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Determining the Influence of the Factors that could Disturb Repeatability of the Measurement Results of the AE Pulses Generated by PDs

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This paper presents detailed results of statistical analyses carried out using parametric tests of goodness of fit referring to determining the influence of placing an insulation layer between the electrodes of the spark gap modeling PDs of the multipoint-plane type on the repeatability of the results obtained.

Keywords: insulation layer, spark gap.

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I. Introduction

At present the AE method can be used in two domains connected with power engineering. Firstly, it can be used for detection, location and evaluation of PD intensity occurring in insulation systems of various power appliances. Secondly, it can be used for detection and evaluation of the intensity of material defects that can occur in the welds of welded steam pipelines of a significant thickness installed in power plants. The potential objects in relation to which the AE method could be specialized are: power transformers, power condensers, transformer passes, current and voltage high power transformers and switchgears with SF_6 gas insulation. The current research into the improvement of the AE method refers to the application of the statistical analysis and the methods of digital signal processing to determine the descriptors the values of which would characterize best the phenomena accompanying the occurrence and development of PDs in insulation systems [1,2,8,10,13-4].

The subject matter of this paper deals with the improvement of the acoustic emission (AE) method in its application in measurements of partial discharges (PDs) occurring in oil insulation systems of power appliances. The detailed subject matter, however, refers to the application of statistical tests for verifying the assumed hypotheses adopted to evaluate the AE pulses generated by PDs.

Within the research carried out so far the authors have determined the shape and peak coefficients, median value and the ranges of dominant frequency spectra characterizing the amplitude spectrum and energy density runs, which were calculated for the AE pulses generated by PDs to identify basic PD forms [3-6]. In the research work carried out so far, however, connected with the application of the method of analyses and statistical conclusion-drawing, the authors have presented the possibilities of using the correlation coefficient and regression analysis to determine the interdependence between the changes of PD generation voltage and the values of the selected descriptors characterizing frequency spectra determined for the AE pulses generated [5,6]. Moreover, using the parametric and nonparametric tests of goodness of fit, the character of probability distribution of the AE pulses measured was tested, and the function graphs and probability density cumulative distribution functions and the normal and semi-normal probability graphs were drawn [6]. Also the possibilities of using the indexes of descriptive statistics, which are the measures of location, dispersion, asymmetry and concentration, as well as the runs of histograms and the density distribution curves corresponding with them, were presented as tools for characterizing the AE pulses generated by various PD forms. Also proved was the usefulness, at the stage of the initial aggregation of data, of frame diagrams, dispersion and symmetry for defining differences and showing similarities between the distributions of the AE pulses generated by various PD forms [5, 6]. Since the research was carried out in laboratory conditions for spark gaps modeling PDs of the surface, point-plane, multipoint-plane, and multipoint-plane with a pressboard layer types, and on indeterminate potential particles and in gas bubbles, it was necessary to determine the repeatability of the measuring results obtained. The evaluation of the repeatability was performed based on the frequency analysis results of the AE pulses measured, putting stress on the descriptor values that make the identification of the basic PD forms possible. The results obtained have been presented [3, 4].

A detailed subject matter of this paper refers to determining the influence of a number of factors that can influence the repeatability of the results of the frequency analysis of the AE pulses generated in spark gaps modeling basic PD forms

In this range, the evaluation of the influence of the following parameters was carried out:

- geometrical configuration and the size of a point electrode for discharges of the point-plane type,
- number of point electrodes for discharges of the multipoint-plane type,
- placement of a pressboard layer between the electrodes of a spark gap which makes the modeling of PDs of the multipoint-plane type possible,
- type of material used for the insulation layer for surface discharges.
- the degree of concentration and the kind of particles of an indeterminate potential for PDs generated in an oil system with particles of an indeterminate potential.
- the generation frequency and the size of gas bubble diameters for an oil system for PD generation in gas bubbles.

Moreover, the influence of the material change and the thickness of insulation layers placed in the propagation path of the AE signals generated by the discharges of the multipoint-plane type on the repeatability of the frequency analysis results was tested. The range of the research carried out also included the evaluation of the influence of the change of insulation oil type and physico-chemical parameters in which discharges of the multipoint-plane type were generated on the repeatability of the selected descriptor values.

This paper presents detailed results of statistical analyses carried out using parametric tests of goodness of fit referring to determining the influence of placing an insulation layer between the electrodes of the spark gap modeling PDs of the multipoint-plane type on the repeatability of the results obtained.

II. Characteristics of the measuring apparatus used and the descriptors making the PD identification possible

The AE signals were generated in the setups modeling the following six partial discharge (PD) forms: point-plane discharges in oil, multipoint-plane type discharges in oil, multipoint-plane type with a layer of pressboard discharges in oil, surface discharges in oil, gas bubble discharges in oil, discharges in indeterminate-potential particles moving in oil. A standard measuring setup, produced by the firm Brüel & Kjær, was used for the measurements of the AE pulses. Detailed characteristics of the model setups, the conditions in which the tests were carried out and the parameters of the measuring apparatus used have been presented in the works [3, 4].

