Determination of the Periodicity for Thermographic Tests of the Electrical Equipment

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***Abstract* — The paper presents a study of the optimal periodicity of testing when aiming to maintain certain reliability. Several methods for the assessment of reliability indicators with a small number of observations are discussed. A methodology for the determination of the period for thermographic inspections, of electrical equipment is given, in the paper.**

Keywords* — *thermographic testing, periodicity, inspections, reliability

I. INTRODUCTION

Modern production aggregates consist of many elements having different nature of action and description. Sometimes in practice, it is convenient to consider them as a whole, i.e. as one element. It can be assumed that this element behaves in the same way as its individual components and generally does not change the reliability of the entire production aggregate. Production losses during the non-operational times as a result of electrical equipment failure can be partially avoided by applying an appropriate prevention strategy, which will ensure maximum time for trouble-free operation of electrical equipment, minimum downtime of electrical equipment, reliability and efficiency of electrical equipment at a given level, minimum operating costs of electrical equipment, etc.

There are different maintenance strategies - implemented through repair, replacement, or inspection. The inspection of electrical equipment is a type of service that is very suitable for the prevention of complex, expensive, and unique production units. The inspection is carried out at predetermined intervals in order to reduce the probability of failure of electrical equipment. The main purpose of the inspections is to limit the downtime, this requires that the inspections have a certain frequency corresponding to the specific operating conditions. On the other hand, the excessive number of inspections will lead to a long downtime for the respective unit and this requires their periodicity to be optimized in terms of maintained reliability indicators [1].

Thermographic testing (TT) of electrical equipment is one of the methods for non-destructive (non-invasive) control of the technical condition, which is gaining more and more application in the industrial factories. The main purpose of the application of thermographic tests is to detect defects in electrical equipment at an early stage of their development, but also the results of TT can be used to predict the reliability of the studied objects for a certain time interval. Despite the possibility of the thermographic test method to provide a fairly reliable prognosis for the condition of the equipment, currently, this possibility isn't widely used in practice, and the results of thermographic tests have recommendable, but not required character for the final assessment of the technical condition [2].

The realization of the capabilities of thermographic tests in the field of technical diagnostics is limited by technical reasons (insufficient sensitivity, spatial resolution, dynamic temperature range, etc.), methodological inaccuracies in the instructions for the conduction of the measurements (incorrect settings of measurement parameters, significant deviations in operating regimes and environmental parameters), as well as the absence of a clear procedure for using the results of the thermographic test. Many of these limitations for the implementation of thermographic tests as a means of prognosis the technical condition have found their solution due to developments in the design and construction of thermal imaging cameras, and the development of a regulatory framework and internal-factory instructions for measurements and processing results.

On the other hand, the low pace of development of methods for applying the results of thermographic tests in predicting the technical condition of electrical equipment is due to the fact that scientific research in this area is focused primarily on identifying equipment defects at different stages of their formation.

At the same time, the information about the absence of temperature deviations of the elements of the electrical equipment from the normal values is no less important in predicting the probability of fault-free operation for both the individual components and the electrical equipment as a whole.

From what has been said so far, it can be concluded that the periodicity of the thermographic testing is an important factor contributing to increasing the authenticity of the assessment of the reliability indicators of the equipment as a whole. Besides, the standards in this area [3] provide for the periodicity of testing to be used as a quantitative parameter in the assessment of reliability indicators based on a small number of observations using additional information [5].

II. METHODS FOR ASSESSMENT OF RELIABILITY INDICATORS WITH A SMALL NUMBER OF OBSERVATIONS

Methods for assessing reliability indicators using additional information are based on a combination of information (basic information) obtained experimentally as a result of tests or operational observations and additional information taken from different sources or obtained as a result of operational experience. In cases where the results of thermal imaging tests lead to the detection of equipment

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malfunctions, these results should be included in the array of initial data in the formation of basic information. While in case of confirmation of the normal condition of the equipment, the results of thermographic tests give the actual values of the controlled parameter, which are replaced in the used mathematical model of the process, describing the dependence of the failure probability on changes in the controlled parameter (temperature) [4].

