LOCATION OF PD SOURCES WITHIN THE BARS ASSIGNED FOR GENERATORS COILS BY MEANS OF ACOUSTIC EMISSION

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Basing on defined AE descriptors and on the Kohonen network an analysis of amplitude distribution of AE impulses registered at many points of tested object for different values of the supply voltage has been carried out. Using of modified loudness method of location the places with maximum activity of PD sources have been determined.

Keywords: *acoustic emission, partial discharge, amplitude distributions, descriptors, Kohonen neuron network.*

1. INTRODUCTION

A proper diagnosis of high voltage insulating systems, particularly on the ground of investigations on partial discharges (PDs), is one of the fundamental operational problems [1-4]. There are different methods which can be applied to measure and evaluate PDs: electric and non-electric ones. In the second group, the method of acoustic emission (AE) is relevant [5, 6].

The AE method gains more and more importance in diagnosis of the state of materials and technical systems, as well as in the control of technological processes [7]. It also refers to insulating system, because such a method enables to localize PDs and - when the transition function is known – to distinguish and determine sources of partial discharges.

PD investigations within the bars assigned for generator coils made by electric method give the typical PD level of order of nanocoulumbs. Such a level, admissible by relevant standards, is guaranteed by manufacturers but a merit of the matter is that bars are made using different and often competitive technologies. Thus PD investigations within the above elements have two goals: for one thing, cognitive, which specifies description of the phenomenon, and for another, practical, used to compare how bar properties are manifested within different technologies. The paper is devoted to PD investigations by means of acoustic emission method.

2. MEASURING AE SYSTEM

Investigations have been made using the measuring system called DEMA-COMP. The block diagram of the measuring system is shown in Fig.1.

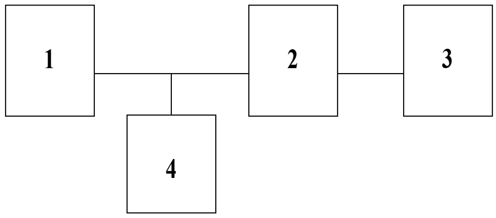

Fig.1. Block scheme of AE measuring system called the COMP-DEMA: 1- set of DEMA instruments, 2- CB6-TP measuring terminal and PCI-610E measuring card, 3- PCIII portable PFX-12, 4- oscilloscope.

A modified measuring stand DEMA provides conditioning and transmission of AE signals to PC. It consists of four measuring channels. Each of these lines is composed of the differential pre-amplifier, the band filter and the line amplifier. The measuring card and the portable computer secure information record to a disc of twelve bit data with 5 mega-samples per second. Dataengine V.I. for Windows under LabVIEW 7.0 was the basic software for programming the measuring card (programs for monitoring the processes and recording the data). For selected fragments of registered data specific programs used to data handling make possible the following analyses of signals: changes in time, phase characteristics, frequency characteristics, and amplitude distributions. Everything can be made for a selected method of signal filtration. Taken results are a base of successive analyses, particularly applied to create given AE descriptors and next to analyse their properties.

3. RESEARCH METHOD AND MEASURING STAND

Investigations have been made in order to register and analyse AE signals coming from PD sources generated within tested bars due to the selected voltage values was applied.

Investigations have been carried out in the firm ENERGOSERVIS (Lubliniec, Poland) on the stand used to study of PDs within bars of generator coils together with the measuring system DEMA-COMP. The measuring range accessible for AE measurements has been established. In such a range, limited by additional earth electrodes, six measuring points (P1, … , P6) have been uniformly displaced.

Investigations carried out by means of AE method have been planned as follows:

a/ the use of measuring lines:

- K0 line - monitoring of a reference voltage,

- K1, K2 and K3 lines – registering AE signals - AE sensors of R6 type (made by the Physical Acoustic Corporation), preamplifiers and DEMA (20dB amplification within DEMA);

b/ AE sensors of R6 (#1, #2, #3) have been placed at measuring points P1, P2, P3;

c/ the tested bar has been energized by the voltage of selected values (0, 5, 10, 15, 20 ,25 and 30kV) for whose three to six samples of two-seconds length AE signals have been registered (sampling frequency of 1 MHz);

d/ AE sensors of R6 (#1,#2,#3) have been moved to measuring points (P2, P3, P4), (P3, P4, P5), (P4, P5, P6), (P5, P6, P1), (P6, P1, P2) and all measurements were made again.

