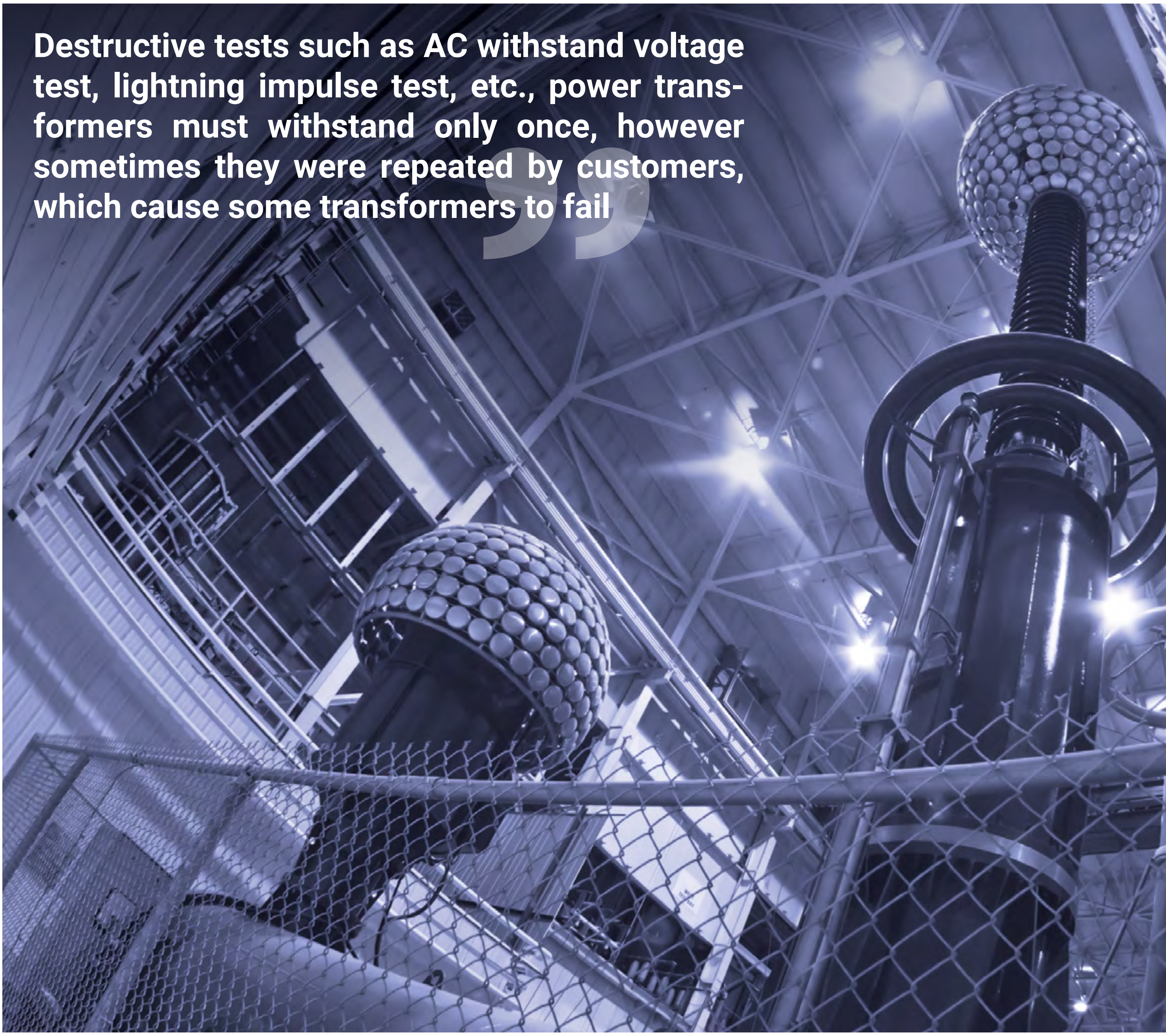

ABSTRACT

Analysis of the time to insulation breakdown of 111 power transformers with ACSD test and 300 insulation models allowed us to determine the probability of breakdown when repeating tests at the factory within 10-30 % (depending on the type of test).

