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IEEE UKRAINE SECTION'S WELCOME

Dear Colleagues,

On behalf of the Organizing Committee and IEEE Ukraine Section ExCom, we express our greetings to IEEE UKRCON-2019 participants who have come to present their papers and enjoy social events in Lviv, Ukraine on July 2 - 6, 2019.

The 2019 IEEE Second Ukraine Conference on Electrical and Computer Engineering (UKRCON) general theme, Advancing Society Through Applied Physics, Electrical and Computer Engineering, reflects the profound impact of ECE research on our daily lives. The IEEE UKRCON-2019 is co-organized by IEEE Ukraine Section and its Chapters, as well as IEEE Application Society, with partnership of IEEE Region 8, European Microwave Association (EuMA), Association of Industrial Automation of Ukraine, Lviv Convention Bureau, Lviv City Council, Lviv Polytechnic National University, Ivan Franko Lviv National University and IT Step University.

This year, 375 papers were submitted and 249 of them were accepted and included in the conference program. Acceptance rate is 72%. As usual, Track 6: Systems Analysis, Reliability, Computer Science & Communications and Track 1: Microwave Techniques, Antennas & Radar Systems include most of all papers. There are 86 and 42 papers respectively. Participants and speakers represent Universities and Research Institutions not only from Ukraine (Lviv, Kyiv, Kharkiv, Chernihiv, Odesa, Dnipro, Ternopil etc), but also from Germany, France, Italy, Spain, USA, Ireland, Estonia, Latvia, Czech Republic, Israel and Canada.

We have an exciting technical program at this conference that will allow members to renew friendships and extend research networks. Our technical program is rich and varied with 8 keynote speeches and 249 technical papers split between 7 parallel oral and poster sessions each day. Besides, there are 2 workshops and a tutorial program co-located.

We would like to thank all of the sponsoring and partnership organizations. Lastly, we would like to thank all of the conference participants for their contributions which are the foundation of this conference.

Sincerely yours,
Ievgen Pichkalov, Felix Yanovsky, Iryna Ivasenko, Mikhail Balaban

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Definition of Accumulated Operating Time Distributions for a Cable Product Insulation Within the Defined Life Cycles

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***Abstract*—Inappropriate state of cable products in electric power supply lines can cause fire accidents. To be able to foresee cable faults it is necessary to develop an approach for estimating state of a cable on the basis of measurements of current state of its insulation. The paper describes an experiment, where distributions of accumulated operating time for cable insulation within the definite life cycles are defined. In the experiment the grade NAYY-J 4×10 cable was used.**

Keywords—cable product insulation, distribution, histogram, experiment, Pearson criterion, accumulated operating time

I. INTRODUCTION

Inappropriate state of cable products in electric power supply lines can cause fire accidents, which is especially dangerous in public places, such as hospitals, educational establishments, entertainment centers etc. Unfortunately for the time being the existing methods, which are used for controlling functional state of cable products' (CPs) insulation [1, 2], do not allow predicting their emergency operation and appearance of CP ignition sources of electric origin for the nearest operating hours. That is why it is necessary to define the possibility of prediction of emergency operation modes at continuous operation of cable lines and to be able to forecast their further usage. On the basis of the performed analysis of CP fire hazards and of the methods of functional state control of insulation during its operation, it is appropriate to develop an approach to predict appearance of ignition sources of electric origin with the help of measurements, reflecting current characteristics of CP insulation. Relevance of the task in question is proved by numerous works (e.g. [3–5]) in that field.

