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Investigation of Defect Formation Process in Transmission and Distribution Equipment

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Abstract. The results of the statistical investigation of defect formation process in the equipment of electric networks are shown. Probabilistic characteristics of the stochastic process of the growing defects formation are determined for the 6/0.4 kV transformers with a high degree of confidence. The results will be used in the evaluation models of the equipment reliability under the actual maintenance condition.

Introduction

During operation the equipment of the power electrical networks is subject to different types of factors. The main damaging effects are differential temperature, atmospherics and switching overvoltage, large current flows, and of course a human factor. These factors have a bad impact on protection constructional materials properties and activate defect formation processes. Periodic diagnostics and monitoring of the equipment with the complex of informative features allow finding the different stages of defects development.

One of the main effective tools applied as the diagnostic equipment of power networks is the heat controlling method (TCE). Heat control is a base of equipment for damage instrumental sorting out in the oil-refining power distribution networks. According to the [1] variations of heating object surface temperature over the ambient temperature allow periodic heat control in order to detect and classify the type of malfunction: $\theta > 5\,°C$ - is “initial” defect; $\theta < 5 < 30\,°C$ - is “developing” defect; $\theta > 35\,°C$ - is “emergency” defect. Classification of defects considers selecting the measures taken for performance assurance. Equipment with the first group of defects can operate for a long time; defects of the second group need clearing during the nearest scheduled repair; the third group malfunctions require switching off the operating equipment for providing unscheduled repair.

Familiar change investigations of transmission and distribution equipment state using heat controlling sample statistics [2] are devoted to determining of non-failure operation and durability parameters. Demonstrative reliability characteristics of the equipment are not well-known to researchers. According to this circumstance the development and applied controlled – service of power networks equipment model are limited [3]. Also this fact determines the issue of investigations in this line.

Methods and Results of Research

Suppose that the random defect formation process is reliant on the type of the process and operational conditions. Periodical heating control allows determining the probability of discontinuous implementation of a real random process.

Information basis for researching probabilistic characteristics formation defect process appears to be the reports on heating control of distribution oil-refining 6-35 kV network equipment during the period from 2008 to 2013. The stochastic event is determined as identification of the certain defect type in the defined type of the equipment. Also assume that observed stochastic process is equal to the process that takes place in field tests of the uniform engineering devices lot. This assumption is compatible with reference point conditions and presents adequate understanding of

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statistical information. The characteristic of random process is a time period between not varying events τ (hour) that is described as random variable.

As an example, consider heating control statistics of power transformers (PT) located in the package of 6/0,4 kV transformer substations. In the examined network the amount of power transformers equals 151. The main representative sample is the second group defects sample (446); the samples of the first and third groups respectively equal 216 and 64. Such ratio of fixed defects indicates the influence of TCE to maintain operational reliability of power transformers.

For the start, the dotted probabilities of formation defect process from each group of malfunctioned PT 6/0,4 kV are determined. Fig. 1 and Fig. 2 show the change in the probability of developing and emergency defects in power transformers 6/0,4 kV data interval operation. The following figures illustrate the experimental dates - the results of observation using TCE and their trends (dashed lines). In addition, the mean intensity of different defects in the transformers of electricity distribution network was calculated. These values are listed in Table 1.

Table 1. The average values of the intensity of defects in power transformers (year^{-1})

Number	Group of defect	Class of power transformers	
		35/6 kV	6/0,4 kV
1	“initial”	0,058	0,149
2	“developing”	0,269	0,644
3	“emergency”	0,192	0,361