Fig.2. General view of DEMA COMP measuring system.

4. MEASURING RESULTS AND THEIR PRELIMINARY PROCESSING

Example AE signals of 60ms (three periods of the supply voltage) registered at one measuring point are presented in Fig. 3. AE impulses are presented by means of auto-scale for a range of values. Basic features of PDs registered by means of AE method are as follows:

- existence of a minimal supply voltage necessary to initiate of PD (about 7kV),
- random and periodical character of AE impulses,
- increase of the RMS as well as the maximum amplitude and duration of generated AE impulses when the supply voltage increases,
- local properties of registered impulses conditioned by location of a measuring point.

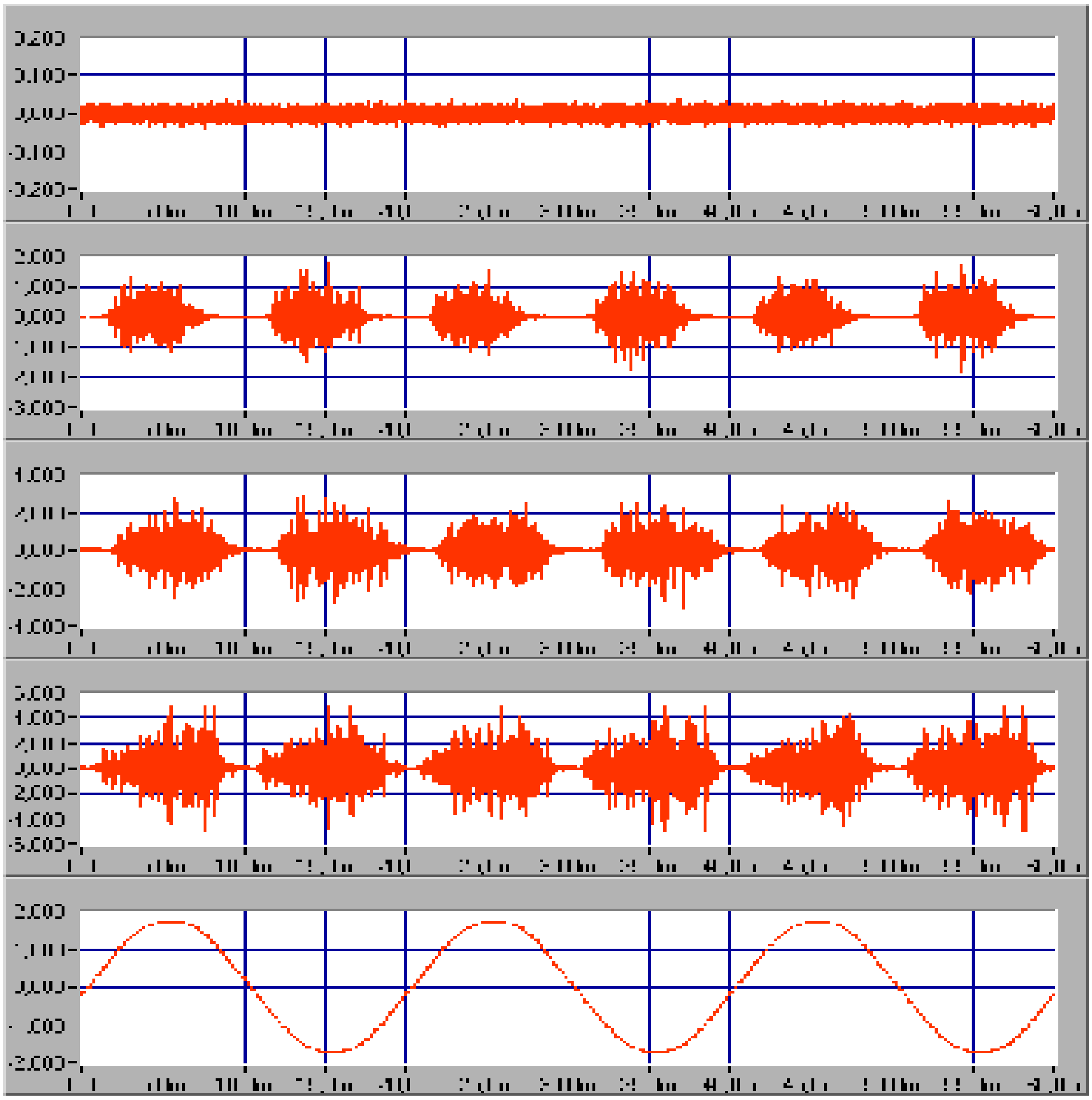

Fig.3a-d. Waveforms V (t) (V in volts, t in milliseconds) of registered AE impulses under the measuring conditions: a measuring point P3, measuring channel K2 (R6#2) and the following supply voltages: a/ 0kV b/ 10kV, c/ 20kV, d/ 30kV.
Fig. 3e. Waveforms V (t) of the reference voltage - K0 line.

Preliminary handling data concerns calculations of four amplitude distributions of registered AE signals (dN/dt - rate of AE counts, dE/dt - power of AE signals and derivatives d(dE/dt)dU , d(dN/ddt)/dU of above amplitude distributions in function of the discrimination threshold). Calculated amplitude distributions diagrams for AE impulses registered within a measuring channel K2 (R6#2) at measuring point P3 for different supply voltages are presented in Fig 4. Such distributions have been calculated for each value of the supply voltage and for registered sets. Amplitude distributions for particular values of supply voltage form separate groups in diagrams. For the power of AE signals and the rate of AE counts logarithmic scale has been chosen in order to distinguish deformation processes. Linear fragments of diagrams curves describe single deformation processes. When the supply voltage raises than the slope of the curve describing the amplitude distribution of the power of AE signals and the rate of AE counts goes down (the curve is more flat). That means a greater advance of the deformation process [8].

