The wavelet analysis the acoustic emission signals generated by multi-source partial discharges

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Within the research work, the results of which are presented in this paper, a comparative analysis of the acoustic emission (AE) signals generated by multi-source partial discharges (PDs) was carried out. The research investigations were carried out in a model system in which PDs were generated with two spark-gaps. A spark-gap in the surface system and a point-plane spark-gap were used due to the fact that these are the most commonly occurring PD forms in power transformers. The AE signals were registered with a contact transducer placed on the external part of the tub. The analysis in the time-frequency domain using a short-time Fourier transform (STFT) was carried out for the AE signals generated by PDs. The results of the analysis are shown in the form of two- and three-dimensional spectrograms of the power spectral density and three-dimensional spectrograms of the amplitude spectrum.

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 Characteristics of the measuring system

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

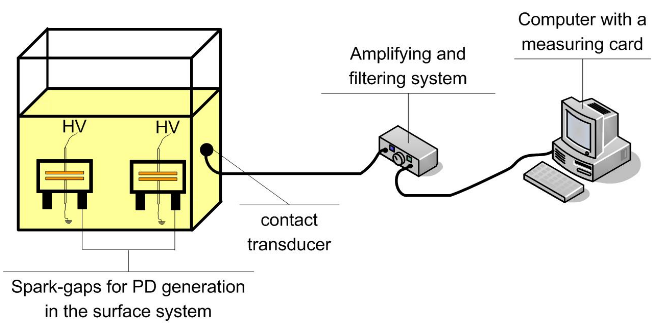


Fig. 1 Diagram of the measuring system

The measurement tub was filled with insulation oil and two spark-gaps generating partial discharges in the sufrace system (SPDs) and a point-plane spark-gap. The spark-gaps were supplied from two test transformers TP 10 with voltage 14.2 kV. The AE signals generated by PDs were registered with a contact transducer WD AH17 by the firm Physical Acoustics Corporation (PAC), placed on the external part of the tub. It is a transducer 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. A piezoelectric transducer was connected with the amplifying and filtering system through a subamplifier. A band-pass filter of the cut-off frequencies of 10 and 700 kHz was used. The measurement signal was amplified by 35 dB. Time runs of the AE signals generated by PDs were registered with a four-channel measuring card CH 3160 by the Acquitec firm. Maximum sampling frequency of the card is 40 MHz at the resolution of 12 bits. During measurement taking a sampling frequency of 2.56 MHz was used ; 51 200 samples were registered, which enabled the signal registration in 20 ms [4].

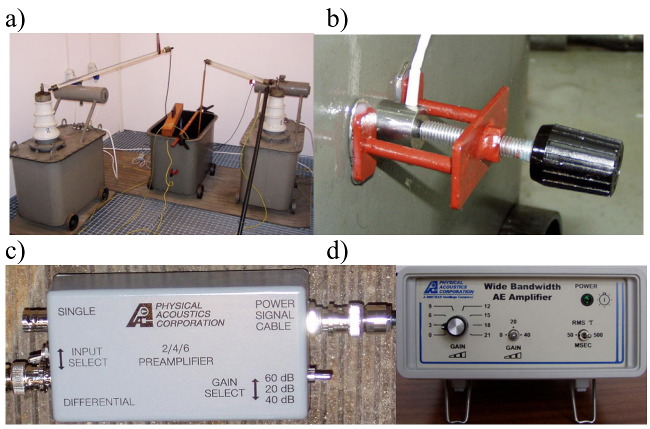


Fig. 2 View of the measuring system : a) measurement chamber, b) piezoelectric transducer, c) subamplifier, d) amplifying and filtering system.

3 Methodology of the research work carried out

The first part of the research work included registration of the AE signals from PDs, separately by a point-plane spark-gap and by a surface spark-gap. The second part of measurements included registration of the AE signals from PDs generated by two spark-gaps simultaneously, taking into account the same supply voltage as in the first part of the experiment. The AE signals from PDs were subjected to a time-frequency analysis using a short-time Fourier transform (STFT) and a wavelet analysis using CWT and DWT. The CWT results are shown in the form of scaling graphs, and the results of the DWT analysis are shown in the form of time runs on seven decomposition levels. The results obtained were supplemented by determining the amount of energy transferred by the particular details.

4 The results of the time-frequency analysis using STFT

Figs 3, 4, 5 show two- and three-dimensional spectrograms of the power density spectrum and three-dimensional spectrograms of the amplitude spectrum corresponding to single- and multi-source discharges.