The descriptors used for identification, the values of which were determined for amplitude and energy density spectra separately, taking into account the polarization of the supplying voltage, and which were consecutively tested for their repeatability, were calculated based on the following relationships:

peak factor $W\{E(f)\}$:

$$W\{E(f)\} = E_{MAX} / E_{RMS} , \qquad (1)$$

where: E(f) - values for amplitude and energy density spectra, respectively, EMAX - maximum value, ERMS - root-mean-square value calculated according to (2):

$$E_{RMS} = \sqrt{\int_{f_1}^{f_2} E^2(f)df \Big/ \int_{f_1}^{f_2} df} \qquad (2)$$

shape coefficient $K\{E(f)\}$:

$$K\{E(f)\} = ERMS / EAVG \qquad (3)$$

where: EAVG - average value calculated from (4):

$$E_{AVG} = \int_{f_1}^{f_2} E(f)df \Big/ \int_{f_1}^{f_2} df \; ; \qquad (4)$$

median frequency:

$$f_{MED} = 2\int_{f_1}^{f_{MED}} E(f)df = \int_{f_1}^{f_2} E(f)df \qquad (5)$$

To process, analyze and visualize the AE pulses registered, numerical procedures written in Mathcad 2001 program by the Mathsoft firm were used. The detailed characteristics of the measuring setup used, its parameters and the way of executing frequency analysis were presented, among others, in the works [3, 4]

In order that the results obtained may be of a general merit and be comparable, the measurements of the AE pulses generated by the PD forms under study were taken at precisely defined experiment conditions concerning the relative value of the PD generation voltage, total amplification value of the signals measured as well as the place of generation and measurement of the AE pulses from PDs. For the comparative analysis were selected, each time through an independent drawing, ten values of a peak coefficient, shape and median frequency determined separately for the amplitude and energy density spectra, taking into account the polarization of the voltage supplying the model setups under study.

III. Examples of the results obtained

The statistical analyses carried out, the results of which have been presented [5,6] confirmed the assumed hypotheses about the normality of the PD population distributions under study and the repeatability of the measurement results obtained.

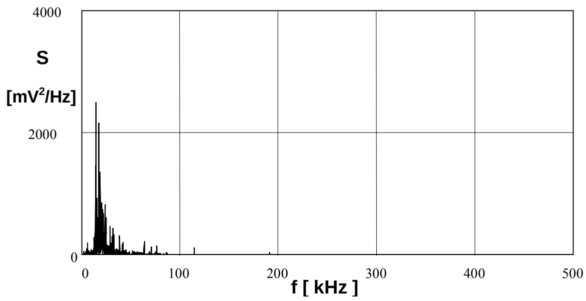

Fig. 1. Energy density spectrum run for AE pulse series generated by PDs in oil in the multipoint-plane system during the negative voltage half-cycle.

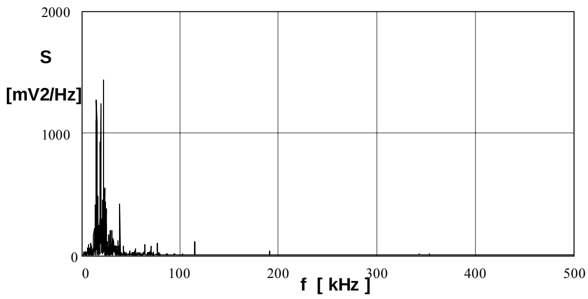

Fig. 2. Energy density spectrum run for AE pulse series generated by PDs in oil in the multipoint-plane system during the negative voltage half-cycle.

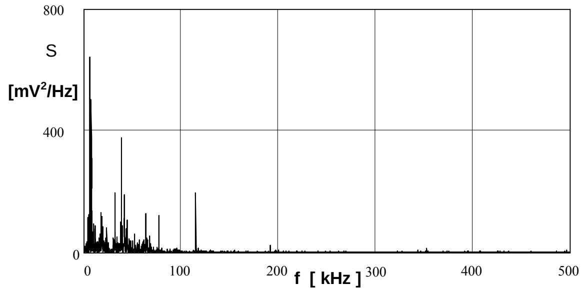

Fig. 3. Energy density spectrum run for AE pulse series generated by PDs in oil in the multipoint-plane with a layer of pressboard system during the positive voltage half-cycle.

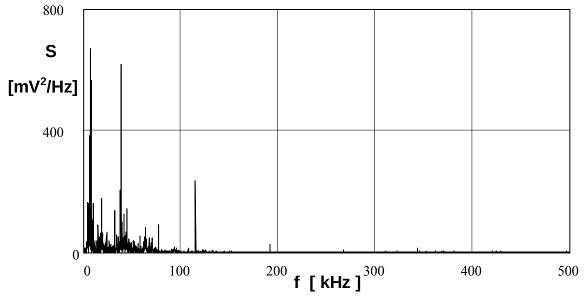

Fig. 4. Energy density spectrum run for AE pulse series generated by PDs in oil in the multipoint-plane with a layer of pressboard system during the negative voltage half-cycle.