Depending on the type and manner of presenting the additional information, the methods for assessing the reliability indicators are divided into three groups.

A. Methods based on the use of preliminary assessments of reliability indicators

This group of methods is based on the application of mathematical models for the formation of point or interval estimates of reliability indicators. In general, the models included in this group can be classified depending on the type of applied mathematical model, which divides them into linear and nonlinear models.

Linear models for assessing reliability indicators are based on the use of a priori estimates of these indicators. Thermographic examinations, in which malfunctions (anomalies) of the equipment or deviations from the nominal operating modes are detected, are included in the set of initial data, based on which the point estimates of the reliability indicators and their variance are formed, using a linear dependence between the reliability indicators of electrical equipment as a whole and the reliability indicators of its components.

The nonlinear models for assessment of the reliability indicators apply a nonlinear connection between the generalized indicators for the reliability of the electrical equipment and the indicators for the reliability of its elements. These models are based on the values of both point estimates and interval estimates of the failure probability.

B. Methods based on the use of preliminary distributions of reliability indicators

This group of methods for assessing the reliability of electrical equipment is based on the use of models of processes leading to failure. Most often the formation of the models uses estimates of time and probability of failure-free operation obtained on the basis of the results of measuring a controlled parameter over time [8].

Unlike the classical statistical approach, which most often considers the failure rate as an unknown but constant quantity that must be estimated from sample data, these methods are based on the Bayesian approach. On the other hand, the Bayesian approach treats the failure rate as a random variable that varies over time. A priori data or even engineering estimates are used to build a preliminary model of the distribution of the probability of failure. As a rule, such a priori distribution is known only for the general case. In each specific case, it is advisable to specify the type and parameters of the a priori distribution used on the basis of experimental data, i.e. to apply empirical data Bayesian methods. They are most useful when information about site malfunctions under different operating conditions is available. These methods provide an opportunity to obtain a relationship between the individual parameters of operating conditions and the probability of failure of the equipment, which is very valuable for long-term predictions of the probability of failure of components and complexes in general.

The choice of parametric Bayesian models for the representation of processes is appropriate due to their flexibility and mathematical convenience. As in practice facility, failure data do not exist, conjugated primary data are used to confirm the chosen a priori distribution model. Under these conditions, the formula of the model for determining the distribution of the probability density can be written as:

$$g(\lambda|x)=\frac{f(x|\lambda)g(\lambda)}{\int_0^\infty f(x|\lambda)g(\lambda)d\lambda}, \tag{1}$$

where: $f(x|\lambda)$ is the probability density distribution of the observed data x for a given unknown parameter λ;

$g(\lambda)$ - preliminary model for the distribution of the parameter λ;

$g(\lambda|x)$ - posterior (corrected) model for the distribution of the parameter λ, given the observed data x.

When $g(\lambda|x)$ and $g(\lambda)$ belong to the same family of distributions, $g(\lambda)$ and $f(x|\lambda)$ are called conjugate distributions. The most widely used distribution, when determining the density of distribution for the purposes of reliability and technical diagnostics is the pair of conjugate distributions - gamma and exponential distributions [9].

The special role of thermographic tests can be traced to a greater extent precisely in such methods, based on obtaining and using preliminary distributions of reliability indicators. The factual prerequisites for the special role of thermographic tests are that they can be used to assess the degree of influence of external factors on the technical condition of individual elements of equipment, even if the impact of these factors has not led to critical consequences - the occurrence of failures.

For example, the heating of oil in transformers during the summer period contributes to the accelerated aging of their insulation. Measuring the temperature of transformer oil in these periods is not a direct assessment of the presence or absence of defects, but can provide initial information for predicting the cumulative function of change in the state of electrical insulation during the period of operation of this transformer in these climatic conditions.

