INVESTIGATION OF PARTIAL DISCHARGE WITHIN GENERATOR COIL BARS ON THE GROUND OF ACOUSTIC EMISSION METHOD

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Investigations of partial discharges within bars of generator coils have been made by means of acoustic emission method. Two ways of analysis of shapes of obtained AE amplitude distributions are presented. The first consists in definition and calculations of advanced AE descriptors, which can distinguish deformation processes. The second way is based on Kohonen neuron network, used to distinguish and classify of images. The results of both method of analysis are compared with the measurements of the apparent charge which have been curried out simultaneously to EA investigations.

Keywords: acoustic emission, partial discharge, amplitude distribution, descriptors, neural network, electric apparent charge

1. INTRODUCTION

The acoustic emission (AE) methods open unique possibilities to observe deformation process [1,2]. Its basic typical limitations are caused by changes of AE elastic waves emitted by partial discharges (PD) sources during propagation, detection and processing of registrated signals. These limitations can be eliminated by means of a choice of proper descriptors and then the AE method – with its several interesting properties – is a credible complementary operational method used to measure and evaluate PDs in different insulating systems [6,7].

Below, investigations of PDs in generator coil bars are considered. Such a typical investigations have two goals: cognitive (relevant phenomena description), and practical (comparison of selected technological properties). Described investigations have been carried out only in order to study of PD phenomena.

2. MEASURING SYSTEM. EXAMPLARY RESULTS

Investigations have been carried out in the firm ENERGOSERVIS (Lubliniec, Poland) on the stand used to study of PDs within bars of generators. The measuring system DEMA-COMP (Fig. 1) and the professional TE 571 detector have been applied to this purpose. The first system with advanced measuring possibilities enables:

- Registrate the AE signals within real time and the frequency band up to 2.5 MHz
- Measuring data handling in order to make of any AE descriptors.

The measuring range accessible for AE measurements has been established for each of investigated bars. In this range, limited by additional earth electrodes, the measuring points are displaced. At selected measuring points AE sensor of R6 type (made by the Physical Acoustic Corporation) have been placed. The supply voltages applied to bars are selected from the range of 0-2 U_N, where $U_N = 15.75$ kV. For each selected voltage AE impulses have been registrated (each for two seconds) and the apparent charge has been measured.

The subsequent analysis is related to AE impulses registrated only in one line characterized by:

A/ identical measuring line parameters (K2 line – AE sensor of R6 type #2, differential pre-amplifier #B, DEMA with amplification of 20 Db),

B/ identical registration parameters (sampling frequency of 1 MHz, real time of registrated fragments 2 s).

