APPLICATION OF STATISTICAL METHODS IN THE ANALYSIS OF THE ACOUSTIC EMISSION SIGNALS GENERATED BY PARTIAL DISCHARGES

Tomasz BOCZAR, Stefan WOLNY
Technical University of Opole, Department of Electrical Engineering and Automatic Control,
ul. K. Sosnkowskiego 31, 45-272 Opole, POLAND, tel. +48 (077) 400-6000, E-mail: tboczar@po.opole.pl

SUMMARY

The subject matter of this paper deals with the improvement of different ways of evaluating of the results obtained during measurements of partial discharges (PDs) using the acoustic emission method (AE). The detailed subject matter of the paper refers to the use of mathematical statistics in the analysis of AE signals generated by PDs.

The results presented are connected with repeatability tests on the selected descriptors which make the identification of basic PD forms possible.

Keywords: *partial discharges (PD), acoustic emission method (AE), the point-plane gap, the descriptors*

1. INTRODUCTION

The subject matter of this paper deals with the applications of statistical analysis in processing the results obtained from high-power tests. First of all, the repeatability of measurements of the acoustic emission (AE) pulses generated in spark gaps modeling basic forms of partial discharges (PDs) will be tested and the repeatability of the results obtained will be checked by analyzing the acoustic emission measured in the frequency domain. Therefore, the subject matter presented in this paper is connected with the issue of developing the possibilities of using the AE method in broadly understood diagnostics of insulation systems of power appliances.

Based on the results obtained from research so far, it has been proved that in strictly defined conditions of taking measurements, comparing the selected criteria, it is possible to identify uniquely basic PD forms. It refers to PDs of the following types: multipoint - grounded plane, point – grounded plane, surface, on particles with indefinite potential and in gas bubbles, which are generated in electroinsulation oil. From among the descriptors characterizing frequency spectra of AE pulses generated by the above-mentioned PD forms, it has been proved that comparing at the same time the shapes of amplitude spectrum runs and energy density runs, and the values of: peak factor, shape, median frequency and the domain frequency intervals in a spectrum for the adopted discrimination threshold, it is possible to identify the PD forms under study. Since the laboratory tests were performed many times and over a long period of time, it is necessary to test the repeatability of the measurement results obtained, especially those of the descriptor values that make the recognition of basic PD forms possible.

2. CHARACTERISTICS OF THE MEASURING APPARATUS USED AND THE DESCRIPTORS MAKING THE PD IDENTIFICATION POSSIBLE

A standard measuring setup by the Brüel&Kjær firm was used to measure and analyze AE pulses generated in setups modeling the defined PD forms. The measuring track consisted of a piezoelectric wideband contact transducer, amplifier equipped with a filter, and a measuring card coupled with a computer. 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 [1,2].

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)}:

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

where: E(f) - values for amplitude and energy density spectra, respectively, E_{MAX} - maximum value, E_{RMS} - root-mean-square value calculated according to (2):

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

- shape coefficient K{E(f)}:

$$K\{E(f)\} = E_{RMS} / E_{AVG} \tag{3}$$

where: E_{AVG} - average value calculated from (4):

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

- median frequency:

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

3. TEST RESULTS OF THE MEASUREMENT REPEATIBILITY

The repeatability tests of the selected descriptors were based on the measurements of PDs of the point – grounded plane type using the acoustic method. They were repeated six times on consecutive measurement-taking days. The measurement cycles took place in similar environment conditions, e.g. temperature, humidity and air pressure. Similar shapes of frequency spectrum runs and the values of the descriptors that characterize them were obtained for the discharges of the type analyzed, thus the descriptors determined for the positive polarization of the supplying voltage were selected for the repeatability analysis. Fig. 1 – 3 show characteristic runs of the AE pulses generated by PDs of the point – plane type measured in the positive voltage half-time. Fig. 1 shows a time run, Fig. 2 amplitude spectra, and Fig. 3 an energy density spectrum.

The conclusions from the analyses carried out were drawn based on the test of significance that is based on the variance analysis for many averages of a single classification [3,4,5]. This test is based on F Snedecor distribution and the assumption that there are given k populations of a normal distribution $N(m_i, \sigma_i)$, where i =1, 2, …, k, or close to a normal distribution, and the variances of all k populations are equal, i.e. $\sigma_1^2 = \sigma_2^2 = ... = \sigma_k^2 = \sigma^2$, but they do not have to be known. Hence, in order to begin the test it was necessary to check first whether the data of PDs for a given type were within a normal distribution. Following the earlier research, already published [3], it was decided, based on the assumption of the concord of the data with the distribution of a normal type, to find out whether there also occurs the equality of the variance of the data. A homogeneity test of many variances [3,4,5] is based on the distribution X^2 and the assumption that there are k normal populations $N(m_i, \sigma_i)$, where i = 1, 2, ..., k, of n_i number. The selected measurement data on which the calculations were performed are presented in Table 1.