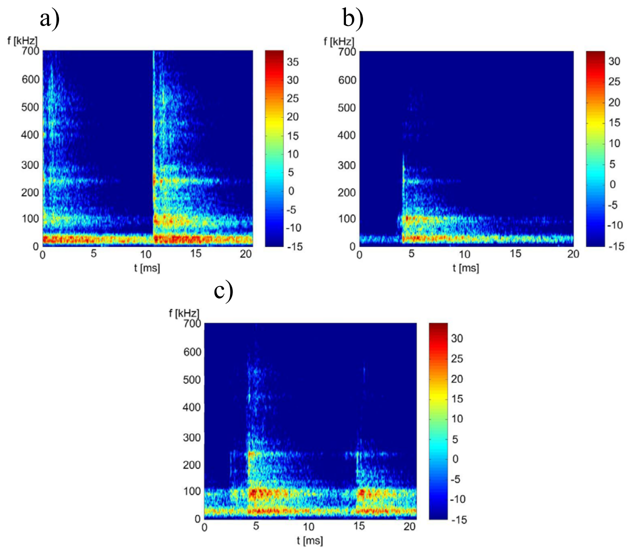


Fig. 3 Two-dimensional spectra of the power density spectrum corresponding to the AE signals generated by PDs: a)single-source (spark-gap 1 –point-plane),single-source (spark-gap 2 - surface), c) multi-source (spark-gaps 1+2)

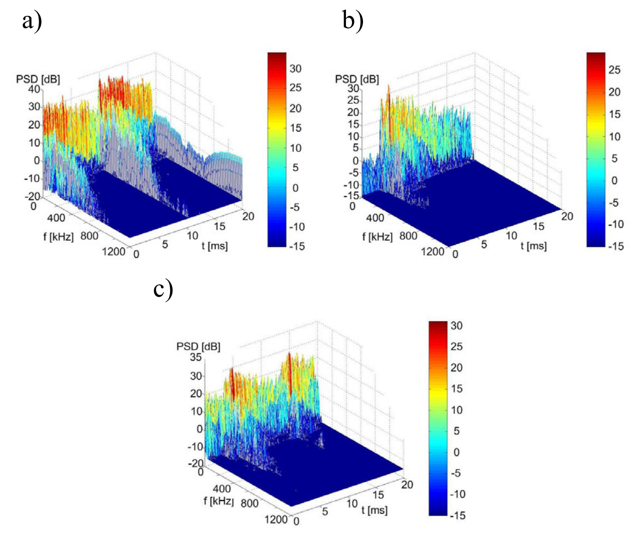


Fig. 4 Three-dimensional spectra of the power density spectrum corresponding to the AE signals generated by PDs: a)single-source (spark-gap 1 –point-plane),single-source (spark-gap 2 - surface), c) multi-source (spark-gaps 1+2)

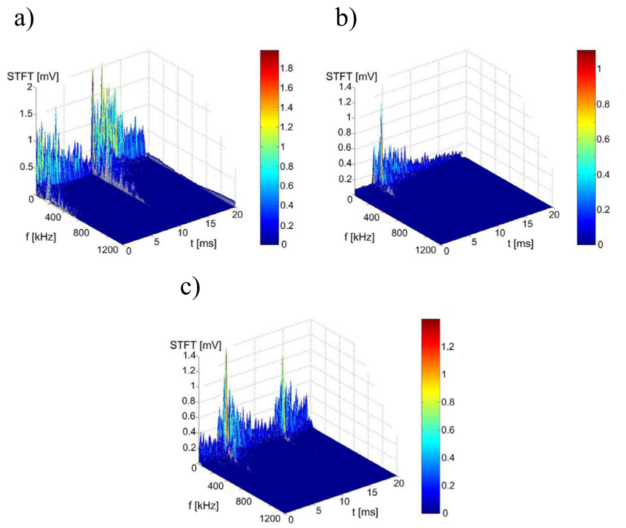


Fig. 5 Three-dimensional spectrograms of the amplitude spectrum corresponding to the AE signals generated by PDs: a)single-source (spark-gap 1 –point-plane),single-source (spark-gap 2 - surface), c) multi-source (spark-gaps 1+2)

Analyzing the two- and three-dimensional spectrograms of the power density spectrum and three-dimensional spectrograms of the amplitude spectrum shown in Figs 3, 4 and 5, time-frequency structures corresponding to the particular PD types can be distinguished. Figs 3a, 4a and 5a show components corresponding to the point-plane discharge, the range of dominant frequencies of which can be divided into two intervals: 20 – 300 kHz and from 300 to 600 kHz. The first interval is characteristic of a bigger amplitude and duration time of time-frequency structures.