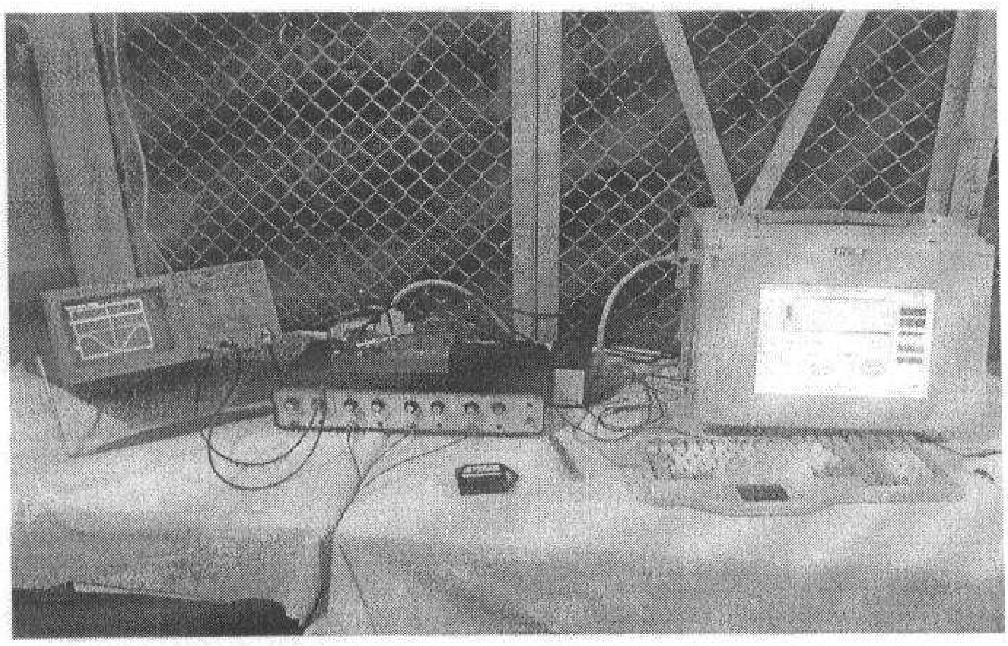

Fig. 1 AE measuring system called the DEMA-COMP

Exemplary of AE fragment signals of 20 ms (two periods of supply voltage) registrated at one measuring point are presented in Fig. 1. AE impulses from Fig.2 are presented by means of auto-scale for a range of values. Basic features of PDs registrated by means of AE method are as follows:

- Random and periodical character of AE impulses,

- Decrease of AE impulse and their duration together with the supply voltage reduction,
- Existence of minimal supply voltage necessary to initiation of PD phenomena,
- Local properties of registrated impulses conditioned by location of the measuring point.