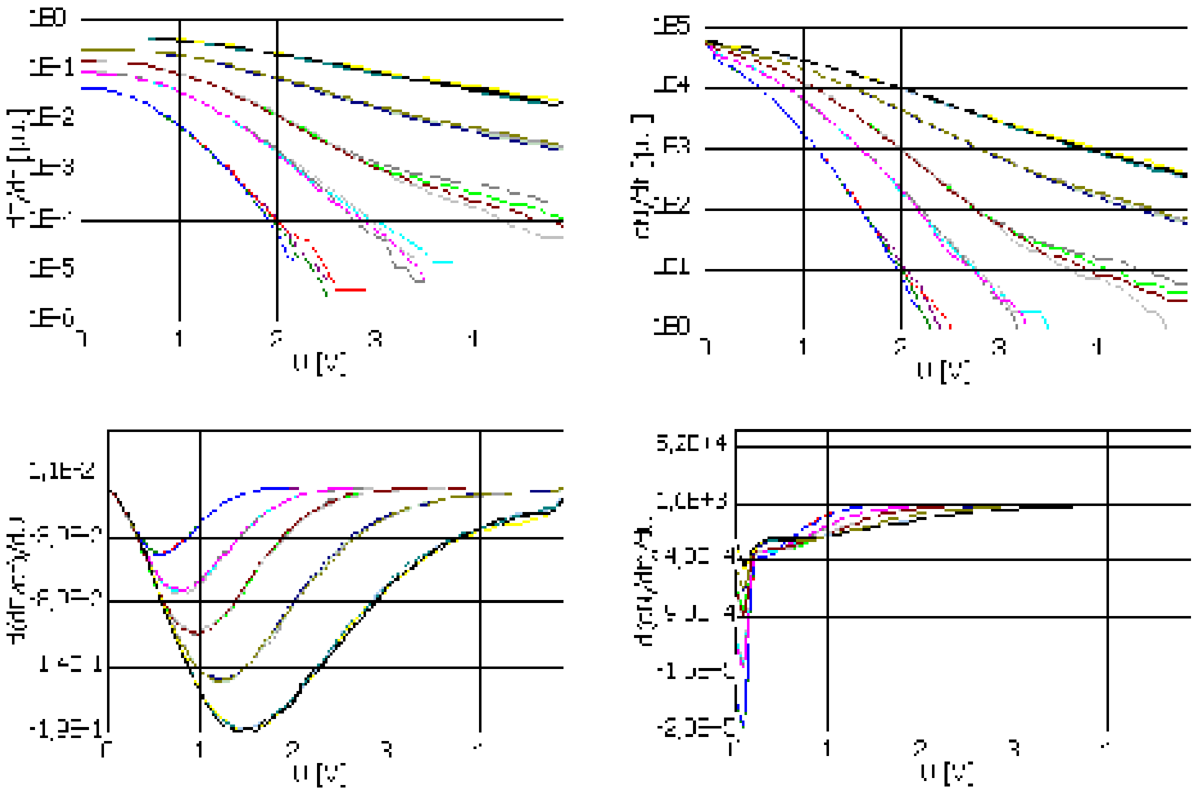

Fig. 4. Families of amplitude distributions of AE signal (dN/dt - rate of AE counts, dE/dt - power of AE signals, d(dE/dt) dU, d(dN/ddt)/dU - derivatives of amplitude distributions in function of the discrimination threshold) under the measuring conditions: measuring point P3, a measuring channel K2 (R6#2) and the following supply voltages: a/ 10kV, b/ 15kV, c/ 20kV, d/ 25kV and e/ 30kV.

5. ADVANCED PROCESSING

Amplitude distributions of AE signals, prepared to analyse their shapes, can be a basis for more detailed analyses – first for AE signal and then for AE source properties. Advanced analysis relating to amplitude distributions is made by means of two methods resultant from definition of AE descriptors and application of Kohonen neuron network.

AE descriptors

To distinguish quantitative features of AE impulses two descriptors, resultant from properties of amplitude distributions of AE impulses, have been proposed [8, 9]. These descriptors are signified by acronyms ACD and ADP. They are defined as the slope of straight line approximating the amplitude distribution of AE counts (ACD) and power of AE signals (ADP) The approximation is made within discrimination threshold range: 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 registered AE impulses. The higher descriptor value (more flat fragment of a curve) signifies more advanced deformation process described by means of AE method. It is worth insisting on the following features of proposed descriptors:

- they are not connected directly with a measured quantity,
- logarithmic scale on diagrams of basic amplitude distributions brings about distinction of individual (single) deformational process and eliminate changes of thickness of interconnected layer (because of multiple assembly of AE sensors).

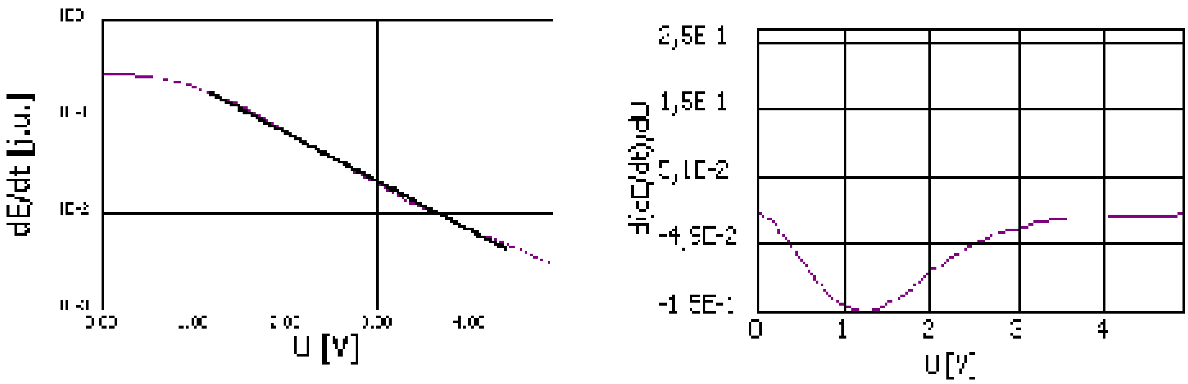

Fig. 5. Amplitude distributions of AE signal (dE/dt - power of AE signals, d(dE/dt)dU - derivatives of power of AE signals) for example AE impulse. ADP descriptor is equal the slope of line approximate the amplitude distributions (ADP=-0,5).

Kohonen neuron network

Amplitude distributions of AE impulses are images for a considered neuron network, built in domain of discrimination threshold values. Essential task of neuron network worked out by Kohonen is to divide input objects into classes and then to construct pattern winner neurons. In such a way an instrument useful to test other measurement results has obtained. The network has determined pattern neurons every time, allowed for connections between considered descriptors (ADC and ADP).

Input vectors have been built for each measuring situation basing on AE amplitude distribution of four quantities: rate of AE counts, derivative of rate of AE counts in function of the discrimination threshold, power of AE signals, derivative of power of AE signals 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 threshold interval. Finally, input vector contains: 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.