The conclusions referring to determining the influence of the constructional and technical conditions as well as metrological conditions under study on the repeatability of the results obtained were drawn at the assumed significance level $\alpha = 0.1$, based on the parametric tests of goodness of fit that are based on the homogeneity analysis of many variances and on the analysis of variances for many averages of a single classification in the case when a few result populations were considered. To determine the repeatability of the results obtained, at the assigned destabilizing parameter change when two populations were compared, a parametric t-Student test was used which makes it possible to verify the thesis of the equality of two average values [9,11,12,15-17]. Within this paper the results connected with evaluation of repeatability obtained for the change of the point electrode geometry for PDs of the point-plane type and for the changes of the transformer oil type for the AE pulses generated by PDs of the multipoint-plane type will be presented.

This paper will present the results connected with the evaluation of repeatability which were obtained when an insulation layer was introduced for PDs for the AE pulses generated by PDs of the multipoint-plane type.

In order to determine the influence of an insulation layer on the repeatability of the measurement results of the AE pulses generated by PDs of the multipoint-plane type, a layer made of a 7 mm pressboard was placed between the electrodes of the spark gap under study.

Figs 1-4 show frequency spectrum runs, separately for both voltage polarizations, of the AE pulses generated in such a selected set-up modeling PDs of the multipoint-plane type with and without a layer of pressboard.

The results obtained have been presented in table form (Tables 1-2). The values of the descriptors drawn for ten measurements, their average value, standard deviation (Table 1) and the values obtained for the homogeneity tests of many variances and the equality of three averages (Table 2) have been presented separately.

IV. Summing-up

The paper presents the results obtained only for one factor that can disrupt repeatability of the results obtained in set-ups modeling basic PD forms. It should be stressed that statistical analyses referring to determining the influence of the other disruptive factors on the selected descriptors characterizing the AE pulses measured in the frequency domain were carried out in an analogous way.

Comparing the values obtained by parametric tests of goodness of fit for three selected descriptors with critical values read from the distribution tables at the assigned significance level $\alpha = 0.1$ and a determined number of the freedom degrees depending on the number of measurements and the number of populations considered of the measurement results obtained, it can be stated that:

- The increase of the number of points in the range from 3 to 12 in the setup for PD generation of the multipoint-plane type did not disturb the repeatability of the results obtained. However, the placement of a pressboard layer between the electrodes of the spark gap used caused a significant change of the determined descriptor values characterizing the amplitude and energy density spectrum runs. The use of the pressboard barrier changed the physical conditions in which PDs are generated and thus such a model setup should be considered as a separate PD form.
- The use of three different types of resin as a layer separating the electrodes in a spark gap for PD generation of the surface type did not influence the repeatability of the measurement results. However, the use of the pressboard layer caused the change of the compared descriptor values obtained and the lack of repeatability the measurement results.
- The changes concerning the point electrode geometry and the introduction of another point for a spark gap making the generation of PDs of the point-plane type possible does not influence the repeatability of the results obtained.
- For the setups that enable modeling of PDs of the point-plane and multipoint-plane types, the lack of repeatability of the descriptors compared was pointed out. In such spark gaps, varying analysis results in the time and frequency domains of the AE pulses generated were obtained.
- The application of insulation oils of various physico-chemical parameters and the oil temperature change in the range from 22^0C to 85^0C did not influence the measurement repeatability of the AE pulses generated by PDs of the multipoint-plane type.
- The placement of barriers made of various types and of various thickness papers and insulation resins on the propagation path of acoustic waves, between a spark gap for PD generation of the multipoint-plane type and a wall of a transformer tub on the surface of which a measuring transducer was attached, did not influence the repeatability of the AE pulses registered. Also some experimental works were performed which referred to the evaluation of the effect of the change of the propagation path length of the acoustic signals generated and determining the changes of the transducer placement in relation to the PD generation area on the repeatability of the AE pulses measured. Also in this case the hypotheses assuming the repeatability of the results obtained were verified, and the results obtained have been presented in the paper [6].
- The changes in concentration of the indeterminate-potential particles in the area of PD generation on the particles which move in insulation oil, and the change of their material did not influence the results of the time-frequency analysis of the AE pulses generated.
- The increase of the diameter and generation frequency of gas bubbles, the flux of which was directed to the area between the electrodes of the spark gap for generation of PDs of the point-grounded plane type, did not influence the measurement results of the AE generated.

Summing up, the laboratory measurements taken repeatedly of the AE pulses generated in the constructed spark gaps modeling basic PD forms are characterized by their repeatability, and the results obtained are resistant to the influence of the changes of the interfering factors considered. This conclusion is true on condition that a 10% margin of error making possibility is taken into account.

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Визначення впливу факторів, які могли б вплинути на відновлення результатів вимірювань AE імпульсами, що виробляються PDs

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У статті наведено детальні результати статистичного аналізу використання параметричних тестувань придатності добавки до визначеного впливу розміщення шару ізолятора між електродами пробоєм іскри багатоточковим PDs-моделюванням на площині на відновлення результатів.