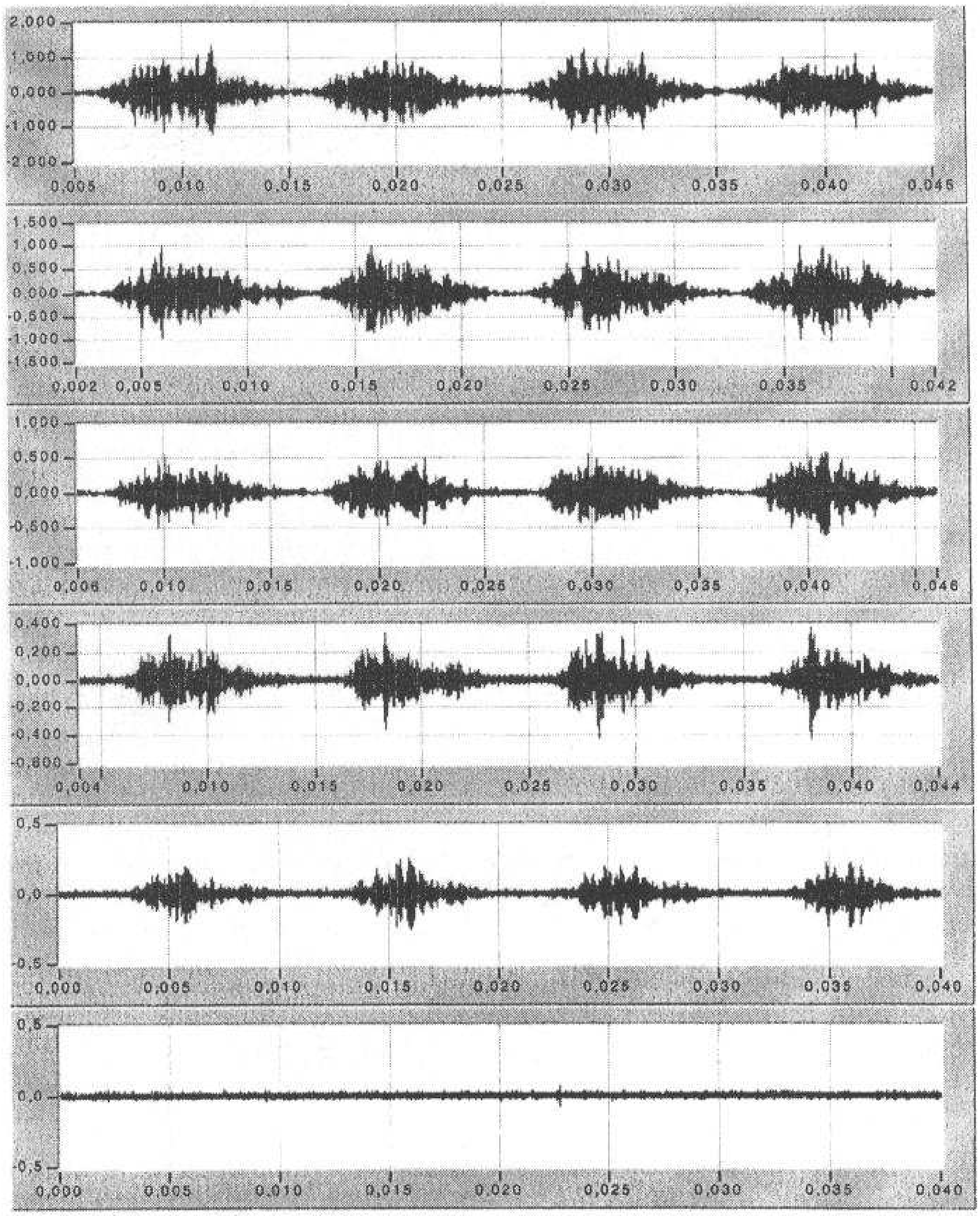

Fig. 2 Fragments of AE impulses registrated at measuring point P3 under supply voltages: a/ 24,5kV b/ 19,7kV c/ 14,8kV d/ 10,0kV e/ 8,1kV f/ 0.0kV

Fig. 3 contains the families of selected AE amplitude distributions calculated from AE impulses registrated at measuring point P3 for different supply voltage values. Two of them are the basic amplitude distributions. They are amplitude distributions of two quantities: rate of counts and power of AE impulses and for better distinguishing deformation processes (simple deformation processes are determined by linear diagram fragments) logarithmic scale has been chosen in diagrams to. The other two amplitude distributions being the derivative of basic amplitude distributions in function of the discrimination threshold are the complementary AE amplitude distributions.

