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THE POSSIBILITIES OF TIME-FREQUENCY ANALYSIS TO IDENTIFICATION OF THE ACOUSTIC EMISSION SIGNALS GENERATED BY MULTISOURCE PARTIAL DISCHARGES

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Abstract
Within the research work carried out, the results of which are presented in this paper, a comparative analysis of the acoustic emission (AE) signals generated by partial multi-source discharges (PDs) was carried out. The research investigations were carried out in a model system in which multisource electrical discharges were generated with two modeling spark-gaps: one spark-gap in the surface system and the other in the multipoint-plane system. The aim of the research carried out was to confirm the suitability of the AE method for diagnosing the insulation condition of high-voltage power appliances, in which multisource PDs may occur. The signal analysis was carried out in the frequency and time-frequency domains. The paper presents a comparative analysis of the AE signals registered from the point of view of the identification possibilities of the particular PD types.

Keywords: partial multi-source discharges, acoustic emission, insulation, power transformer.

1 Introduction

The introduction of a free electric power market in Poland caused the establishment of competing manufacture and distribution enterprises. With liberation of the energy market the requirements referring to the quality of the electric energy supplied and the reliability of its supply increased. The improvement of the electric power system reliability is connected, among others, with precise diagnostics of electric power transformers, which are one of the most sore points of electric power systems. The assessment of the insulation condition in respect of PD occurrence is an important element of a complex diagnostics of electric power transformers. Presently, diagnostic examinations of the transformer insulation condition are carried out by using a few non-destructive methods: the gas chromatography, electrical and AE methods [6, 7].

In recent years the development of the AE method was caused by introduction into the description of the AE signals generated by PDs a combined time-frequency analysis. Based on the frequency and time-frequency descriptions it is possible to detect PDs in single-source systems [1, 2, 3]. In electric power transformers being in use the occurrence of multi-source discharges is possible. Therefore it is necessary to carry out laboratory research tests on the possibilities of applying the AE method for detection of PDs in multi-source systems. The paper presents an excerpt from the research work on comparing the AE signals generated by single- and multi-source PDs.

2 Measuring set – up

Figure 1 presents a diagram of the measuring system for generation, registration and analysis of the AE signals generated by PDs.