6. LOCATION OF PD SOURCES

6.1 AE descriptors

Descriptor values have been determined for calculated amplitude distributions. In such a way for each measuring point and each value of the supply voltage the set values has been gained (e.g. Fig. 6) The mean value and average standard deviation are determined for theses sets (see Fig. 7).

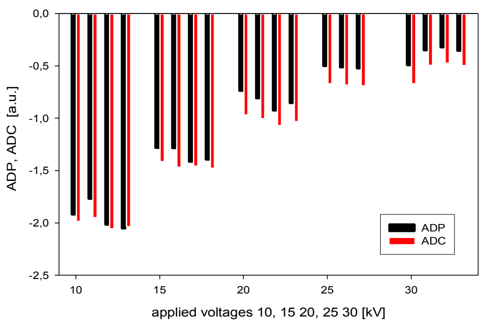

Fig. 6. ADP and ADC descriptors calculated for amplitude distributions showed in Fig. 4 (a measuring point P3, a measuring channel K2 (R6#2) supply voltages: 10kV, 15kV, 20kV, 25kV and 30kV.

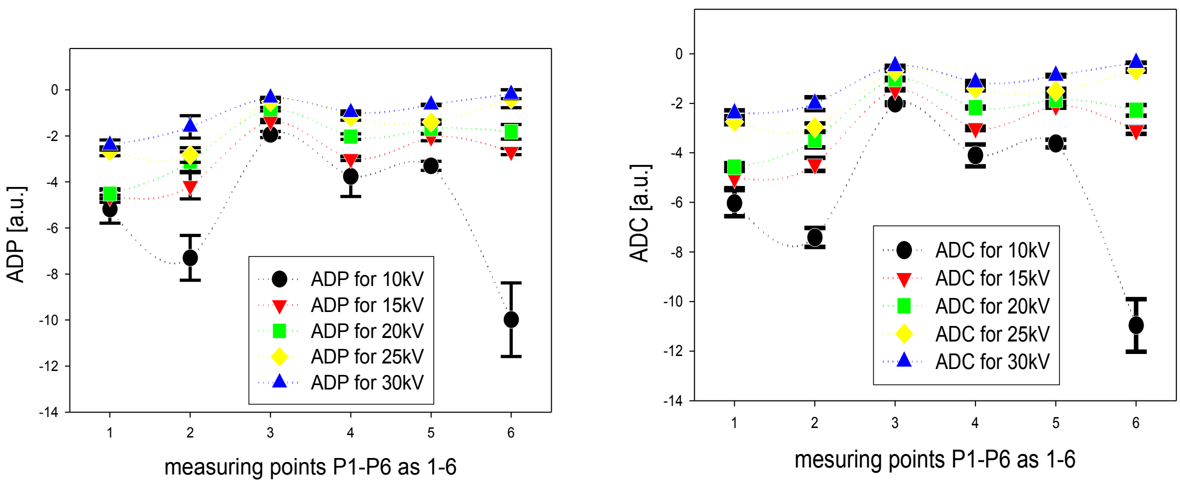

Fig. 7. ADP and ADC descriptors for AE impulses registered at P1-P6 measuring points within a measuring channel K2 (R6#2) for following supply voltages: 10kV, 15kV, 20kV, 25kV and 30kV.

Descriptors from Fig. 7 are grouped together into families depending on values of supply voltage. They locally describe deformation processes, so within one family (for one value of the supply voltage) the maximum descriptor value locates maximum PD sources. Statement of sources positions with maximum activity is made in Table 1. Both descriptors point identically at maximum sources (at a measuring point P3) for every values of the supply voltage and at a measuring point P6 for 25kV and 30kV of supply voltage.

Table 1. Location of max PD sources with ADP and ADC descriptors.

Supply voltage U [kV]	Location of max PD sources with ADP	Max. value of ADP [a.u.]	Location of max PD sources with ADC	Max. value of ADC [a.u.]
10	P3	-1,94	P3	-2,01
15	P3	-1,35	P3	-1,45
20	P3	-0,84	P3	-1,02
25 25	P6 P3	-0,39 -0,51	P6 P3	-0,67 -0,68
30 30	P6 P3	-0,19 -0,35	P6 P3	-0,40 -0,61

6.2 Kohonen neuron network

Location of maximum PD sources is made by two stages.