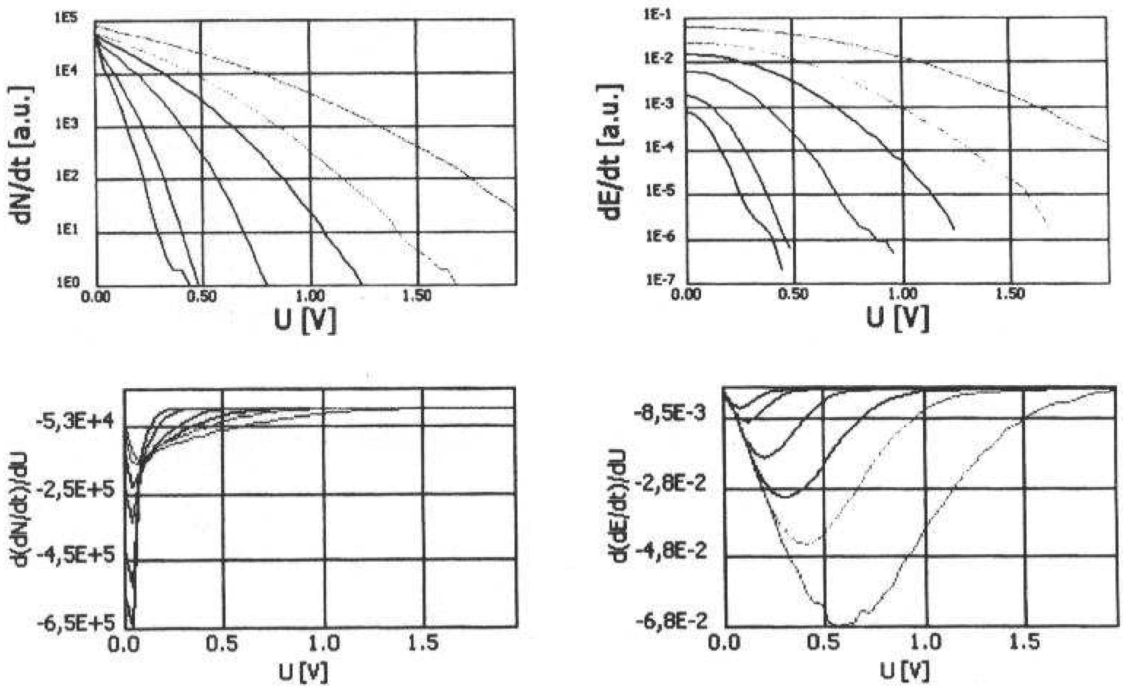

Fig.3. Families of amplitude distributions of AE signal (dN/dt – rate of AE counts, P – power of AE signals, $d(dN/dt)/dU_T$ – derivative of amplitude distributions of rate of AE counts in function of the discrimination threshold, dP/dU_T – derivative of amplitude distributions of power of AE signals in function of the discrimination threshold) registered at measuring point P3 under following supply voltages: a/ 24,5kV b/ 19,7kV c/ 14,8kV d/ 10,0kV e/ 8,1kV.

4. ANALYSIS OF CALCULATED AE AMPLITUDE DISTRIBUTIONS

4.1 AE descriptors

PD sources are described by measured mean value of electrical apparent charge. Activated PD sources generate AE elastic waves which change during their propagation, registration and processing. Such processes cause that quantitative comparison of electric apparent charge and AE descriptors describing AE impulses registrated at measuring point is no sense. There is a need to search, define and verify of advanced AE descriptors connected with properties of AE sources although we still have only the AE impulses registrated at measuring point.

At present stage of analysis the processing of registrated signals is under control and properties of AE sensor are known. In spite of repeatable conditions relevant to assembly of AE sensors there is no certainty of stable thickness of acoustic coupling medium during detection. This disadvantage can be controlled by using of logarithmic scale in basic amplitude distributions of AE impulses diagrams and making analysis of shape properties of AE amplitude distributions (not absolute values). AE propagation area and changes of elastic waves during their propagation are unknown but using of logarithmic scale in basic amplitude distributions of AE impulses diagrams causes similar changes of AE signals generated by neighboring AE sources.

For basic amplitude distributions of AE impulses the range of discrimination threshold values, when straight lines can approximate these distributions, have been defined. The lower value of the range is treated as such discrimination threshold value when the first derivative of basic AE distribution reaches its minimum. The upper value is determined by 90% of maximum value of registrated AE impulses. The slope factors of approximated straight lines determine AE descriptors. In such a way the following descriptors have been defined:

- ADC descriptor (Amplitude Distribution of AE Counts)
- ADP descriptor (Amplitude Distribution of Power of AE signal).

The above descriptors are calculated basing on AE amplitude distributions using respectively:

- Amplitude distribution of rate of AE counts and its derivative for ADC descriptor,
- Amplitude distribution of power of AE signals and its derivative for ADP descriptor).

Calculated AE descriptors (ADC, ADP) together with respective correlation factors (σ_{ADC}, σ_{ADP}) for 15 analyzed measuring situations are presented in TABLE 1. Each of these situations is described by its name, the name of measuring point and supply voltage value. The table contains mean value of independently measured apparent charge (q).

Tables 2 and 3 contain classification of analysed measuring situations made in respect of ADC and respectively ADP descriptors. Lower position (No) for a given measuring situation manifests more advanced deformation process described by the AE method. The electrical method (measurement of apparent charge) also classifies the advance limit of deformation process because the greater value of apparent charge means the more advanced deformation process. Obviously, the electric method "sees" PD phenomena globally (in whole system), whereas the AE method "sees" PD phenomena by means of elastic waves coming from different PD sources and registrated by AE sensor.