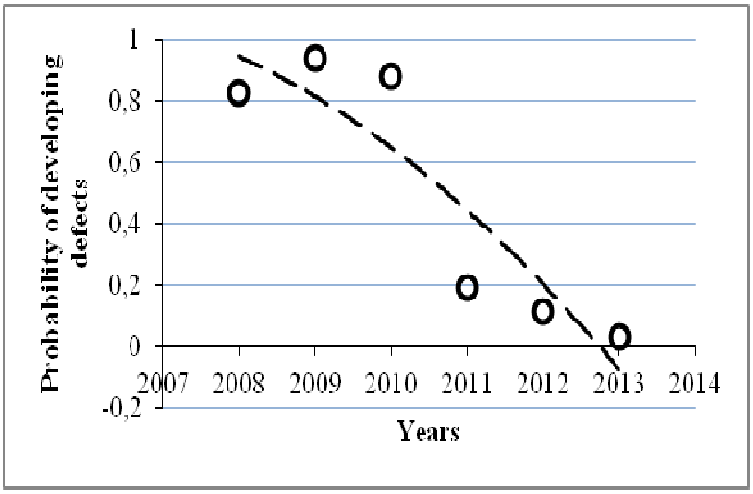

Figure 1. Probability of developing defects in power transformers

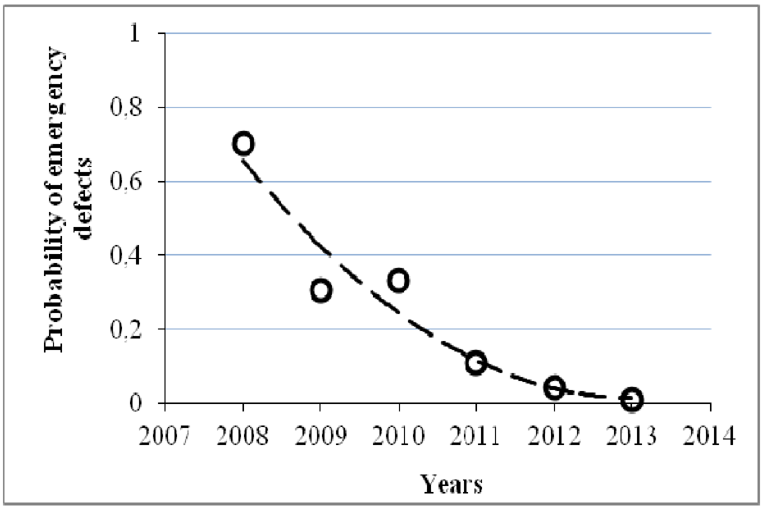

Figure 2. Probability of emergency defects in power transformers

As it is shown in Fig. 1 and Fig. 2 the tendency to reduction the probability of defects in the second and third groups is result of routine or emergency repairs. Also the average values of probability of occurrence the different groups of defects by month of generalized calendar year were determined. Fig. 3 shows the plot of probability of the second type of defect formation process in PT 6/0,4 kV. The plot illustrates that growing type of defects is more evident in spring time. This time interval is characterized by the rapid change of air temperature with 0°C crossing and changing electric load of substation.

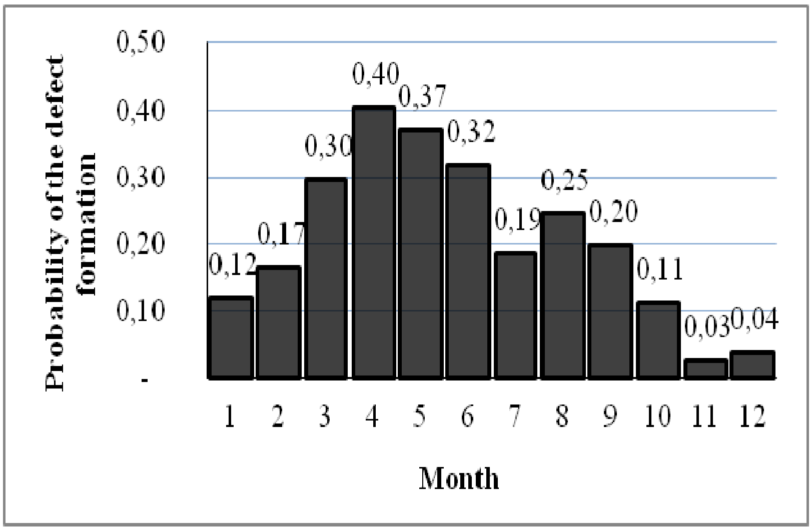

Figure 3. Probability change of the second type defect formation in PT

Next, flow stochastic process characteristics have been investigated. The hypothesis has been tested that the flow of homogenous stochastic events is temporally homogeneous, ordinary and not corollary. According to the experimental results, the cumulative probability distribution function (Eq. 1) of time intervals between defects appearance has been determined with variable time $\tau \in [0 \div 800]$.