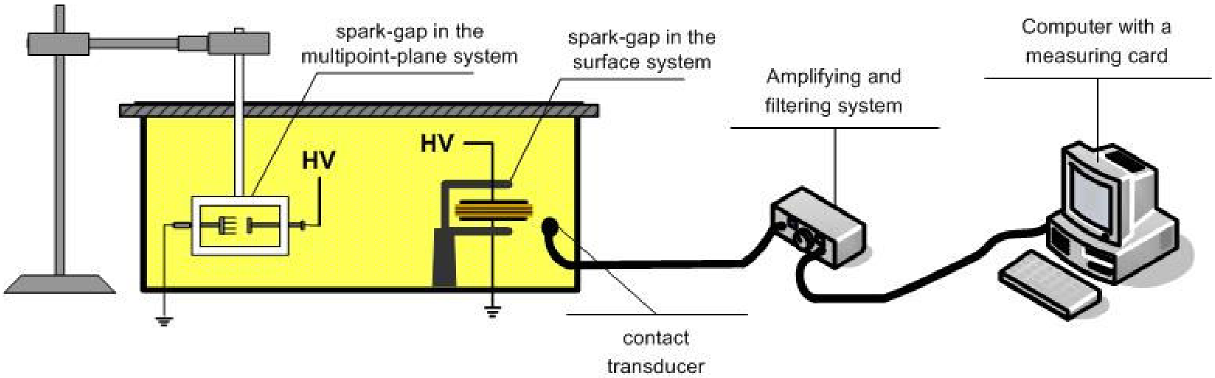


Fig. 1 Diagram of the measuring system

Due to the complexity of the generation processes of the AE signals from multisource PDs of various types, the research experiment was carried out in the Laboratory of Insulation System Diagnostics of the Electrical Power Engineering of Opole Technical University. The measuring tub was filled with insulation oil, in which two spark-gaps generating PDs were immersed. One spark-gap generated PDs in the surface system and the other generated discharges in the multipoint – plane system. The spark-gaps were supplied from two TP 60 test transformers with voltage corresponding to 80% of breakdown voltage of each of the systems. The AE signals generated by PDs were registered with a WD AH17 contact transducer by the firm Physical Acoustics Corporation (PAC), which was placed on the external part of the tub. This transducer is characteristic of high sensitivity (55 dB ± 1.5 dB in relation to V /ms^{-1}) and a wide transfer band from 100 kHz to 1 MHz in the range ± 10 dB.
The measuring transducer was connected with the amplifying and filtering system through a subamplifier. A band-pass filter of cut-off frequencies 10 and 700 kH was used. The measuring signal was amplified by 43 dB. Time runs of the AE signals generated by PDs were registered with a four-channel measuring card by the firm Acquitek CH 3160. During the measurement taking the sampling frequency of 2.56 MHz was applied and the AE signal of the time of 20ms was registered. The testing was carried out in a measuring cell, which was a specialized room; silenced and electromagnetically screened. The view of the measuring cell, transducer, subamplifier and the amplifying and filtering system are shown in Fig. 2.

a) b)

Fig. 1. Overall view of the measuring system:
a) high-voltage test system, b) measuring apparatus

3 Methodology of the research work carried out

The first part of the research work carried out included registration of the AE signals generated by single-source PDs – the AE signals generated in the surface system and in the multipoint-plane spark-gap system were measured separately. During the other part of the measurement taking, the AE signals from PDs generated by two spark-gaps simultaneously were registered, taking into account the same supplying voltage as in the first part of the experiment. The AE signals measured, coming from the particular single- and multisource PDs, were subjected to the time-frequency analysis using a short-time Fourier transform (STFT) and continuous and discrete wavelet transforms (CWT and DWT). The results obtained were shown using two- and three-dimensional spectrograms of the power spectral density, three-dimensional spectrograms of the amplitude spectrum, CWT scaling graphs and time runs of details at the seventh wavelet decomposition level and column diagrams visualizing the size of the energy transferred by the particular details.

In order to show coherent structures obtained through a STFT transform in two and three-dimensional spectrograms, a threshold function cutting off components of lower amplitude values was applied. In calculations using STFT transforms, carried out within the scope of this research work, a Hamming time window, which is used most often for the analysis of fast-changing runs, was used.

Scaling graphs obtained by using a continuous wavelet transform (CWT), on which time-frequency pictures were drawn, were determined with a computer program written together with IPPT PAN. The basic function was a wavelet which was a system of two subsets of basic wavelets, which were eight-element sets of a discrete function sinus [6].

The wavelet decomposition DWT of the AE pulses measured was carried out by using a symlet wavelet of the eighth order, the time run of which, the scheme of the wavelet decomposition tree structure and the diagram of dependences frequency –scale have been presented, among others, in monograph [1]. Frequency intervals corresponding with the particular details are listed in Tab. 1.

Table 1. Width of frequency bands corresponding with the particular details

Detale	Median Frequency [kHz]	Frequency Band [kHz]
D1	500,0	250-750
D2	250,0	125 - 375
D3	125,0	62,5 - 187,5
D4	62,5	31,2 - 93,7
D5	31,25	15,6 - 46,8
D6	15,6	7,8 – 23,4
D7	5,86	3.91 - 7.81

The time-frequency analysis was carried out for the AE signals generated by PDs of the length of 20 ms, comprising a whole acoustic event occurring in a single period of the voltage supplying the spark-gap under study.

4 The analysis of the results obtained

Figs 2, 3, 4 show the results of the time frequency analysis corresponding twith the AE signals generated by PDs in the single- and multisource systems.