C. Methods based on the use of models of the process leading to failure

Methods based on the use of a model of processes leading to failure are used to estimate the mean time between failures and the probability of failure-free operation of electrical equipment. When developing the applied models, it is assumed that there is a parameter whose values are uniquely related to the condition of the equipment (or at least two of its states: operational and inoperable). In this case, based on monitoring of this parameter and the change of its values over time an assessment, for the probability of failure-free operation or failure, is formed [6, 7].

III. MODELS TO DETERMINE THE PERIODICITY OF THE THERMOGRAPHY TESTS FOR A GROUP OF UNIFORM ELEMENTS

From the very beginning of the application of thermographic tests, for the purposes of diagnostics of electrical equipment, they are used most intensively in the last of the considered groups of methods. This is due to the fact that the anomalies in the thermal fields of the elements of the electrical equipment precede the critical (emergency) manifestation of the development of these anomalies.

Currently, the periodicity of thermographic tests is dictated by factors that differ significantly from the considerations of the approaches to improve the accuracy of predicting the probability of failure. Existing guidelines include terms such as seasonal testing, which are a broad concept in terms of the periodicity of inspections. In fact, the failure rate of the equipment depends on the time of operation (the stage of the life cycle of the facility). Therefore, the interval between tests must also be variable over time and planned on the basis of the available a priori data on the degree of deterioration of the technical condition of the objects: the technical resource and the actual service life.

This requires adjustment of the dependencies to form an assessment of the average failure rate of the equipment and the probability of its fault-free operation.

When using the results of thermographic tests to assess the probability of failure *Q(t)* of the equipment, the latter can be obtained by the following dependence:

$$Q(t) = \Phi\left(\frac{T_{\lim} - mt}{\sqrt{A_1 t - A_2 t^2}}\right) - \Phi\left(\frac{T_{\lim} - T_r}{\sqrt{A_1 t - A_2 t^2}}\right), \qquad (2)$$

where: $\Phi(z)$ is the Z-score function;

t - actual service time of the equipment;

T_{lim} and T_r are the allowable limit value of temperature and temperature at a rated operating mode of the equipment;

A_1, A_2 and m – calculation coefficients.

The calculation coefficients depend on the number N of the uniform types of devices or their elements for which the statistical sample is formed and the reported temperature values for each of the elements included in the given group. The following dependencies are used to determine the calculation coefficients:

$$A_1 = \frac{\sum_{j=1}^{N}\sum_{i}^{k-1}(z_i^j)}{N.(k-1)}$$

$$z_i^j = \left(\frac{(T_i^j - T_{i-1}^j) - \sum_{i}^{k}(T_i^j - T_{i-1}^j)}{k}\right)^2, \qquad (3)$$

$$A_2 = \left(\frac{\Delta T}{dN}\right)^2, \qquad (4)$$

$$m = \frac{\left[\sum_{j=1}^{N}\sum_{i}^{k}(T_i^j - T_{i-1}^j)\right] / \left[t_d.k\right]}{N}, \qquad (5)$$

where: T_i^j is the temperature of the j-th device obtained from the i-th temperature measurement;

k - the number of temperature measurements of the j-th device or element for the survey period;

ΔT - the difference between the maximum and minimum values of the temperature of the equipment in k measurements and the periodicity of thermographic tests t_d;

The application of this model allows obtaining the periodicity of thermographic tests on the basis of the set values of the reliability indicators and the actual value of the service time of the facility.

IV. CONCLUSION

The results of the thermographic tests of the electrical equipment are essential for the prediction of its fault-free operation both in the detection of defects in the elements and in the confirmation of the serviceable condition of the examined equipment.

When thermographic testing of electrical equipment is planned, the interval between tests must be changed on the basis of a priori data on the degree of deterioration of this device.

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