II. DEFINITION OF ACCUMULATED OPERATING TIME DISTRIBUTIONS

A. General Description of the Experiment

For CPs it is typical to have various accumulated operating times (AOTs) for fixed operation intervals. CP AOTs are characterized by considerable variance, i.e. those AOTs can be represented as random values characterized by a certain distribution. We reduced the task of definition of distribution of CP insulation AOTs to the estimation of CP insulation AOTs till the moment the CP insulation resistance reaches the critical value of 0.5 MΩ [6]. The following experiment was carried out. The cable of grade NAYY-J 4x10 was exposed to alternating voltage of 5 kV for 9 hours. Every 15 minutes the insulation resistance of 9 pieces of the cable was measured. It should be noticed, that insulation resistance received under overvoltage of 5 kV does not correspond to the values that would have been received at normal operation load (up to 1 kV). But as it is impossible to waste time with watching the cable operation (for 20 years or more), the data for accelerated testing were used. We defined distributions of AOTs for the following operation intervals: $1/4$ hour, $1/2$ hour, $3/4$ hour, 1 hour and more. The procedure was the following one. An ordered sample set $x_1, x_2, ..., x_n$ of CP insulation AOTs for fixed testing intervals was built. Over that set the histograms of AOTs were calculated. A hypothesis about the type of CP insulation of AOTs distribution was accepted and the point values of the assumed distribution parameters were estimated [7]. Then the consistency of the experimental data with the hypothesis about the AOTs distribution was verified.

B. Distribution for the Case of $1/4$ Hour of Testing

Using the relevant experimental data we analyzed the distribution for the case of $1/4$ hour of testing. According to statistics the number of samples was $n = 56$. In Fig. 1 there are several variants of AOTs histograms built for different numbers of equal intervals. The aim was to receive the best approximation according to the criterion of minimum inversion number. The initial number of intervals was defined as:

$$k = 1 + 3.3 \cdot \lg n . \quad (1)$$

We assumed that the best histogram is the histogram with only one inversion and larger number of intervals (the histogram of Fig. 1c was chosen).

Then we selected a smooth theoretical curve that reflected considerable features of the experimental distribution and smoothed randomness, caused by insufficient volume of statistical data. Here we accepted a hypothesis about the uniform distribution of the CP insulation AOTs. Parameters of the uniform distribution should have been defined in such a way, that they would describe the experimental data in the best way. To achieve that, the method of moments [7] was used. That method was selected due to simplicity of its implementation and due to sufficient accuracy of the performed calculations. For derivation of the estimates of $\hat{a}$ and $\hat{b}$ parameters of the uniform distribution the following system of equations was formulated:

$$\begin{cases} \frac{a+b}{2} = \frac{\sum_{i=1}^{n} t_i}{n}; \\ \frac{(b-a)^2}{12} = \frac{\sum_{i=1}^{n} (t_i - m)^2}{n-1}, \end{cases} \quad (2)$$

where t_i are the AOT values; n is the number of samples; $m = M[X]$ is the mean value. Suppose, S is the statistical rms, solution of (2) for $\hat{a}$ and $\hat{b}$ parameters gives:

$$\begin{cases} a = m - \sqrt{3}S; \\ b = \sqrt{3}S + m. \end{cases} \quad (3)$$

The received estimates of the uniform distribution parameters are $\hat{a} = 160\,M\Omega$ and $\hat{b} = 202\,M\Omega$ (Fig. 1).

The hypothesis about consistency of the experimental data with the accepted hypothesis about uniform distribution was verified with the help of Pearson criterion. According to that criterion the measure of disagreement between theoretical and empirical distributions made $H = 0.3333$. According to the table [7] the value P was 0.90; that value is the probability of the fact that the received disagreements between theoretical and stochastic distributions were caused just by accidental reasons. So, according to the results of statistical verification with significance level of ε=0.10 there were no reasons to discard the hypothesis that the AOTs have the uniform distribution with parameters a, b:

$$g(x) = \begin{cases} 0, x < a, \\ \frac{1}{b-a}, a \le x \le b, \\ 0, x > b. \end{cases} \quad (4)$$

We built histograms of AOTs for the case of $1/4$ hour of testing for other CPs and verified the consistency of experimental data with theoretical ones. With the significance level of no worse than 0.10 we concluded that there were no reasons to discard the hypothesis that accumulated operating time values for the case of $1/4$ hour of testing were distributed with the uniform distribution.