$$F(\tau) = 1 - p(\tau) \tag{1}$$

where $p(\tau)$ - is the probability of nonoccurrence growing defect.

Approximation of logarithmic function (Eq. 2) with the degree of confidence 0.982 confirms that the derivative of this function (Eq. 2)

$$p(\tau) = \frac{dF(\tau)}{d\tau} \tag{2}$$

is the exponential function with variable λ_d:

$$F(\tau) = 0,2072 \cdot \ln(\tau) - 0,3804 \tag{3}$$

Fig. 4 shows the probability of occurrence $F(\tau)$ and nonoccurrence $p(\tau)$ of developing defect in 6/0,4 kV power transformers. Points correspond to experimental dates of probabilities, full lines graphs are trend lines provided with the required degree of confidence. Fig. 4 confirms that the examined flow of the second type defects in PT 6/0,4 kV has the properties of the “simplest” flow [4] and probability distribution function of time intervals between occurrence of defects has exponential law characteristic with intensity $\lambda_d = 0,005$ (hour^{-1}). More rigorous proof the reliability of the results was the checking of null hypothesis of the exponential law of time intervals distribution between the emergences of defects, made by Pearson χ^2 criterion. Verification not refuted this hypothesis.

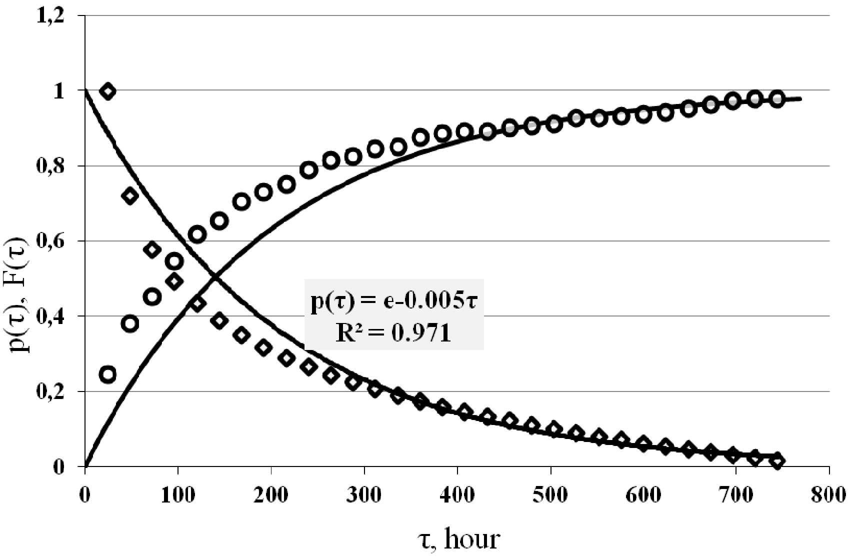

Figure 4. Change of probabilities according to the value of time interval between emergences of growing defects in PT 6/0,4 kV

According to the intensity of occurrence developing defects the mean time between defects of the second group in PT 6 / 0.4 kV can be calculated. The value of which equals:

$$T_d = \frac{1}{\lambda_d} \tag{4}$$

Thus, according to the (Eq. 4) and characteristics of random process, which was observed using TCE, the defects of the second group in PT 6 / 0.4 kV of distribution networks will appear every $T_d = \frac{1}{0,005} = 200$ hours. This information may change the schedule of TCEs and periodic preventive maintenance, for eliminating developing defects in the equipment.