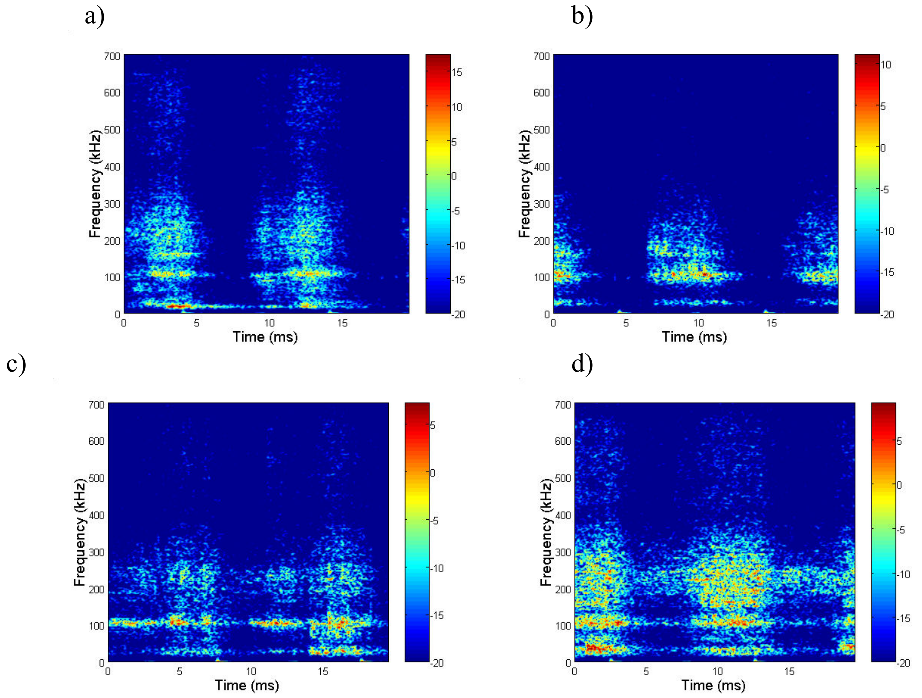


Fig. 2. Two-dimensional spectrograms of the power spectral density corresponding with the AE signals generated by PDs:
a) single-source in the surface system, b) single-source in the multipoint-plane system c) multisource - case 1, d) multisource - case 2

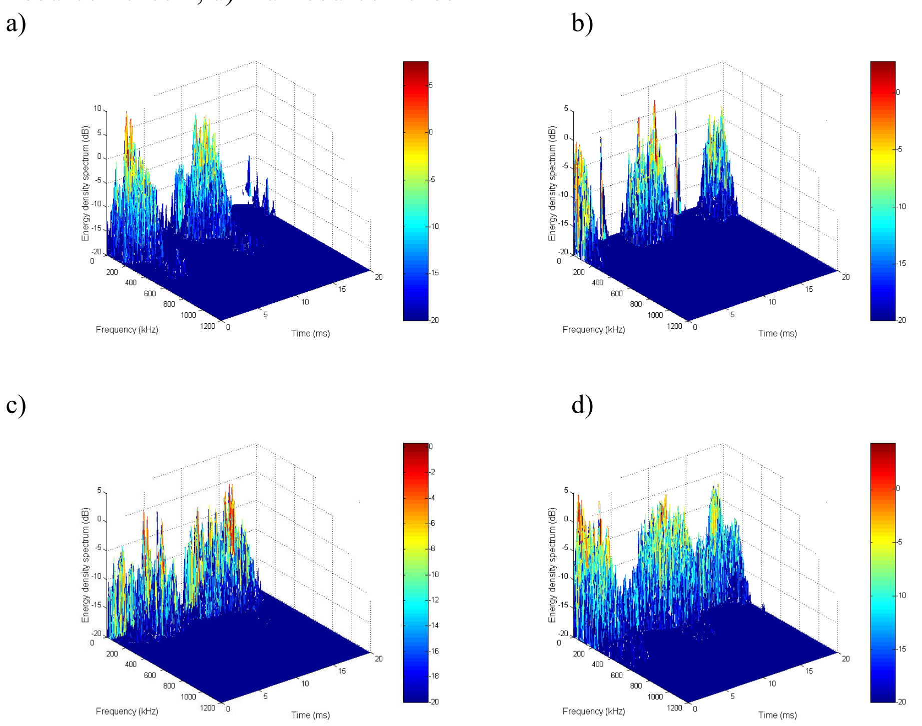


Fig. 3. Three-dimensional spectrograms of the power spectral density corresponding with the AE signals generated by PDs:
a) single-source in the surface system, b) single-source in the multipoint-plane system c) multisource - case 1, d) multisource - case 2