The first stage resolves itself to built input vectors for AE impulses registered at a given measuring point under five chosen values of supply voltage (10, 15, 20, 25 and 30 kV). Kohonen neuron network was to find the winning neurons (for each measuring point separately) and classify input vectors. Example results of theses tasks (for measuring point P3) are presented in Fig. 8 and in Table 2. From the table it results that winning neurons contain values representative for amplitude distributions of AE impulses registered under a constant value of the supply voltage. Some equivalents of amplitude distributions (shown in Fig. 4) can be separated within winning neurons. Kohonen neuron network divides input vectors into classes preserving arrangement of deformation processes according to ADC and ADP values. The conclusive are representative for every measuring point.

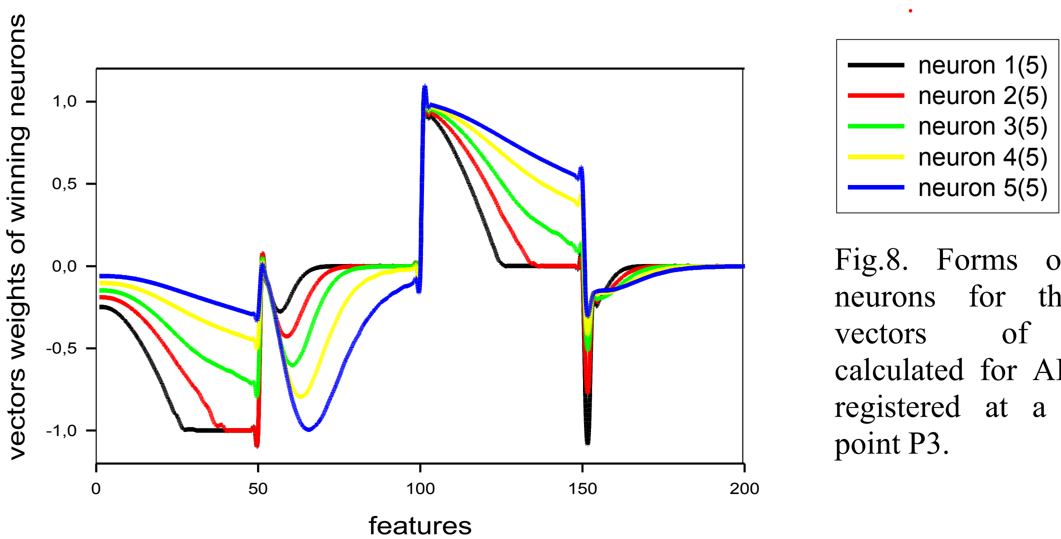

Fig.8. Forms of winning neurons for the set of vectors of features calculated for AE impulses registered at a measuring point P3.

Table 2. Results of input vector classification built for AE impulses registered at P3 measuring point.

U [kV]	Name of file	class 1(5)	class 2(5)	class 3(5)	class 4(5)	class 5(5)
10	Mb2	**1**	0	0	0	0
10	Mb2(1)	**1**	0	0	0	0
10	Mb2(2)	**1**	0	0	0	0
10	Mb2(3)	**1**	0	0	0	0
15	Mb2	0	**1**	0	0	0
15	Mb3(1)	0	**1**	0	0	0
15	Mb3(2)	0	**1**	0	0	0
15	Mb3(3)	0	**1**	0	0	0
20	Mb4	0	0	**1**	0	0
20	Mb4(1)	0	0	**1**	0	0
20	Mb4(2)	0	0	**1**	0	0
20	Mb4(3)	0	0	**1**	0	0
25	Mb5	0	0	0	**1**	0
25	Mb5(1)	0	0	0	**1**	0
25	Mb5(2)	0	0	0	**1**	0
25	Mb5(3)	0	0	0	**1**	0
30	Mb6	0	0	0	0	**1**
30	Mb6(1)	0	0	0	0	**1**
30	Mb6(2)	0	0	0	0	**1**
30	Mb6(3)	0	0	0	0	**1**