TABLE 1 Statement of analyzed measuring situations and calculated properties of AE descriptors

No	Name	Meas. Point	U [kV]	Q [nC]	ADP [a.u.]	σ_{ADP}	ADC [a.u.]	σ_{ADC}
1	P5-5	P5	24,5	10	-2,3	0,99	-2,3	1,00
2	P5-4	P5	19,7	8	-2,8	0,99	-3,3	1,00
3	P5-3	P5	14,5	4	-3,1	0,99	-4,2	0,99
4	P5-2	P5	9,7	1	-10	1,00	-11	1,00
5	P5-1	P5	6,8	0,035	-9,8	0,99	-10,8	0,99
6	P4-5	P4	24,5	10	-2,9	1,00	-3	1,00
7	P4-4	P4	19,7	7,5	-3	0,97	-3,4	0,98
8	P4-3	P4	14,5	6	-6,8	0,98	-8,2	0,99
9	P4-2	P4	10,0	0,95	-14,4	1,00	-19,6	1,00
10	P4-1	P4	8,6	0,03	-20,8	0,99	-31,9	0,99
11	P3-5	P3	24,5	10	-2,6	1,00	-2,8	1,00
12	P3-4	P3	19,7	8	-3,4	0,99	-3,4	0,99
13	P3-3	P3	14,8	3,8	-5,6	0,99	-5,7	0,99
14	P3-2	P3	10,0	1,5	-9,2	0,99	-9,9	0,99
15	P3-1	P3	8,1	0,13	-9,1	0,99	-11,3	0,98

TABLE 2. Classification of analyzed situations in respect of ADP values

No	Name	Q [nC]	ADP [a.u.]
1	P5-5	10	**-2,3**
2	P3-5	10	**-2,6**
3	**P5-4***	**8**	**-2,8**
4	P4-5	10	**-2,9**
5	P4-4	7,5	**-3**
6	**P5-3***	**4**	**-3,1**
7	P3-4	8	**-3,4**
8	**P3-3***	**3,8**	**-5,6**
9	*P4-3**	*6*	***-6,8***
10	P3-1	0,13	**-9,1**
11	P3-2	1,5	**-9,2**
12	P5-1	0,035	**-9,8**
13	P5-2	1	**-10**
14	P4-2	0,95	**-14,4**
15	P4-1	0,03	**-20,8**

TABLE 3. Classification of analyzed measuring situations in respect of ADC values

No	Name	Q [nC]	ADC [a.u.]	RMS [a.u.]	U_{MAX} [V]
1	P5-5	10	**-2,3**	0,2663	2,016
2	P3-5	10	**-2,8**	0,2399	1,687
3	P4-5	10	**-3**	0,236	1,826
4	**P5-4***	**8**	**-3,3**	**0,1765**	**1,596**
5	P4-4	7,5	**-3,4**	0,1778	1,489
6	P3-4	8	**-3,4**	0,1735	1,239
7	**P5-3***	**4**	**-4,2**	**0,1104**	**1,726**
8	**P3-3***	**3,8**	**-5,7**	**0,112**	**0,965**
9	*P4-3**	*6*	***-8,2***	*0,05473*	*0,696*
10	P3-2	1,5	**-9,9**	0,05999	0,509
11	P5-1	0,035	**-10,8**	0,04859	0,289
12	P5-2	1	**-11**	0,04652	0,449
13	P3-1	0,13	**-11,3**	0,03994	0,451
14	P4-2	0,95	**-19,6**	0,02373	0,202
15	P4-1	0,03	**-31,9**	0,01778	0,164

Data presented in TABLE 2 and TABLE 3 enables one to compare classification made in regard of the electric and AE method. With regard to the electric method, results of this comparison are as follows: the AE method localise as more advanced such deformation processes which taking place in measuring situations P5-4*, P5-3*, P3-3*, the AE method localise as less advanced such deformation processes which taking place in measuring situations P4-3*.