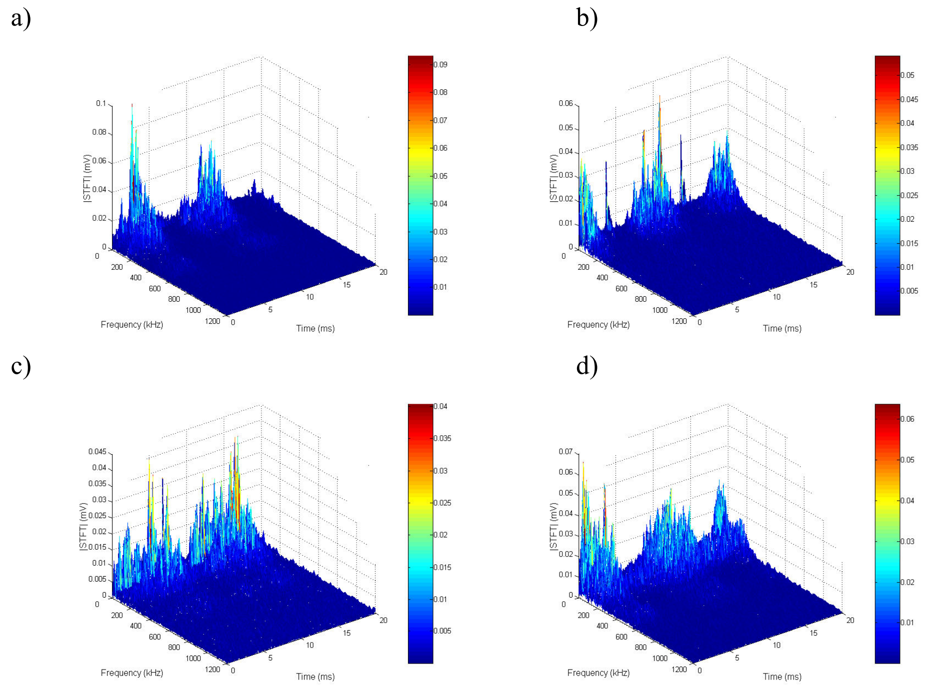


Fig. 4. Three-dimensional spectrograms of the amplitude spectrum corresponding with the AE signals generated by PDs:
a) single-source in the surface system, b) single-source in the multipoint-plane system c) multisource - case 1, d) multisource - case 2

Analyzing two- and three-dimensional spectrograms of the power spectral density, shown in Figs 2, 3 and 4, and two- and three-dimensional spectrograms of the amplitude spectrum, it is possible to separate time-frequency spectra corresponding with the particular types of PDs. Figs 2a, 3a and 4a show components corresponding with a discharge in the surface system, the range of dominant frequencies which can be divided into two intervals: (15 ÷ 390) kHz and (430 ÷ 650) kHz. The former interval is characteristic of a higher amplitude and duration time of time-frequency structures.

Figs 2b, 3b and 4b show time-frequency pictures corresponding with PDs generated in the multipoint-plane system. These structures are characteristic of the frequencies from the range from 20 to 370 kHz. In this band, frequencies from the range 20 ÷ 210 kHz can be distinguished, which are characteristic of a significantly higher amplitude and duration time.

Time-frequency pictures drawn in Figs 2 c-d, 3 c-d, 4 c-d, were determined for the AE signals generated by multisource PDs, i.e. at a simultaneous supplying of the two modeling spark-gaps. It is inferred from the analysis of the pictures obtained that during the occurrence of two different PD generation sources in paper-oil insulation the approximate recognition of each type of electrical discharges is possible, especially in the case of the occurrence of the both PD forms in various time moments. For example: the analysis of the results of the time-frequency transformations (case 1), shown in Figs 2c, 3c, 4c, makes it possible to identify the acoustic signal registered as a discharge generated in the multipoint-plane system.

Figs 2d, 3d, 4d show the analysis results of the AE signals coming from multisource PDs generated by two spark-gaps modeling at the same time moment (case 2). During registration and digital processing of these signals, an increase of electrical discharge intensity in the time of 20 ms was observed. A much wider dominant frequencies range from the interval (15 ÷ 650) kHz, shown in Figs 2d, 3d, 4d, bespeaks of the occurrence of electrical discharges of the surface type, and the intensity increase of the amplitudes components in the band (20 ÷ 370) kHz bespeaks of a simultaneous occurrence of multisource PDS overlapping of frequency components coming from PDs generated in the surface and multipoint-plane systems.