KEYWORDS:

ACSD test, SI test, LI test, LIC test, power transformers, probability of breakdown, ZTZ

I adhere to the axiom: "If you have a suit, and I have a different one, we exchanged suits, and everyone has ONE suit, but if you have an idea, and I have another idea, then after the exchange of ideas, everyone has TWO ideas" and cite another example from the experience of the ZTZ test station, unknown to English-speaking readers. The question raised in the title of the article became very relevant in the 1980s for ZTZ, when the number of power transformers produced for foreign customers increased sharply. The cases of the late arrival of customer representatives (CRs) to the FAT (factory acceptance test) also increased significantly, and the planned management system forced the plant to carry out tests before their arrival.

Upon the arrival of the CRs at the plant, the tests usually had to be repeated. The issue of repeated dielectric tests deserved special attention. Short-duration induced AC withstand voltage test (ACSD), lightning impulse test (LI), lightning impulse on the tail (LIC) test, switching impulse test (SI) are destructive tests, and the insulation of power transformers must only withstand them once. When repeating tests, GOST was allowed to apply 90 % and IEC 75 % of the established norm. But only in rare RCs agreed to such a decrease. Typically, the plant was forced to repeat

Determination of the statistical distribution laws of the characteristics of power transformers was conducted, and several distribution functions were tested for different quantities

What is the probability of a power transformer breakdown when repeating dielectric tests?

the 100 % ACSD test, with the risk of failure of a known-good transformer.

In accordance with GOST, 3 (three) pulses were supplied to the LI, LIC, SI tests before the arrival of CRs. In many cases, it was possible to agree with the CRs on the application of only one additional fourth impulse. The coincidence of the oscillograms of the fourth pulse with the oscillograms of the first two pulses convincingly testified to the "healthy" of the transformer.

Thus, the problem of assessing the probability of insulation breakdown when repeating dielectric tests required a solution. But there are also technical reasons to continue testing. For example, both external interference and the beginning of damage to the internal insulation can cause a slight distortion of the oscillograms on one or two of the pulses. This is sometimes seen in practice, especially with LIC tests. Applying additional impulses usually clears things up. I had a case where I was testing a transformer, and the distortion of the second and third impulses was caused by an insulation overlap on the bridge crane-wiring diagram. After the crane was removed to a safe distance, the fourth and fifth pulses were applied, which confirmed that it was the crane that caused the distortion of the second and third pulses, and there were no problems with the transformer. Further, during the ACSD and SI tests of a number of three-phase transformer designs, individual sections of insulation are twice exposed to 100 % influences. Knowing the probability of breakdown allows the designer to optimally reinforce the insulation of these areas in advance.

To assess the risk of a repeat test, breakdown data on the main insulation of the transformers during the ACSD tests were collected and analysed over a 20-year period (histograms in Fig. 1). The selection did not take into account breakdowns of bushings and tap-changer.

It was evident that there is a need for solving the problem of assessing the probability of insulation breakdown when repeating dielectric tests

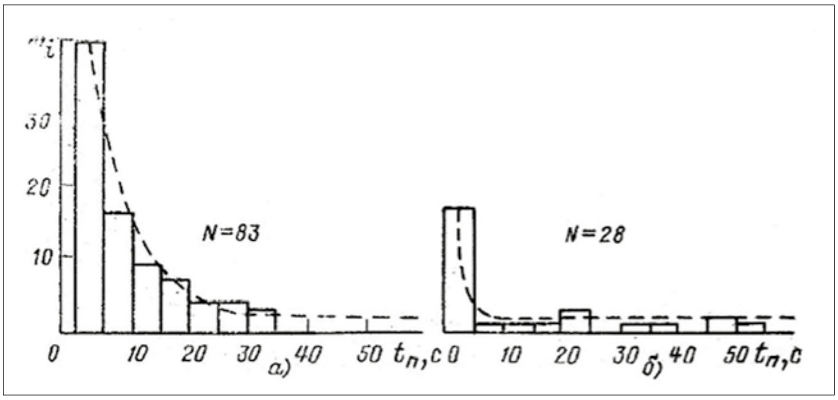

Figure 1. Histograms of time to the breakdown of insulation of power transformers during ACSD tests