The second stages resolves itself to build input vectors for AE impulses registered at every measuring points under supply voltage 10, 15, 20, 25 and 30kV. Kohonen neuron network was to find winning neurons and to classify such input vectors. In this case, in order to better distinguish deformation processes, seven winning neurons have been searched. Weights of these neurons and classification results regarding input vectors are presented in Fig. 9 and in Table 3. From a shape analysis of winning vectors it results that Kohonen neuron network creates still winning neurons and puts straight them according to ADP and ADC values. Classification results of input vectors are presented within successive lines of Table 3. Each result concerns an input vector describing AE impulses registered at successive measuring points under a given value of the supply voltage. In such a way, input vectors for Kohonen neuron network have been divided into families of identical values of the supply voltage. An input vector has been distinguished within each family. The highest class has been assigned to this quality because a measuring point connected with such a vector locates position of a PD source characterized by maximum intensity. In order to present better classification of impulses made by Kohonen network, besides Table 3 diagram in Fig. 9 are made. Families of classes assigned to input vectors for AE impulses measured at different points for one value of the supply voltage are marked. Classes assigned by Kohonen network are connected with an advance degree of deformation processes whose dominate near a measuring point. The highest class assigned within one family precise position of a measuring point where (close by) PD sources with maximum intensity can be found. Positions of sources with maximum activity, determined in such a way, are presented in Table 4. Analysis of AE impulses using Kohonen neuron network shows maximum PD sources at P3 measuring point for all values of the supply voltage and at P6 measuring point for 30kV. It is a result almost identical comparing with an effect of analysis regarding features of ADP and ADC descriptors.

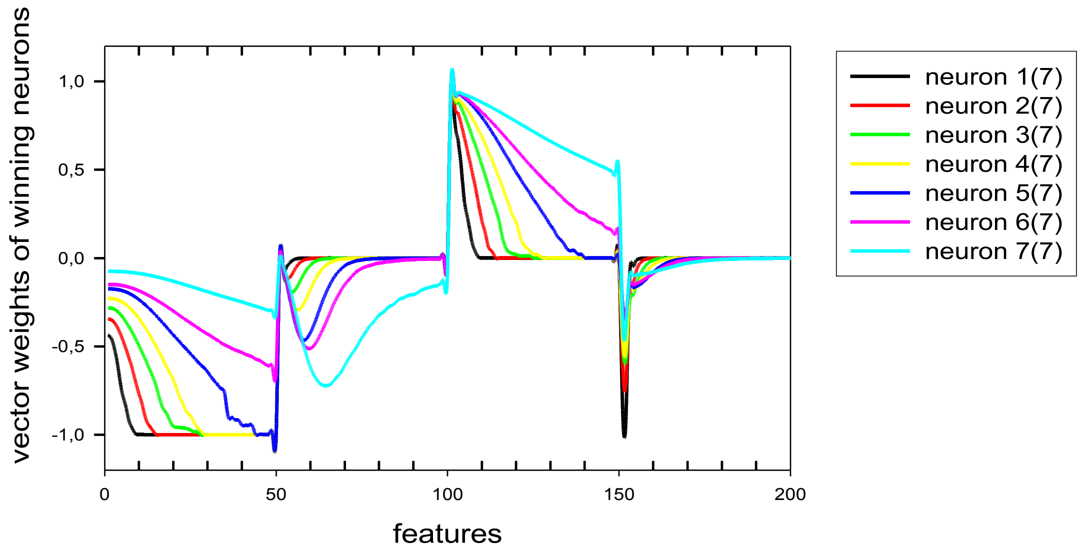

Fig. 9. Forms of winning neurons for the set of vectors of features calculated for all AE impulses.

Tab. 3. Classification results of input vectors built for all AE impulses.

no	supplied voltage U [kV]	measuring point	class 1(7)	class 2(7)	class 3(7)	class 4(7)	class 5(7)	class 6(7)	class 7(7)
1	10	P1	1	0	0	0	0	0	0
2	10	P2	1	0	0	0	0	0	0
3	**10**	**P3**	0	0	0	**1**	0	0	0
4	10	P4	0	1	0	0	0	0	0
5	10	P5	0	1	0	0	0	0	0
6	10	P6	1	0	0	0	0	0	0
7	15	P1	0	1	0	0	0	0	0
8	15	P2	0	1	0	0	0	0	0
9	**15**	**P3**	0	0	0	0	**1**	0	0
10	15	P4	0	0	1	0	0	0	0
11	15	P5	0	0	0	1	0	0	0
12	15	P6	0	1	0	0	0	0	0
13	20	P1	0	1	0	0	0	0	0
14	20	P2	0	0	1	0	0	0	0
15	**20**	**P3**	0	0	0	0	0	**1**	0
16	20	P4	0	0	0	1	0	0	0
17	20	P5	0	0	0	1	0	0	0
18	20	P6	0	0	1	0	0	0	0