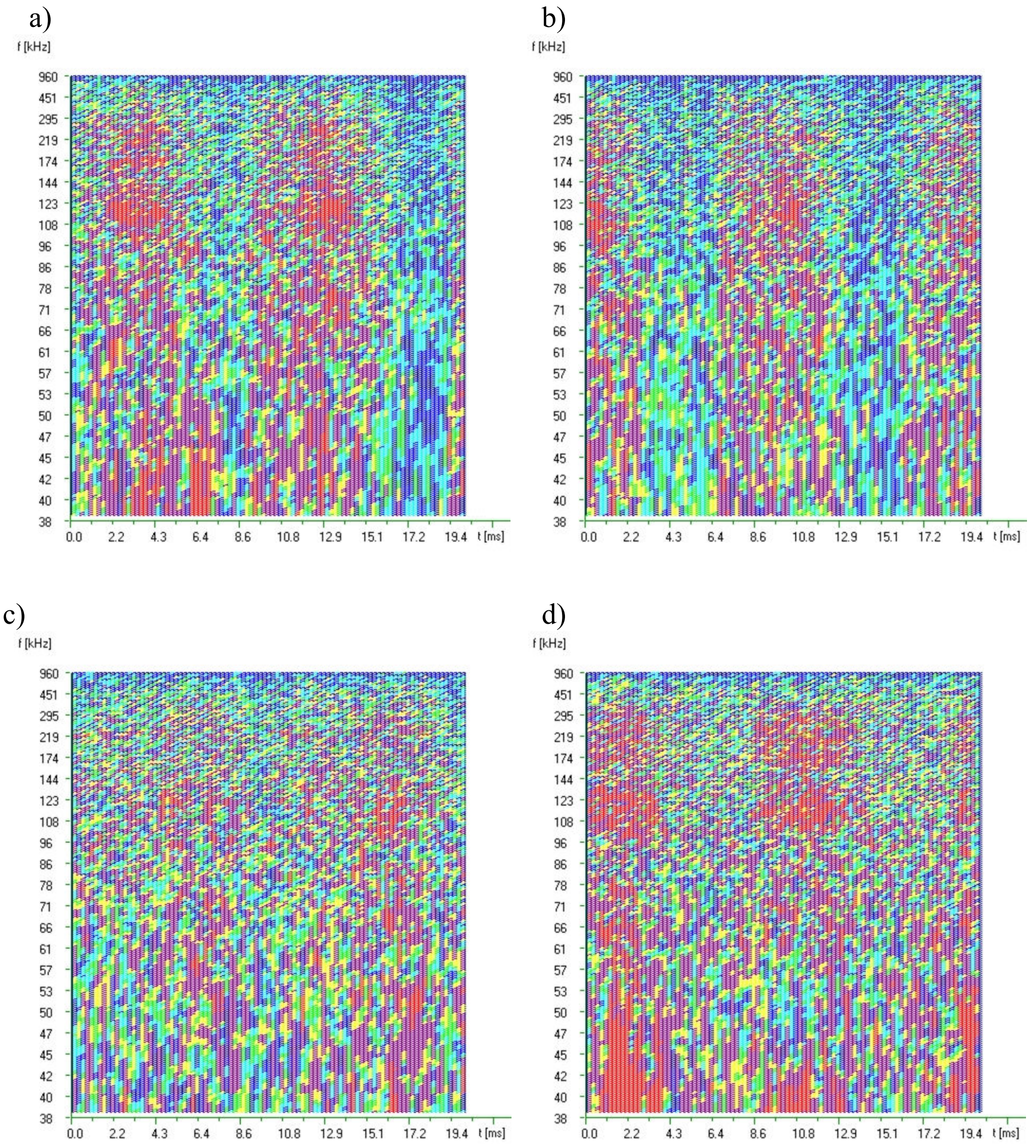
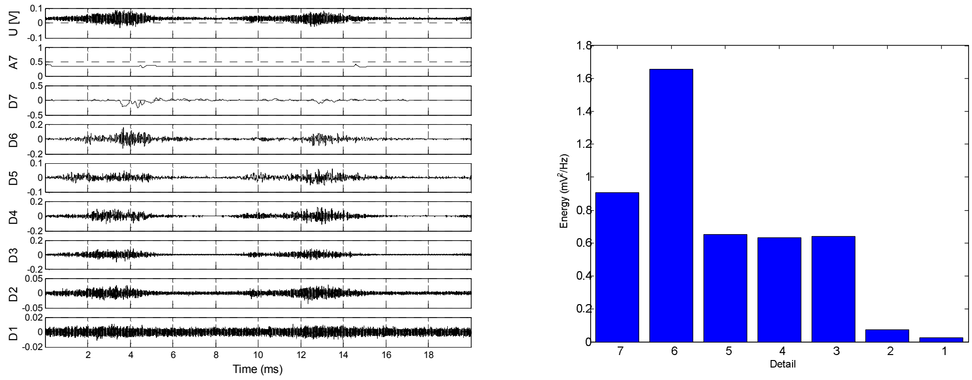