4.2 Analysis by means of Kohonen network

Amplitude distributions of AE impulses can be treated as images for a considered neuron network, built in domain of discrimination threshold values. The network has been chosen basing on the following assumptions:

a) amplitude distributions of AE impulses are learning data for a neural network, based on these distributions input vectors for each measurement conditions are created,

b) investigated neural network should be able to divide the set of input pictures into different classes and create a representative pattern images for each class,

c) analysis results carried out by the neural network are compared with electric apparent charge values just after it's the classification.

Kohonen network, which is self-organising feed-forward neural network with unsupervised learning, fulfils presented assumptions.

Input vectors have been built for each measuring situation basing on AE amplitude distribution of four quantities: power of AE signals, derivative of power of AE signals in function of the discrimination threshold, rate of AE counts, derivative of rate of AE counts in function of the discrimination threshold. Independent variables are features and each of their intervals ([1,50], [51,100], [101,150], [151,200]) correspond to determination threshold interval [0,2] V. Finally, input vector contain: logarithms of rate of AE counts, over graduated derivative of amplitude distributions of rate of AE counts versus discrimination threshold, logarithms of power of AE signals, over graduated derivative of amplitude distributions of power of AE signals versus discrimination threshold. Over graduation is common to every measuring situation in the field of one amplitude distribution. Kohonen network, dividing input objects into 5 classes, has been built. Images of pattern of winning neurons are presented in Fig. 4. It is visible that:

- the network determines pattern neurons keeping up connection between ADC and ADP descriptors,
- four winner neurons have a similar character, whereas one winner neuron differs from the others (class 3),
- dividing into Kohonen classes relates to dividing of deformational processes in respect their stage of advancing (as it was shown by the ADC and ADP descriptors).

