(t)=f(X(t), N, Y, D, S, T)$$

where $T$ is a set of rules for the transition to one or another EE operation scenario; $D$ is an interpreter of decisions taken at a particular stage of the scenario.

We can assess the number of classes and possible events in the EE operating scenario on the basis of normative and technical documentation analysis, opinions of the specialists in this field, as well as real statistics of failures and violations in the EE operation.

We can see an example of the EE condition classification at the Figure 1.

Figure 1. Variant of EE condition classification according to the results of non-destructive control.

The scale of condition levels can be formed taking into account real defects arising in the equipment, or in terms of their criticality level. In this case, both a compact (from the point of view that the values of the parameters vector exceed the boundaries of the tolerance limit) and extended (from the point of view the degrees of a defect criticality) scales can be used.

3. Technique for electric equipment operation scenario developing

Let us present a step-by-step procedure for the developing of a general and a particular scenario for the EE operation process control in accordance with (2).
The proposed technique assumes the formalization of the with the definition of applied non-destructive control technologies, the list of controlled parameters and their normative values, a set of classes/categories of the EE condition (see Fig. 2, blocks 1-3). We should take into account the complexity of establishing unified normal values (limits) for the measured EE parameters, when forming the relationship <parameters> → <class of EE condition>. That’s why we can use the linguistic estimates of parameter values by membership functions and fuzzy modeling method [12].

In accordance with the selected EE condition scale, we can form a list of events in the scenario of its operation (see Fig. 2, block 3), which determine the options for control actions.

The general scenario is drawn up (see Fig. 2, block 4) on the basis of combining information about possible events, transition rules and the appropriate interpreters of the decisions-making.

Further, the script is embedded in the process of selected EE condition monitoring and processed either in real time or at a given frequency with the actual recommendations to the personnel issuance based on the appropriate algorithms for data processing and analyzing (see Fig. 2, block 5). There also is a procedure for adjusting the scenario taking into account the accumulated EE operation process data, the results of scenarios execution for certain types of equipment, as well as the improvement of procedures for collecting, processing and analyzing non-destructive control data (see Fig. 2, block 6).

An example of building a general scenarios for EE operating and interpreting options for making decisions (control actions) in a tree format is shown in Figure 3 and Table 1.
Figure 3. Variant of the EE operation scenario according to the results of non-destructive control.

Table 1. An example of EE operation scenario forming.

| Decision category identifier | Type of control actions |
|-----------------------------|-------------------------|
| $D_1$                       | Operation in accordance with the existing documentation. Preventive EE condition monitoring by standard method during 2-3 years |
| $D_2$                       | Operation with inspection of EE elements by the standard method (frequency and timing are consistent with expert estimates not exceeding 1.5 years) |
| $D_3$                       | Operating limitation. Re-control of EE condition by the standard method during 6-9 months |
| $D_4$                       | Additional individual non-destructive control for localizing and monitoring the defect development dynamics. Re-control of EE condition by the standard method during 6-9 months |
| $D_5$                       | Limiting the EE operation and its condition control in order to localize the defects. Carrying out preventive measures based on the control results |
| $D_6$                       | EE condition monitoring (instrumental and visual) with a frequency of 2-3 months. Defect elimination at the nearest decommissioning |
| $D_7$                       | Urgent EE preventive repair with decommission, defect location and elimination |
| $D_8$                       | The EE condition individual control in the absence of the possibility (for technical, technological, economic reasons) of immediate decommission. Taking measures to ensure the EE safe operation and prevent its failure |
| $D_9$                       | Replacement the EE in case of its further use inexpediency |
| $D_{10}$                    | Development of a set of EE emergency repair measures |

We should note that can consider the results of the analysis of typical defects of various equipment and its elements, for example, power transformers, circuit breakers, high-voltage bushings (“heating”, "heating")
“arc”, “spark”, “thermal breakdown”, “creeping discharge”, “corona discharge”) and the specifics of the used non-destructive control methods as prerequisites for adjusting the EE condition scale and its operating scenarios in general.

4. An example of using scenario developing technique

Let us consider an example of the above technique application when choosing an operation scenario for the high-voltage based on the results of infrared control (IR) [13]. We used the data of IR diagnostics of circuit breakers (CB) high-voltage bushings obtained from oil production facilities located in the Perm krai.

To assess the CB condition we used 4 alternative classes (“normal” (y₁), “norm with minor deviations” (y₂), “norm with major deviations” (y₃), “critical/pre-accident” (y₅)) and the technique, considered in [14, 15]. The proposed scenarios are focused on a proactive approach to managing the EE condition, therefore, the case of an equipment failure was not considered.

For comparison, Figure 4 shows scenarios for selecting control actions for two 35 kV circuit breakers: defective and normally functioning. The path for making the final decision on the further equipment operation is highlighted in red.

![Diagram]

**Figure 4.** Developing operation scenario of the defect (a) and normal (b) circuit breaker using the infrared control results.

In the first case, according to the results of the control a defect associated with the excessive temperature of the external contacts on the bushing pin of one of the CB phases (more than 50°C) was found. In the second case, no excess temperature was observed (no more than 0.5°C).
In fact, the proposed scenarios implementation make it possible to timely carry out the necessary repair and maintenance (for the example under consideration – unscheduled maintenance with broaching of bolted contacts) and prevent a possible emergency.

5. Conclusion
We presented an approach to the developing of an EE operation scenario, which allows to integrate data getting from its elements non-destructive condition control systems. The approach is flexible and focused on the possibility of using various scales for classifying the EE condition and sets of control actions aimed at maintaining its operability.

The procedure for an EE operation scenario generating is universal and can be automated using the methods of data mining, machine learning, hybrid approaches to modeling [16-19]. The practical implementation of the proposed approach can be considered as one of the mechanisms for the functioning of a unified intelligent system for the equipment condition diagnostics and effective managing based on the results of non-destructive control [15, 200].

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