Fig. 5. Scaling graphs of the AE signals generated by PDs:
a) single-source in the surface system, b) single-source in the multipoint-plane system c) multisource - case 1, d) multisource - case 2

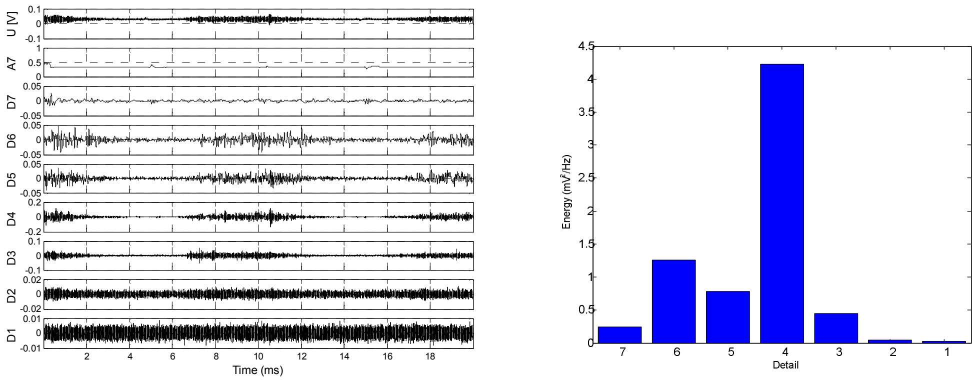
Figs. 5 a-d show CWT scaling graphs, on which time-frequency pictures of the AE pulses registered were drawn. The pictures determined by using CWT contain a lot of information of a qualitative character on time-frequency structures of the AE pulses measured. The analysis of the scaling graphs in Fig. 5 confirms the possibility of identification of the particular sources of electrical discharges of various types using CWT. Like in the case of the results obtained by using a STFT transform, also this time the particular AE signals coming from single- and multisource discharges differ in the band of dominant frequencies, thanks to which they can be identified.

In the systems of diagnostics of insulation systems of power appliances, the application of parameters more adjusted to expert algorithms, which can be applied in the process of identification and initial classification of PDs, is required. In this case, a more synthetic description is obtained using a discrete form the wavelet transformation (DWT) [3].

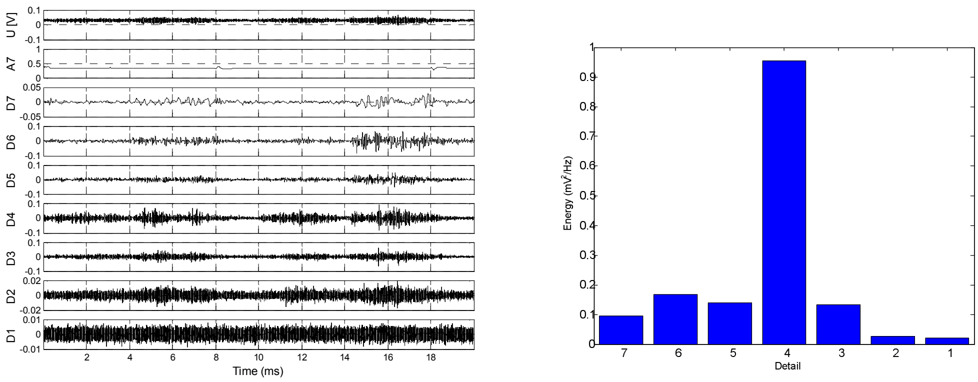
a)



b)



c)



d)