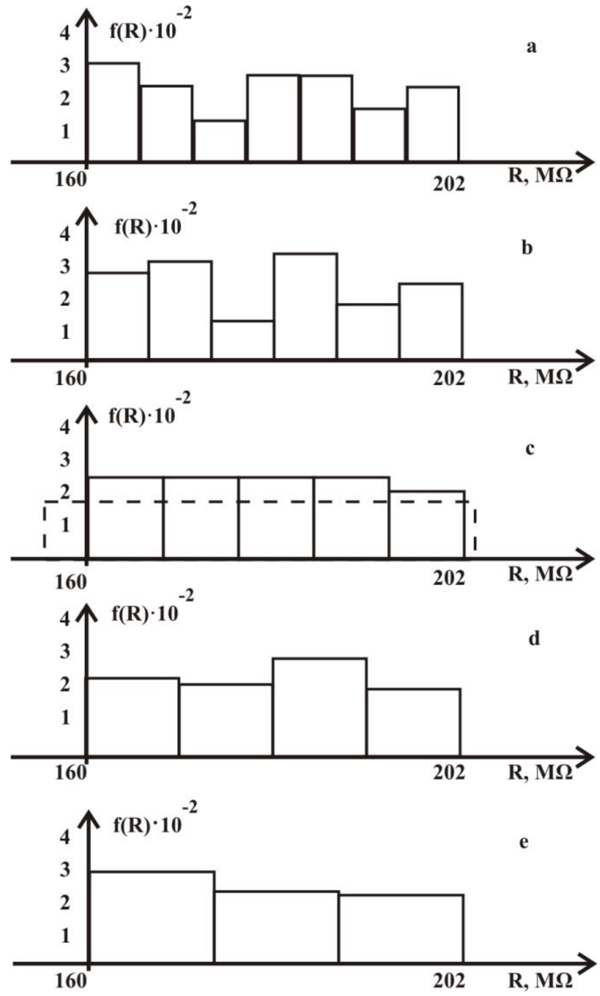

Fig. 1. Histograms of insulation resistance distributions built for different number of intervals

C. Distribution for the Case of $1/2$ Hour of Testing

Using the relevant experimental data we analyzed the CP insulation AOTs distribution for the case of $1/2$ hour of testing. We assumed, that if the CP insulation AOTs for the case of $1/4$ hour of testing have uniform distribution, than the task can be reduced to convolution of two independent identically distributed random values with the distributions $f_x(x) = \frac{1}{b-a}$ and $f_y(y) = \frac{1}{b-a}$. As a result we received:

$$q(z) = \begin{cases} 0, \quad z \le 2a, \\ \frac{z-2a}{(b-a)^2}, \quad 2a \le z \le a+b, \\ \frac{2b-z}{(b-a)^2}, \quad a+b \le z \le 2b, \\ 0, \quad z \ge 2b, \end{cases} \quad (5)$$

where $z = x + y$ is the distribution of the $X+Y$ value.

In Fig. 2 there are several variants of AOTs histograms built for different numbers of equal intervals. The best histogram according to the criterion of minimum number of inversions is the histogram of Fig. 2b.

Than it was necessary to choose a theoretical distribution that should have described the experimental one. Out of the received expression (5) and according to the form of the experimental data (Fig. 2) the Simpson distribution was chosen. Fig. 2 b represents the histogram and the Simpson distribution that approximates the histogram.

In (5) we denoted $A = 2a$ and $B = 2b$; then (5) took the form:

$$q(z) = \begin{cases} 0, z \le A, \\ \frac{4(z-A)}{(B-A)^2}, A \le z \le \frac{A+B}{2}, \\ \frac{4(B-z)}{(B-A)^2}, \frac{A+B}{2} \le z \le B, \\ 0, z \ge B. \end{cases} \quad (6)$$

For Simpson distribution (6) the first and the second central moments are defined as:

$$m = \frac{A+B}{2}, \quad D = \frac{(B-A)^2}{24}. \quad (7)$$

To derive the estimates $\hat{A}$ and $\hat{B}$ of the Simpson distribution the following system of equations was built:

$$\begin{cases} \frac{A+B}{2} = m^*, \\ \frac{(B-A)^2}{24} = (S^*)^2. \end{cases} \quad (8)$$

Solution of the system (8) for $\hat{A}$ and $\hat{B}$ gives:

$$\begin{cases} A = m^* - \sqrt{6}S^*, \\ B = \sqrt{6}S^* + m^*. \end{cases} \quad (9)$$

The received estimates of the parameters were $A = 320\ M\Omega$, $B = 404\ M\Omega$.