The times from the beginning of the tests to the moment of breakdown tп are given for two groups of transformers that differ in the method of filling oil into the tank: histogram **a)** filling oil under full vacuum, histogram **b)** filling at half vacuum. Histograms are plotted at time intervals of 5 seconds. The third part of the breakdowns of transformers of the first group (HV and EHV) occurred at a voltage rise of 225 Hz; three breakdowns occurred at a voltage drop at 98, 95 and 90 % after an ACSD hold of 27 seconds. The stability of the tп distribution was tested. For this, the series of $t_{п}$ values recorded in chronological order was divided into two groups, and the mean values, standard deviations and asymmetries of both groups were compared. These values did not differ statistically for both groups, which confirmed the stability of the distribution over time and with changes in the sample size. Approximately half of the transformers of the second group (medium voltage) were tested at 100 Hz (ACSD 60 seconds), the other half at 225 Hz. Almost half of the breakdowns occurred at a voltage rise, one breakdown at a voltage drop of 225 Hz.

The distributions of $t_{п}$ are sharply uneven for both groups. In the initial part, they have a decreasing character, and after 30 seconds for the first group and after 5 seconds for the second group, they are close to uniform. This character of distributions corresponds to the typical dependence of the failure rate of products on the load time (running-in period and the period of normal operation) known from the theory of reliability. Based on physical concepts, the "weak link" principle and the statistics of extreme values of Gumbel are applicable for the distributions under consideration. Indeed, standard testing has shown that in the initial part, the distribution obeys Weibull's law with a shift parameter equal to zero. However, the parameters of scale (a = 7.36) and shape (b = 0.94) are such that a simpler exponential distribution can be applied for our purpose.

The dependences of the number of breakdowns $m(t)$ on-time t over the entire time range were approximated by a composition of exponential and uniform distributions:

- for the first group of transformers in the form: $m(t) = 0.005 + 0.13\,e^{-0.13t}$ (1)
- for the second group of transformers in the form: $m(t) = 0.014 + 0.72\,e^{-0.72t}$ (2)

We also collected and analysed data on which, in the order of application, the pulse breaks through the insulation of transformers during LI, LIC, SI tests. It turned out that breakdowns occur more often at the first pulse, but the amount of data was insufficient for statistically reliable conclusions. Therefore, the transformer insulation models (parts of the windings with a cardboard barrier in an oil channel) were tested to breakdown. The models were dried and filled with oil as for transformers of the first group. One hundred breakdowns were obtained at ACSD at 50 Hz, SI, and LI tests.

It turned out that the distribution of the time before the breakdown of the models during ACSD tests (Fig. 2a) and the approximating formula are similar to the transformers of the first group:

$$m(t) = 0.006 + 0.15\,e^{-0.15t} \quad (3)$$

The confidence regions for the parameters of dependencies (1) and (3) overlap each other. That is, both samples can be considered as belonging to the same general population. Hence the following conclusions: 1) equations of the form (1) and (3) reflect the objective nature of the regularities of breakdowns of the main insulation of transformers, 2) this character can be considered independent of the frequency of 50, 100 or 225 Hz, 3) the test results of models during testing of SI and LI can be transferred to real transformers.

Calculations according to formulas (1) and (3) showed that doubling the duration (repetition) of the ACSD test will lead to an increase in the probability of breakdown of the "healthy" insulation of transformers of the first group by no more than 15 %. For the second group of transformers, repetition of tests is more

The statistics of extreme values of Gumbel are applicable for the distributions, but testing has shown that in the initial part, the distribution obeys Weibull's law with a shift parameter equal to zero for modelling the breakdowns

dangerous (calculation by formula (2) gave a breakdown probability of about 85 %).