Equipment Reliability Simulation in Case of Developing Defects

For assessment the influence of the intensity the appearance of defects in PT 6/0.4 kV on changing its service reliability was used the model which represented in [4]. Technical system reliability model is obtained using homogeneous Markov processes with continuous time. This model is a oriented graph (Fig. 5). Graph nodes are the system conditions, which characterized by probabilities p_i, $\left(i = \overline{1, n}\right)$; arcs of graph illustrates transitions from i-th to j-th condition with intensities λ_{ij} $(j \neq i)$.

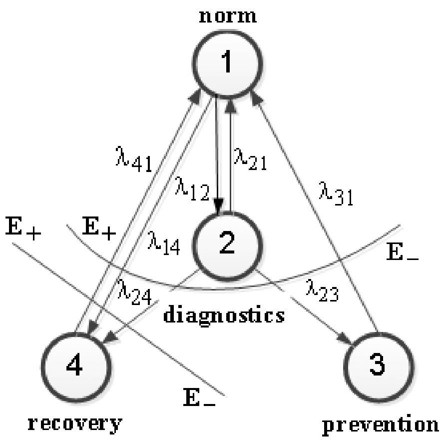

Figure 5. Model of PT reliability

For description of the graph is used the system of equations (Eq. 5), written for the probability of conditions.

$$\begin{cases} 0 = \lambda_{12} \cdot p_1 - (\lambda_{21} + \lambda_{23} + \lambda_{24}) \cdot p_2 \\ 0 = \lambda_{23} \cdot p_2 - \lambda_{31} \cdot p_3 \\ 0 = \lambda_{14} \cdot p_1 + \lambda_{24} \cdot p_2 - \lambda_{41} \cdot p_4 \\ \sum\limits_{i=1}^{4} p_i = 1 \end{cases} \quad (5)$$

The main feature of the equations system (Eq. 5) is the presence of normality condition $\sum\limits_{i=1}^{4} p_i = 1$ which characterizes the complex of events (transitions from i-th to j-th condition) as a complete group of events. The numerical solution of a homogeneous algebraic equations system (Eq. 5), for example by using the Gauss method, allows calculating the probability of each PT condition. During the variation of the operation PT process time at some arbitrary interval $t \in [0 \div \Delta T]$ (ΔT - is arbitrary interval of operation, year) it is possible to obtain dependencies $p_i(t)$, $(i = \overline{1, n})$. The best results during service PT on the actual condition have been achieved by maximization of failure-free operation probability $p_1(t)$. If the dependence $p_1(t)$ is a monotonic function with variable t on the interval ΔT, we are able to calculate the optimal value of mean time between maintenance of PT ($t_{optimal}$) from condition:

$$\frac{dp_1}{dt} = 0 \quad (6)$$

Fig. 6 shows an algorithm of numerical solution of the equation (Eq. 5) with the optimization of the time period between preventive maintenance according to the condition (Eq. 6).

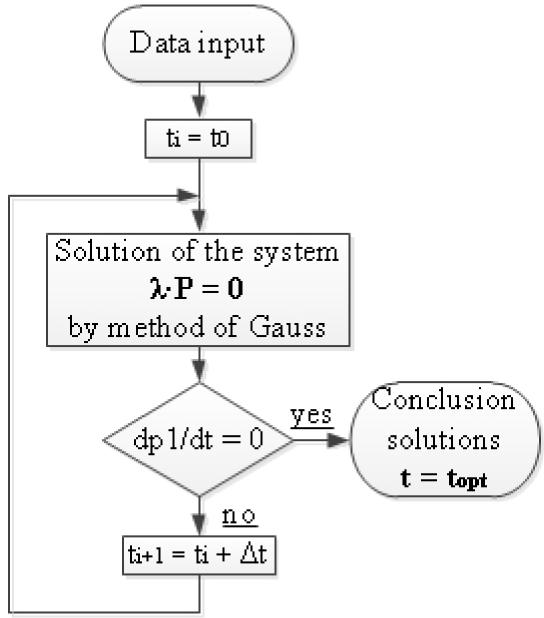

Figure 6. The algorithm of problem solving

For researching the influence of the intensity of occurrence developing defects in PT to the probability of failure-free operation and for determining the optimal values of the mean time intervals between maintenance the series of calculations was carried out. The intensities of the transitions in the equations system (Eq. 5) are described by the following values:

$\lambda_{12} = 2$ year^{-1} $\lambda_{21} = 8610$ year^{-1} $\lambda_{23} = 1380$ year^{-1} $\lambda_{24} = 7{,}1$ year^{-1}

$\lambda_{31} = 1110$ year^{-1} $\lambda_{41} = 200$ year^{-1} $\lambda_{14} = 0{,}015 + 0{,}01 \cdot t$, year^{-1}

Changing during calculations the previously obtained intensity magnitude of occurrence of developing defects in PT 6/0,4 kV was allowed in the range $\lambda_d = (43{,}8 \pm 5)$ year^{-1}. Calculated results of reliability indexes PT 6/0,4 kV using designed algorithm (Fig. 6) are shown in Fig. 7. According to the results of calculating the maximum probability of non-failure operating with intensity of developing defects $\lambda_d = 43{,}8$ year^{-1} is achieved as the result of preventive maintenance with intervals values equal $t_{opt} = 4{,}2$ year.

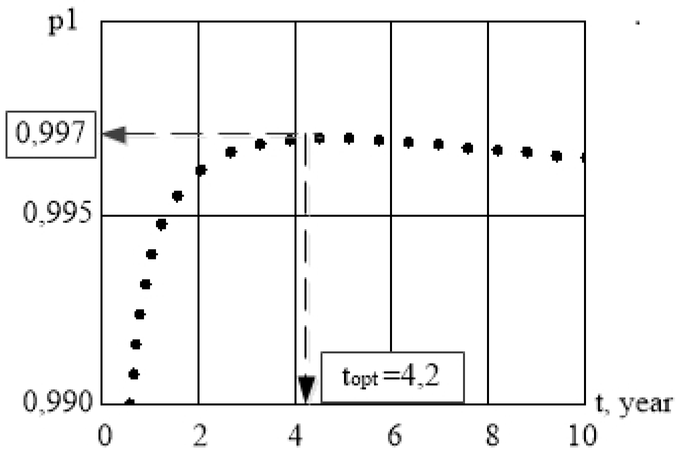

Figure 7. Search topt according to dependence $p_1(t)$ with $\lambda_d = 43{,}8$

Conclusion

1. Investigation of the defects formation process in transmission and distribution equipment as the stochastic process with discontinuous samples of heating control statistics is the issue and has practical implications for modeling and evaluation of operational reliability during condition based maintenance.
2. Reasonableness of the investigation is determined by the rigor application of a random process theory and mathematical statistics methods. The practical result is probabilistic characteristics of the growing defects flow in 6/0.4 kV power transformers, that reliability is confirmed by viability of the hypothesis in accordance with one of the goodness-of-fit tests.
3. Simulation of operational reliability of the transmission and distribution equipments using the obtained values of the defects intensities allows optimizing periodicity preventive measures.

References

[1] RD 153-34.0-20.363-99. Fundamental principles of infrared detection methodology in the equipment and OHTL. RAO “UES”, Moscow, 2000 (in Russian).

[2] A.B. Vlasov, Prediction of durability contact joints according to the experimental results of heat controlling diagnostics, Electrotekhnika. 2003. N 12, pp. 27-33 (in Russian).

[3] V.M. Levin, D.V. Tanfilieva, Increasing efficiency of electrical networks operational processes control, NSTU Vestnik, 2011, N 2, pp. 135-146 (in Russian).

[4] E.S. Wentzel, Investigation of manipulations: tasks, principles and methodology, Nauka. Fizmatlit, Moscow, 1988 (in Russian).