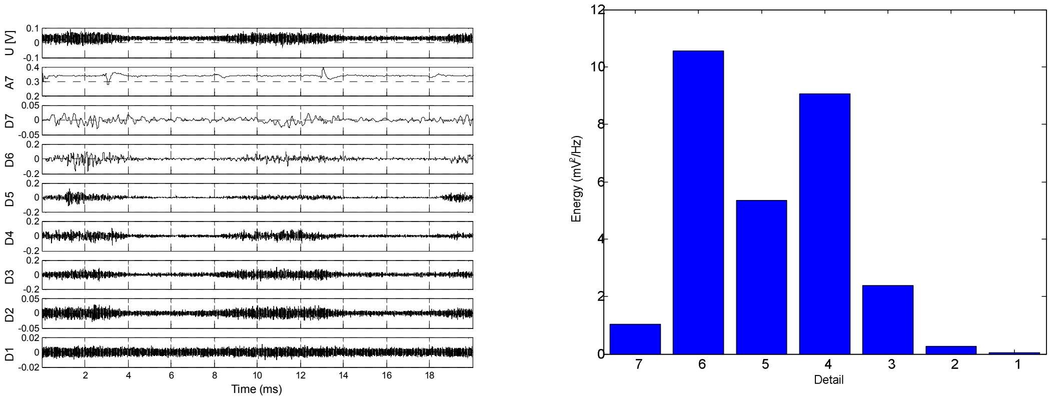


Fig. 6 Wavelet decomposition of the AE signals for the particular details and energy size transferred by the particular details:
a) single-source PDs in the surface system, b) single-source PDs in the multipoint-plane system, c) multisource PDs - case 1, d) multisource PDs - case 2

The results of the multiresolution wavelet decomposition, which were obtained for the AE signals measured, are shown in Figs 6 a-d and 7 a-d. Within graphic presentation of the results obtained there are shown, respectively: time run of the AE pulses measured, approximation A at the seventh decomposition level, runs of details D1-D7 and a column diagram visualizing the size of energy transferred by the particular details. The results obtained by using DWT confirm the possibility of PD forms identification which also occur simultaneously. For the signals generated in the surface system, details D3-D7 have the biggest participation in the size of the energy transferred, which corresponds with frequencies from the range (3.91 ÷ 187.5) kHz, and the participation of detail D7 - (3.91 ÷ 7.81) kHz should be treated as an interfering signal resulting from the work of the measuring apparatus. For the AE signals, the source of which are electrical discharges generated in the multipoint-plane modeling system, details D3-D6 are most visible in the results of the wavelet decomposition, which corresponds with the frequency range (7.8 ÷ 187.5) kHz. The comparison of the power fraction obtained from the analysis of the AE signals registered during generation of discharges in two spark-gaps modeling simultaneously (Figs 7 c-d) makes an approximate identification of each of the sources possible. In the case of the signal from Fig. 7c we deal only with electrical discharges of the multipoint-plane type, and in the case of the analysis of the signal from Fig. 8d with a discharge of the surface type and a discharge in the multipoint-plane system.

5 Conclusions

Constant development of the research work aiming at the improvement of the AE method used for the assessment of the transformer insulation condition required taking into consideration all factors which can influence the assessment of the measurement results. Modern digital technology makes an accurate interpretation of the results obtained possible not only in the time and frequency domains but also in the time-frequency domain. The research results presented in this paper confirm the possibility of PD detection in the case of the multisource discharge occurrence. The identification of basic PD forms generated in multisource systems is possible when the time-frequency analysis JTFA (Joint Time- Frequency Analysis) is applied. The aim of such an analysis is presenting spectrum changes on the time-frequency plane resulting from PD occurrence, assessing interim conditions of the signals and determining the kind and size of interference occurring during the measurements of the AE signals.

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