In the SI test, the breakdown of isolation models on the first impulse was 58 times, on the second - 32, on the third - 10. In the LI test, the breakdown of isolation models on the first impulse was 46 times, on the second - 33, on the third - 21. That is, the "running-in" effect is less pronounced than with the SI test. This is explained by the lesser influence of the "weak links" and the greater influence of the random factor due to the shorter pulse duration LI. Since only three pulses were applied during the SI and LI tests, the dependence of the number of breakdowns on the number of pulses was not approximated (a small number of points for statistics). It can be assumed that when the fourth and each subsequent SI pulse is applied, the breakdown probability is 10 %, and for the LI pulse, it is 20 %.

Since there is not enough transformer failure during the LIC test and such tests have not been performed on models, statistically reliable conclusions about the likelihood of failure when repeating these tests are not possible. But, given the shorter duration of the LIC pulse compared to the LI pulse, it can be logical to assume that for Soviet practice (three LIC pulses in a separate test, regardless of the LI test [2]), the probability of breakdown at the fourth pulse will be, for example, 30 %. According to IEC, the test is combined with a full impulse test in one sequence. Recommended order of application of different pulses: one full pulse of reduced level; one full impulse of full level; one or more interrupted low-level pulses; two intermittent full-level pulses; two full impulses of full level [3].

Conclusion

1. Repeating ACSD test – breakdown probability ~15 %.
2. Application of the fourth and each subsequent SI pulse - breakdown probability no more than 10 %.
3. Application of the fourth and each subsequent LI pulse - breakdown probability no more than 20 %.
4. Application of the fourth and each subsequent LIC pulse - a breakdown probability of approximately 30 % can be taken.

Doubling the duration (repetition) of the ACSD test will increase the probability of breakdown of the "healthy" insulation of transformers of the first group by no more than 15 %

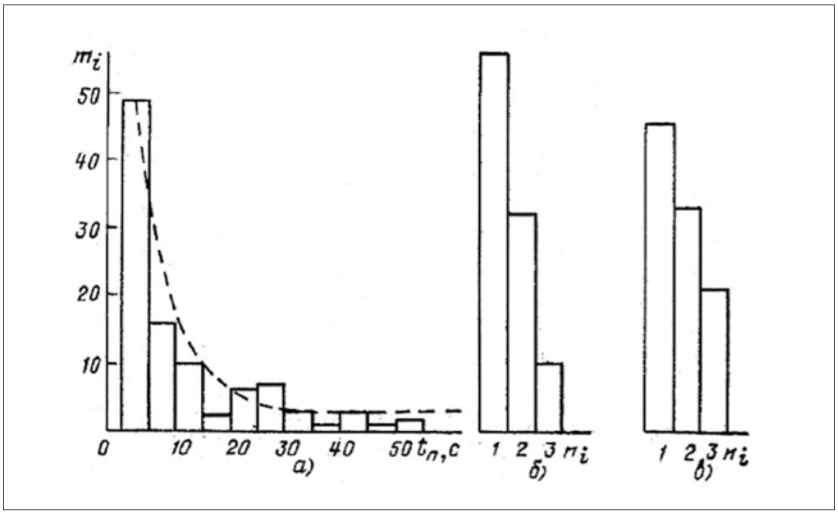

Figure 2. Histograms of breakdowns of insulation models at ACSD (a), SI (б), and LI (c) test n_i is the ordinal number of the applied pulse.

5. I would be glad if my colleagues clarify my possibly outdated conclusions 1-3 in relation to modern designs of power transformers. Also of interest are the data on the probability of breakdown when repeating the LIC test according to the IEC method.

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Vitaly Gurin graduated from Kharkov Polytechnic Institute (1962) and graduated from school at the Leningrad Polytechnic Institute. Candidate of technical sciences in the Soviet scientific system (1970). For 30 years, he tested transformers up to 1.150 kV at ZTZ, including the largest one of that time in Europe, and statistically analysed the test results. For over 25 years, he was the Executive Director of Trafoservis Joint-Stock Company in Sofia (the diagnosis, repair and modernisation in the operating conditions of transformers 20–750 kV). He has authored about 150 publications in Russian and Bulgarian and is the main co-author of GOST 21023.