19	25	P1	0	0	1	0	0	0	0
20	25	P2	0	0	1	0	0	0	0
21	**25**	**P3**	0	0	0	0	0	0	**1**
22	25	P4	0	0	0	0	1	0	0
23	25	P5	0	0	0	0	1	0	0
24	25	P6	0	0	0	0	0	1	0
25	30	P1	0	0	0	1	0	0	0
26	30	P2	0	0	0	1	0	0	0
27	**30**	**P3**	0	0	0	0	0	0	**1**
28	30	P4	0	0	0	0	0	1	0
29	30	P5	0	0	0	0	0	1	0
30	**30**	**P6**	0	0	0	0	0	0	**1**

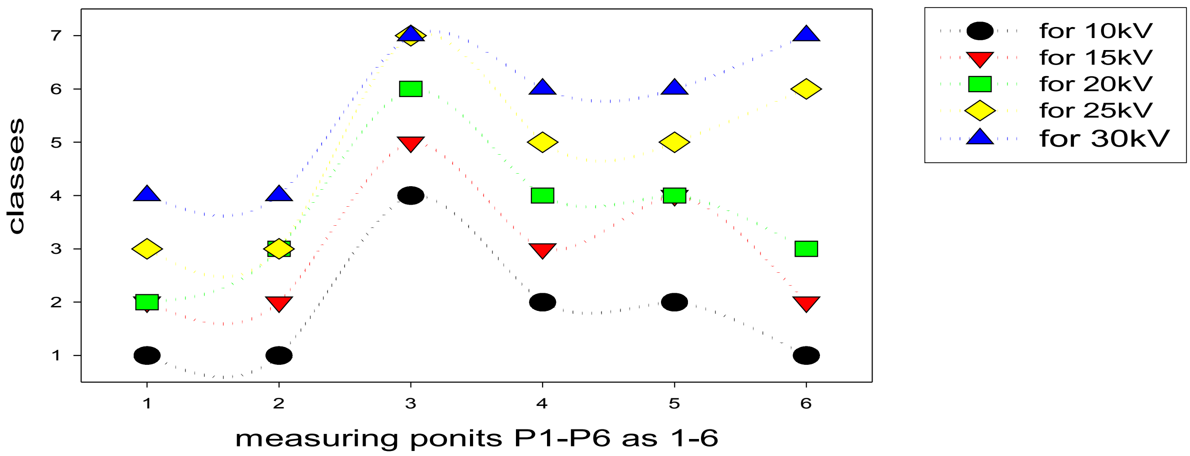

Fig. 10. Classification results of input vectors built for AE impulses registered at P1-P6 measuring points within measuring channel K2 (R6#2) for following supply voltages: 10kV, 15kV, 20kV, 25kV and 30kV.

Table 4. Location of max PD sources with neuron network of Kohonen

Supply voltage U [kV]	Location of max PD sources	No of max class
10	P3	4(7)
15	P3	5(7)
20	P3	6(7)
25	P3	7(7)
30 30	P6 P3	7(7) 7(7)

7. RECAPITULATION

Investigations of partial discharges within bars of generator coils have been made by means of the AE method using DEMA-COMP AE MEASURING SYSTEM.

AE impulses have been registered at different points of a tested object and under different values of supply voltage. For registered AE impulses the following amplitude distributions have been calculated: dN/dt - rate of AE counts, dE/dt - power of AE signals and derivatives d(dE/dt) dU, d(dN/ddt)/dU of above amplitude distributions in function of the discrimination threshold.

Advanced analysis of calculated amplitude distributions have been made by means of two methods: AE descriptors and application of Kohonen neuron network. In the both cases, an analysis result is location of PD sources with maximum activity. The used location methods can be treated as modification of highest loudness method.

Acknowledgment
The investigations were carried out within the frame of the research project **4T10C 035 22** sponsored by the Polish Committee of Scientific Research.

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