Figs 3b, 4b, 5b show time-frequency images corresponding to PDs in the surface system. These structures are characteristic of the frequencies from the range from 20 to 320 kHz. In this band, frequencies from the interval 20-130 kHz can be distinguished, which are characteristic of a much bigger amplitude and duration time.

The components from the interval 20-50 kHz are characteristic of the longest duration time for PDs generated both in the point-plane system and in the surface system.

An increase of discharge intensity registered in the time of 20 ms was observed during registration of the AE signals generated by multi-source PDs. Figs 3c, 4c, 5c show the results of the time-frequency analysis of the AE signals generated by two spark-gaps. Since the ranges of dominant frequencies are different for the point-plane spark-gap than for the surface spark-gap, it is possible to distinguish PD forms generated by different types of spark-gaps. There can be observed two structures – one of them corresponds to a discharge generated by the point-plane spark-gap and the other one is connected with a surface discharge. Maximum amplitude values are similar in both structures.

5 Wavelet analysis of the measurement results obtained

A wavelet analysis is required for the description of the AE signals generated by PDs, which are characteristic of the low- and high-frequency component content. It makes the analysis of the AE signal from PDs using narrow observation windows at higher frequencies and adequately wide for low frequencies possible.

Fig. 3 shows CWT scaling graphs.

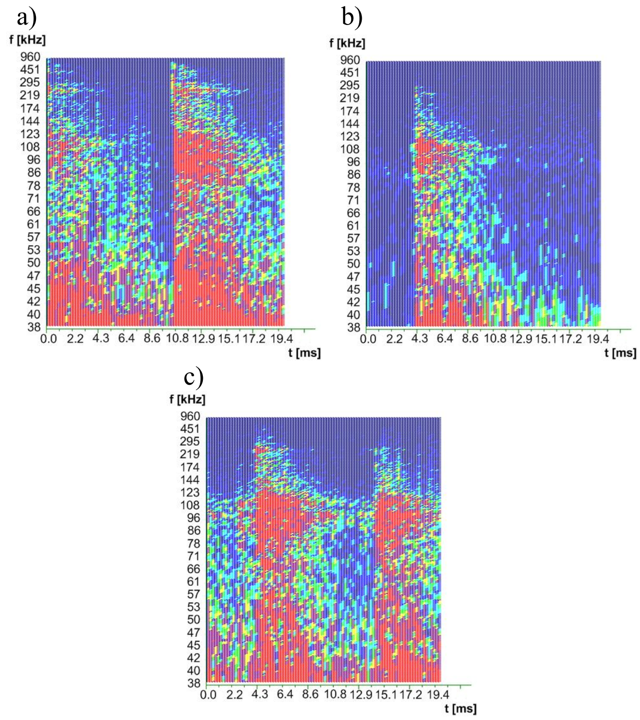


Fig. 6 CWT scaling graphs corresponding to the AE signals generated by PDs: a)single-source (spark-gap 1 –point-plane), b) single-source (spark-gap 2 - surface), c) multi-source (spark-gaps 1+2)

Figs. 6 a-c 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. 6 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.