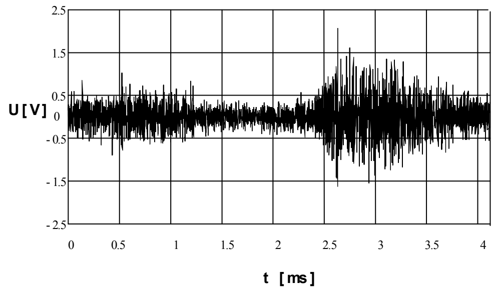


Fig. 1 Time run for AE pulse series generated by PDs in the point - plane system at oil in the positive voltage half-period

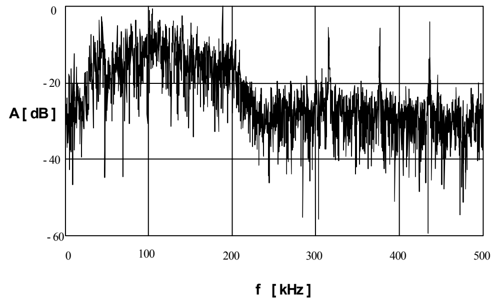


Fig. 2 Amplitude spectrum run for AE pulse series generated by PDs in the point - plane system at oil, in the positive voltage half-period

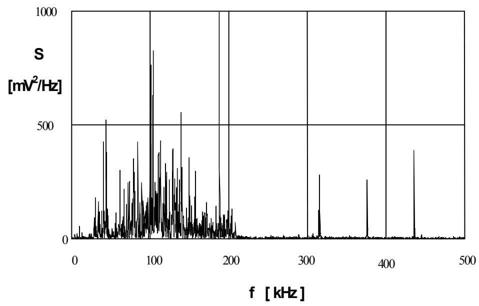


Fig. 3 Energy density spectrum run for AE pulse series generated by PDs in the point - plane type at oil in the positive voltage half-period

Because the calculations presented in Table 1 can be described by a normal distribution and their variances are equal, it was possible to carry out a test of variance analysis for many averages in order to determine the repeatability of the test results.

The test hypotheses assume, respectively:

Ho : $m_1 = m_2 = m_3 = m_4 = m_5$; where m is the average from population,

H_1 : not all averages are equal to one another.

Peak coefficient of the energy density spectrum (positive polarization)				
number $\mathbf{n_i}$	Average $\underline{\mathbf{X}}$	Deviation **S**	**Test χ^2**	**TEST F**
6	1.2904	0.0798	**0.176592543**	**0.13290121**
6	1.3221	0.0776		
6	1.3154	0.0731		
6	1.3204	0.0831		
6	1.3141	0.0706		
6	1.3087	0.0805		
Shape coefficient of the energy density spectrum (positive polarization)				
6	3.1163	0.4018	**1.285717867**	**0.081815181**
6	3.0653	0.5516		
6	3.2046	0.4816		
6	3.1076	0.4337		
6	3.1081	0.3360		
6	3.0564	0.4702		
Median frequency of the energy density (positive polarization)				
6	126.143	2.2763	**2.070542801**	**1.326778926**
6	123.973	2.4470		
6	126.698	1.7841		
6	125.583	2.5790		
6	125.303	1.8489		
6	123.958	3.1275		

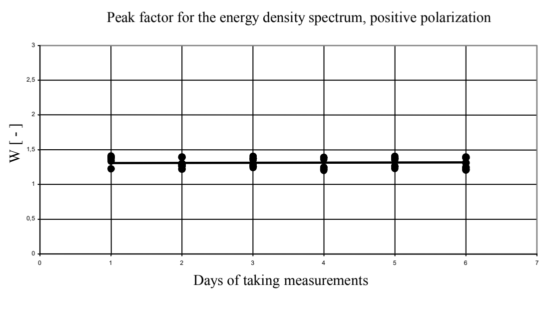
Tab. 1 Calculation results of the selected descriptors determined through PD measurements listed in order to carry out the test of measurement repeatability