The hypothesis about consistency of the experimental data for the PC insulation AOTs for the case of $1/2$ hour of testing with the accepted Simpson distribution was verified with the help of Pearson criterion. According to the results of statistical verification it was concluded that with significance level of ε=0.10 there were no reasons to discard the hypothesis that the AOTs have the Simpson distribution of the form:

$$g(x) = \begin{cases} 0, x \le 2a, \\ \frac{x-2a}{(b-a)^2}, 2a \le x \le a+b, \\ \frac{2b-x}{(b-a)^2}, a+b \le x \le 2b, \\ 0, x \ge 2b. \end{cases} \quad (10)$$

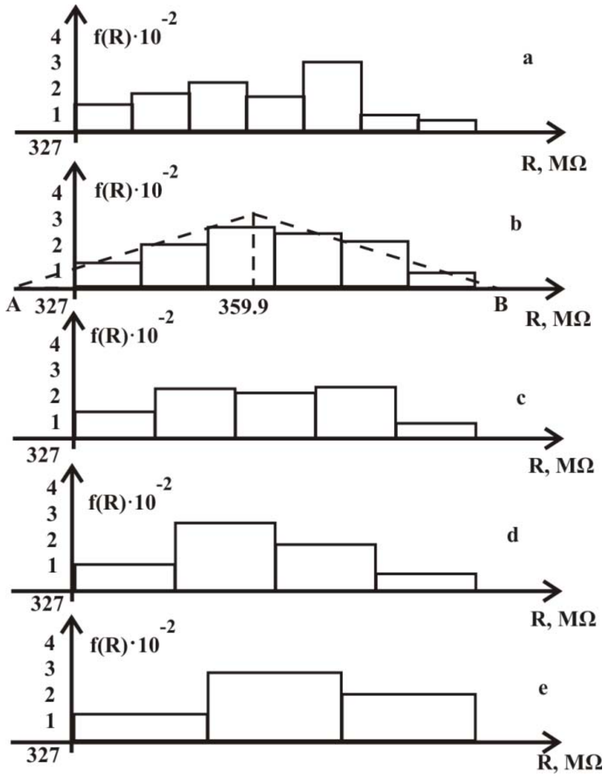

Fig. 2. Histograms of insulation resistance distributions built for different number of intervals

We built histograms of AOTs for the case of $1/2$ hour of testing for other CPs and verified the consistency of experimental data with theoretical ones. With the significance level of no worse than 0.10 the verification permitted us conclude, that there were no reasons to discard the hypothesis that the AOT values for the case of $1/2$ hour of testing were distributed with the Simpson distribution.

D. Distribution for the Case of $3/4$ Hour of Testing

Reasoning the same way it was done earlier, we supposed that the theoretical AOTs distribution for the case of $3/4$ hour of testing could be received as a convolution of two independent random values X and Y with respectively uniform $f_X(x) = \frac{1}{b-a}$ and Simpson (5) distributions. Than the z value distribution should have been received as:

$$q(z) = \begin{cases} 0, z \le 3a, \\ \frac{(z-3a)^2}{2(b-a)^3}, 3a \le z \le 2a+b, \\ \frac{(z-3a)^2 - 3[z-(b+2a)]^2}{2(b-a)^3}, \\ \quad 2a+b \le z \le a+2b, \\ \frac{(3b-z)^2}{2(b-a)^3}, a+2b \le z \le 3b, \\ 0, z \ge 3b. \end{cases} \quad (11)$$

Estimates of the a and b parameters of that distribution were found by the method of moments:

$$a=\frac{4m}{3}-\frac{4s}{3}\sqrt{8};\;\; b=\frac{4m}{3}+\frac{4s}{3}\sqrt{8}. \qquad (12)$$

The received estimates of the parameters were $a=486\ M\Omega$, $b=610\ M\Omega$.