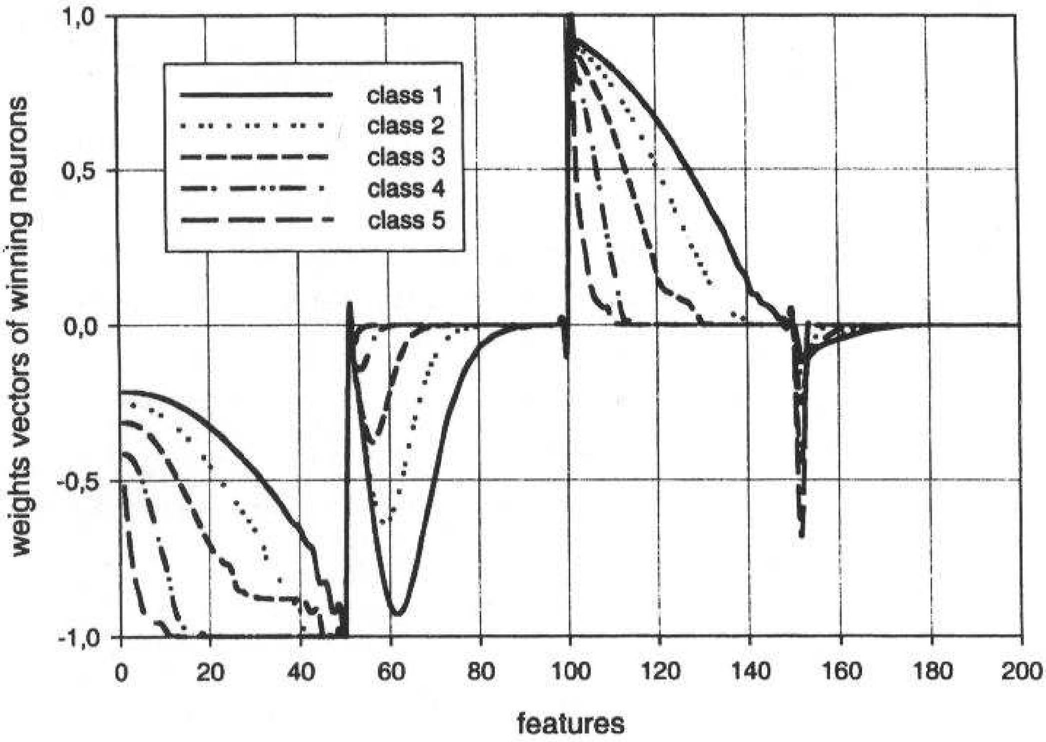

TABLE 4. Division of input objects made by Kohonen network

No	Name	c.1	c.2	c.3	c.4	c.5	Q	ADP	ADC
1	P5-5	1	0	0	0	0	10	-2,3	-2,3
2	P3-5	1	0	0	0	0	10	-2,6	-2,8
3	P4-5	1	0	0	0	0	10	-2,9	-3
4	**P5-4***	**1**	**0**	**0**	**0**	**0**	**8**	**-2,8**	**-3,3**
5	P4-4	0	1	0	0	0	7,5	-3	-3,4
6	P3-4	0	1	0	0	0	8	-3,4	-3,4
7	**P5-3***	**0**	**0**	**1**	**0**	**0**	**4**	**-3,1**	**-4,2**
8	**P3-3***	**0**	**0**	**1**	**0**	**0**	**3,8**	**-5,6**	**-5,7**
9	*P4-3**	*0*	*0*	*0*	*1*	*0*	*6*	*-6,8*	*-8,2*
10	P3-2	0	0	0	1	0	1,5	-9,2	-9,9
11	P5-1	0	0	0	1	0	0,035	-9,8	-10,8
12	P5-2	0	0	0	1	0	1	-10	-11
13	P3-1	0	0	0	1	0	0,13	-9,1	-11,3
14	P4-2	0	0	0	0	1	0,95	-14,4	-19,6
15	P4-1	0	0	0	0	1	0,03	-20,8	-31,9

Classification of input object into classes, made by the network, is presented in TABLE 4. Properties of this classification are good visible after arrangement of input objects (measuring situations) in respect of electric apparent charge values (TABLE 4). They are:

- the Kohonen network classifies input objects in respect of electric apparent charge,
- the Kohonen network distinguishes input objects described by ADC and ADP as locally more/less (P5-4*,P5-3*,P3-3*/P4-3*) advanced includes them among a class where are objects characterized by greater/smaller value of electric apparent charge.

5. RECAPITULATION

Investigations were aimed at study of PD phenomena within generator coil bars basing on the AE method. Nevertheless, obtained results have been confronted with parallel investigations made by means of the electric method (measurements of electric apparent charge). AE impulses have been registrated at several measuring points, under selected supply voltages, basing on the measuring system DEMA-COMP.

As a result of preliminary data handling, four amplitude distributions have been calculated: rate of AE counts, derivative of amplitude distributions of rate of AE counts in function of the discrimination threshold, power of AE signals, and derivative of amplitude distributions of power of AE signals in function of the discrimination threshold. Analysis of obtained AE amplitude distributions deals with their shapes. Such analysis was made by means of two ways.

The first way consists in definition and calculating of advanced AE descriptors, which can distinguish deformation processes. These descriptors are signified by acronyms ADC and ADP. Descriptor value determines the advance degree of a given deformation process connected with a given distribution. Comparison of these results with classification made by means of the electrical method shows their compatibility. Additionally, the AE method is able to locate processes more/less advanced. The idea of location is based on comparison the electric apparent charge with ADC and ADP values.

The second way is based on Kohonen network, used to distinguish and classify of images. Such neuron network classifies input objects in regard of electric apparent charge and – additionally – distinguishes input objects described by ADC and ADP descriptors as locally more/less advanced.

Classification results concerned measuring situations and analyzed by both methods are shown in TABLE 4.

Both methods applied to analyze of amplitude distributions are complementary to one another. They indicate that AE signals reach sensor from large areas and create a global image of the phenomenon. AE elastic waves in such built acoustic image are registered with weights proportional to distance between source and AE sensor. Such summation causes domination of local effects in an averaging image which appear on the global background. That enables to localize AE signals against a background of values averaging within a large area.

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