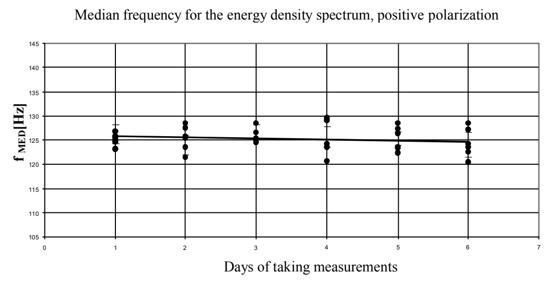
α	degrees of freedom **(k - 1)**	χ^2_α	1 degree of freedom **(k – 1)**	2 degree of freedom **(n·k – k)**	$\mathbf{F_\alpha}$
0.05	5	**11.07048257**	5	30	**2.533553811**

Tab. 2 χ^2_α value readout from the table of distribution for the test of homogeneity of many variances and F_α value for the test of variance analysis for many averages

The calculated value of distribution F and the value readout from the table for the significance level $\alpha = 0.05$ is presented in Tables 1 and 2, respectively. Since in each case the inequality $F < F_\alpha$ takes place, there are no bases for rejecting the Ho hypothesis which says that all the selected PD descriptors are equal to one another. This statement proves, at the same time, that in the setup under study the repeatability of the experiment results takes place with a 5% error tolerance. Also the tests carried out for peak factors, shape and median frequency in the negative polarization and for the amplitude spectrum ended with identical results.

The test result is graphically presented in Fig. 4.





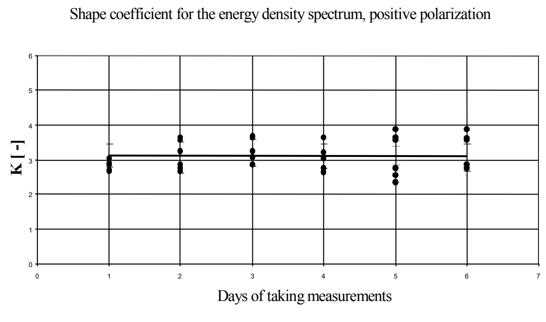


Fig. 4 Repeatability of peak factor, shape coefficient and median frequency for the energy density spectrum, positive polarization

4. CONCLUSION

Based on the results obtained during the tests performed it can be stated that for the adopted identification criteria of the particular descriptors the equality of their values takes place. It was also proved that in the setup under study modeling discharges of the point - plane type the repeatability of the experiment results takes place with a 5% error tolerance.

It should be also noted that the tests performed for the peak factor, shape coefficient and median frequency at the negative polarization and for the amplitude spectrum ended in the same result. This proves that the adopted descriptor can constitute some identification criteria, the values of which do not depend on the measuring series analyzed.

REFERENCES

[1] Boczar, T.: “Identification of a Specific Type of Partial Discharges form Acoustic Emission Frequency Spectra” IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 8, No 4 August 2001, pp. 598-606.

[2] Boczar, T.: „Widma emisji akustycznej generowanej przez wyładowania niezupełne w izolacji olejowej” Studia i Monografie Oficyna Wydawnicza Politechniki Opolskiej, z. 114, Opole, 2000.

[3] Boczar, T., Wolny, S.: „Application of calculus of probability for the randomness evaluation of acoustic emission signals generated by partial discharges” 31st International Conference “Defektoskopie 2001”, Czech Society for Nondestructive Testing, Prague, Czech Republic, 20-22.11.2001, pp. 55-62.

[4] Gren, J.: “Statystyka matematyczna, metody i zadania” PWN, Warszawa, 1985.

[5] Van Brut, R. J.: “Stochastic properities of partial discharges phenomena”. IEEE Transactions on EL, vol. 26, no. 5, 1990, pp. 642-665.

BIOGRAPHY

Tomasz Boczar (Ph. D. eng.) was born in 1968 in Prudnik in Poland. He graduated from the Department of Electrical Engineering and Automatic Control, Technical University of Opole in 1993. In 1998 he was graduated PhD degree in Electrical Engineering Silesian University of Technology, Institute of Electrical Power Engineering in Katowice, Poland. In present time is engaged in different applications of the acoustic emission method and other nondestructive method especially in diagnostics of insulation setups of electric appliances. In these fields he published more than 50 journal and conferences papers and one monograph. He is lecturer and research worker of Technical University of Opole.

Stefan Wolny (Ph. D. eng.) was born in 1970 in Radomsko in Poland. He graduated from the Department of Electrical Engineering and Automatic Control, Technical University of Opole in 1995. In 2000 he was graduated PhD degree in Technical University of Opole. In present time is engaged in different applications of the insulation oil electrification, measurements of return voltage of dielectrics, acoustic emission method and other nondestructive method especially in diagnostics of insulation setups of electric appliances. In these fields he published more than 30 journal and conferences papers. He is lecturer and research worker of Technical University of Opole.