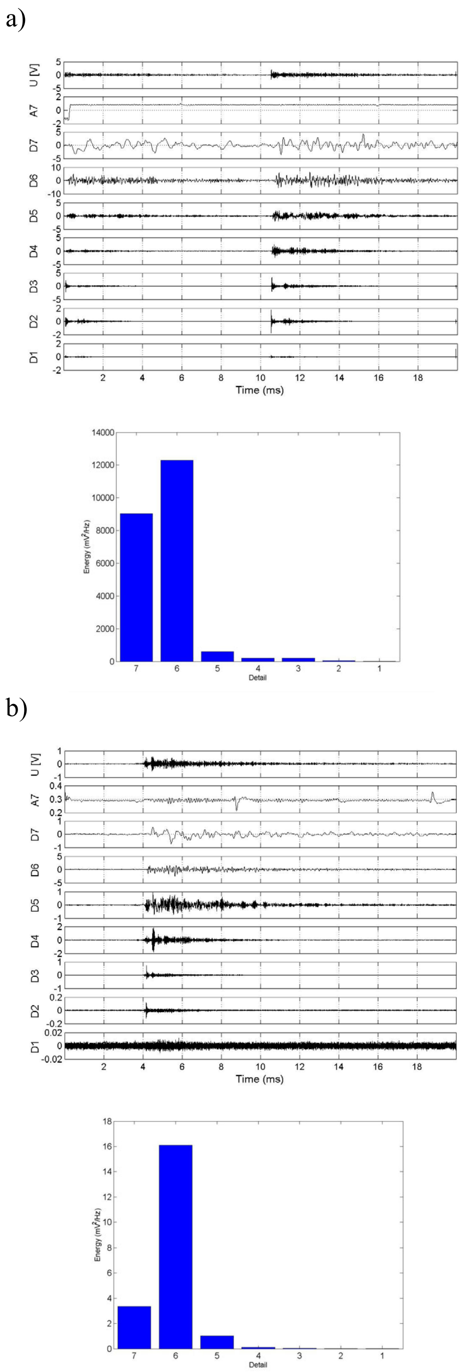
The time-frequency analysis using a CWT contains a large number of pieces of information, which is presented on scaling graphs. This cam limit the possibilities of CWT application as a parameter which can be used for building an expert system diagnosing insulation condition in electric power appliances. A much more synthetic time-frequency description is provided by the analysis carried out by using a DWT. The time-frequency analysis using a DWT can constitute a supplement of the results obtained by using a CWT [5, 8].

For the AE signals from PDs analyzed one by one, an original time run, approximation at the seventh decomposition level and the runs of seven details were determined. Moreover, the amount of energy transferred by each detail was determined in the form of column diagrams.

Table 1 shows the width of the frequency bands corresponding to the particular details

Details	Mid-band frequency [kHz]	Frequency band [kHz]
D1	960	640 – 1280
D2	480	320 – 640
D3	240	160 – 320
D4	120	80 – 160
D5	60	40 – 80
D6	30	20 – 40
D7	15	10 – 20

Table 1 The width of the frequency bands corresponding to the particular details



c)

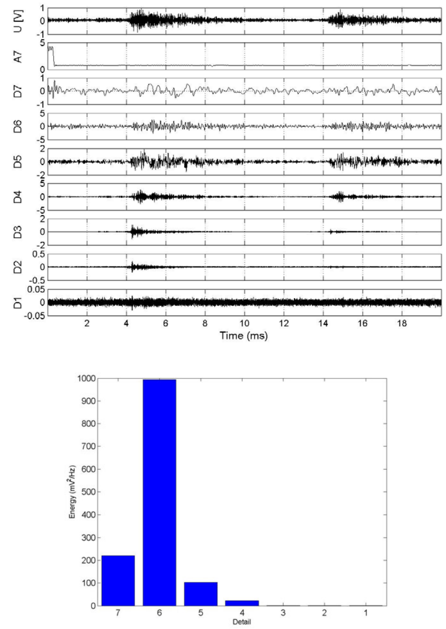


Fig. 6 Discrete wavelet decomposition and the amount of energy transferred by the particular details corresponding to the AE signals generated by PDs: a)single-source (spark-gap 1 –point-plane), b) single-source (spark-gap 2 - surface), c) multi-source (spark-gaps 1+2)

Analyzing wavelet decomposition runs determined for the AE signals generated by single- and multi-source PDs it can be observed that the runs of Details D6 and D7 are characteristic of the biggest amplitude. In the signals analyzed, there are also present Details D5 and D4, which are characteristic of a smaller amplitude. The registered AE time signals generated by PDs in the point-plane system are characteristic of a much bigger amplitude than the runs corresponding to discharges of the surface type. Power participation of the particular details in the AE signals measured, generated by PDs, is confirmed by the column diagram enclosed to the decomposition runs, which visualizes the amount of the energy transferred by the details analyzed. Detail D6 has the biggest power participation in the analyzed AE signals from PDs. The application of the wavelet analysis using DWT does not make it possible to distinguish unmistakably the type of multi-source PDs, but is a good index of the power assessment of discharges.

6 Summing-up

The introduction of the wavelet analysis to the description of the AE signals generated by PDs constitutes a significant supplement of the processing methods, analysis and in consequence interpretation of the measurement results obtained, which have been used so far. The wavelet analysis carried out by using a CWT and DWT increases the assessment accuracy of PDs measured by the AE method.

The research work results presented in this paper confirm the possibility of PD detection in the case of occurrence of multi-source discharges. However, it is necessary to carry out laboratory investigations using other PD types and to determine recognition possibilities of basic PD forms in the case of occurrence of multi-source discharges.

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