We verified the hypothesis about consistency of the experimental data for the PC insulation AOTs for the case of $3/4$ hour of testing with the accepted distribution (11) with the help of Pearson criterion. According to the results of statistical verification it was concluded that with significance level of ε=0.10 there were no reasons to discard the hypothesis that the AOTs have the distribution of the form:

$$g(x)=\begin{cases} 0, x\le 3a, \\ \dfrac{(x-3a)^2}{2(b-a)^3}, 3a\le x\le 2a+b, \\ \dfrac{(x-3a)^2-3(x-(b+2a))^2}{2(b-a)^3}, \\ \qquad 2a+b\le x\le a+2b, \\ \dfrac{(3b-x)^2}{2(b-a)^3}, a+2b\le x\le 3b, \\ 0, x\ge 3b. \end{cases} \qquad (13)$$

We built histograms of AOTs for the case of $3/4$ hour of testing for other CPs and verified the consistency of experimental data with theoretical ones. With the significance level of no worse than 0.10 the verification permitted us conclude, that there were no reasons to discard the hypothesis that the AOT values for the case of $3/4$ hour of testing were distributed with the distribution (13).

E. Distribution for the Case of 1 Hour of Testing and More

Theoretical distribution for the CP insulation AOTs for the case of 1 hour testing (and more) can be derived as a convolution of four (and more) identical distributions (4). Convolution of four distributions (4) can be approximated with Gaussian distribution; convolution of six and more random uniform values gives a distribution that is almost identical to Gaussian. So for the interval of an hour or more, the distribution of the CP insulation AOTs can be considered Gaussian. Distribution of the CP insulation AOTs for the case of 1 hour testing was written as:

$$g(x)=\begin{cases} 0, x< r_{\min}(1), \\ \dfrac{c_1}{\sigma_1\sqrt{2\pi}}\exp\left(-\dfrac{(x-\mu_1)^2}{2\sigma_1^2}\right), \\ \qquad r_{\min}(1)\le x\le r_{\max}(1), \\ 0, x> r_{\max}(1), \end{cases} \qquad (14)$$

where μ_1 and σ_1 are the mean value and the rms of the CP insulation AOTs; c_1 is the normalizing factor.

Estimates of the parameters μ_1 and σ_1 of that distribution were found by the method of moments:

$$\begin{cases} m=\mu_1-\sigma_1 k, \\ s^2=\sigma_1^2\left\{1-k^2-\dfrac{c_1}{\sqrt{2\pi}}\left(u_2\,\mathrm{e}^{-\frac{u_2^2}{2}}-u_1\,\mathrm{e}^{-\frac{u_1^2}{2}}\right)\right\}, \end{cases} \qquad (15)$$

$$k=\frac{c_1}{\sqrt{2\pi}}\left\{\exp\left(-\frac{u_2^2}{2}\right)-\exp\left(-\frac{u_1^2}{2}\right)\right\};$$

$$u_1=(r_{\min}(1)-\mu_1)/\sigma_1;\quad u_2=(r_{\max}(1)-\mu_1)/\sigma_1.$$

As the system (15) is non-linear, its solution was found by numerical methods.

We built histograms of AOTs for the case of 1 hour of testing for other CPs and verified the consistency of experimental data with theoretical ones. With the significance level of no worse than 0.10 the verification permitted us conclude, that there were no reasons to discard the hypothesis that the AOT values for the case of 1 hour of testing were distributed with the distribution (14).

III. Conclusions

In the paper the distributions of accumulated operating times for the definite CP for fixed intervals of accelerated testing were defined, and the following distributions were received: uniform distribution for the testing time of $1/4$ hour; Simpson distribution for the testing time of $1/2$ hour; distribution (13) for the testing time of $3/4$ hour; truncated Gaussian distribution for the testing time of 1 hour and more. Parameters of the received distributions were defined by the method of moments. The received distributions of the CP insulation AOTs for fixed operation intervals can be used to calculate the reliability rates of insulation for future CPs and to predict remaining lifetime of CPs used in cable lines (i.e. to define the time when the CP insulation resistance should reach the critical value of 0.5 MΩ). That will contribute to the reliability of electrical power supply of facilities of various destinations.

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