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Partial discharge acoustic emission signal analysis

Streszczenie. *Artykuł opisuje analizę sygnałów emisji akustycznej wyładowań niezupełnych oraz metody analizy widmowej. W szczególności opis dotyczy przekształcenia Fouriera oraz przekształcenia falkowego. Wyszczególniono zalety i różnice obu tych przekształceń. (**Analiza sygnałów emisji akustycznej wyładowań niezupełnych).**.*

Abstract*. This paper describes partial discharge acoustic emission signal analysis and methods of spectral analysis. It focuses especially on Fourier and Wavelet transform and points out the suitability and differences between these transforms.*

Słowa kluczowe: wyładowania niezupełne, emisja akustyczna, przekształcenie Fouriera, przekształcenie falkowe.
Keywords: partial discharge, acoustic emission, Fourier transform, wavelet transform.

Introduction

In term of signal classification in time domain partial discharge signals can be considered as random or stochastic signal due to their characteristics, i.e. their occurrence in time has random nature. Partial discharge signal analysis is usually a part of very complex and sophisticated evaluation method of partial discharge measurements in electric power high voltage devices. This analysis can contribute for more precise localization of partial discharges in such devices and helps to find the defective part of insulation system of such devices. On the Department of Electric Power Engineering of FEI TU Košice there were made laboratory measurements of simulated partial discharges by acoustic method [4]. Partial results of these measurements undergo various evaluation methods in order to recognize the type of partial discharge from partial discharge (PD) acoustic emission (AE) signals.

Statistic signal classification in time domain

A method for basic statistic classification of measured signals was designed. Usually when we measure the acoustic emission of partial discharges, we get a very huge set of AE pulses. If we want to analyze these pulses in time domain we have to estimate the most probable shape of the signal that is measured under some certain conditions, i.e. we need to create an estimated template signal which represents the whole class of AE pulses. Simple signal average is very time-blurred, so we used time alignment based on correlation function. As a result we get an estimated PD AE pulse template. More detailed description of this method can be found in [3].

In frequency domain we have to choose the most suitable transformation method and a graphical representation that would show the most meaningful parameters of PD AE pulses. Next we summarize the application of Fourier transform and we introduce Wavelet transform as better solution for spectral analysis of partial discharge acoustic emission signals.

Usage of Fourier transform in spectral analysis

In general transforms are very good tools for signal parameter recognition and help us to get more detailed information about it. Among the most widely used transforms we can find Fourier transform that displays the spectral content of the analyzed signal.

The Fourier transform (FT) is the generalization of complex Fourier series. The Fourier series is an extension of periodical function to an infinite sum of sine and cosine functions which are orthogonal. The calculation and the examination of Fourier series are well known as harmonic analysis of the function and are well utilizable for random periodical signal decomposition to simple parts. Thus the analysis becomes simpler and it is easier to find the overall solution for the problem under examination of its approximation.

Let *f* be a continuous integrable function of real variable *x*. Its Fourier transform is defined as:

$$F(k) = \int_{-\infty}^{\infty} f(x) \cdot e^{-\mathrm{i}\cdot 2\pi k x} \cdot dx \tag{1}$$

Let *F* be an integrable function. Then the inverse Fourier transform is defined as:

$$f(x) = \int_{-\infty}^{\infty} F(k) \cdot e^{\mathrm{i}\cdot 2\pi k x} \cdot dx \tag{2}$$

The result of Fourier transform is amplitude-frequency characteristics and phase-frequency characteristics. Fourier transform is often executed as Discrete FT (DFT) or Fast FT (FFT). These characteristics give us the overview over the content of individual harmonic frequency elements of the examined signal of PD AE. The main disadvantage of this transform is the lack of information about time positioning of these basic harmonic frequencies. However, in the case of partial discharge acoustic emission signals which are non-stationary signals this information is very important for intended analysis e.g. for reflected signal recognition in insulation system. Therefore it is more suitable to use a transform which beyond the spectral analysis preserves the time information for separate spectral elements.

Introduction to wavelet transform

The problem of uncertainty of time distribution of spectral elements results from physical principle – Heisenberg's principle of uncertainty: we can get spectral decomposition with high resolution of frequencies but with low resolution in time domain or we get more precise time localization of spectral elements but with low frequency resolution. The solution for this problem is MRA – Multi-resolution Analysis: various spectral elements of the signal are analyzed with different resolution in time. This approach is especially suitable in the case of non-stationary signals like PD AE pulses.

The starting point for this solution can be Short Time Fourier Transform (STFT). In the case of STFT the signal is divided to small segments of short time duration. These signal chunks are supposed to be stationary. For this purpose a window function "*w*" is introduced. The width of this window is same as the duration of stationary signal chunk. If we choose for the window function a special shaped signal with the shape of a small wave – wavelet with definite definition domain, we get the so called continuous wavelet transform (CWT). It is defined as:

$$CWT_x^{\psi}(\tau,s)=\Psi_x^{\psi}(\tau,s)=\frac{1}{\sqrt{|s|}}\int x(t)\Psi^*\left(\frac{t-\tau}{s}\right)dt \tag{3}$$

where: $x(t)$ is the analyzed signal in time domain and t is time.

The transformed signal is a function of two variables, τ and s, function $\psi(t)$ is the transforming function called *mother wavelet function*. It is known a wide variety of functions used as wavelet functions. Based on the principles of Short-Time-Fourier-Transform the transformation function - wavelet with its „short-time“ shape is shifted in time domain in successive steps. Thus the time position information of spectral elements is scanned and this information is displayed as time-translation parameter in transformed domain. The wavelet function is then multiplied with the analyzed signal and after integration and energy normalization a coefficient is calculated for the individual time-translation.

This algorithm is then repeated for other values of *s* parameter. This parameter corresponds to scaling factor of transforming function thus the wavelet changes its width (it is contracted or dilated).

Graphical representation of the transformed function of two variables in translation-scale domain is a picture with more or less bright points. The brightness of these points correspond calculated coefficient for spectral element with certain frequency and certain position in time.

Spectrum helpfulness comparison

In figures 1 – 2 acoustic emission signals in time domain are displayed together with its amplitude frequency characteristics (FT). Figures 3-4 show the wavelet transform of these signals. The pulses were acquired in laboratory under conditions described in more detail in [4].

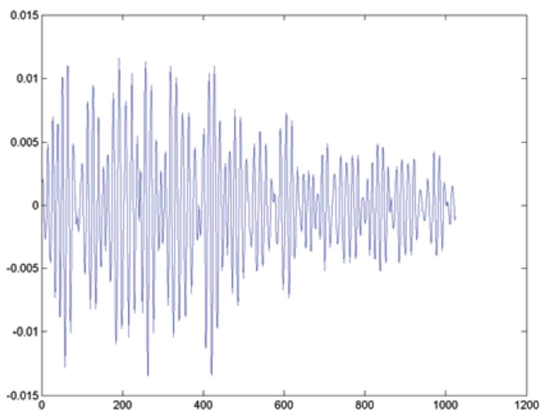

Fig. 1a. Partial discharge signal – homogenous insulation system, time domain

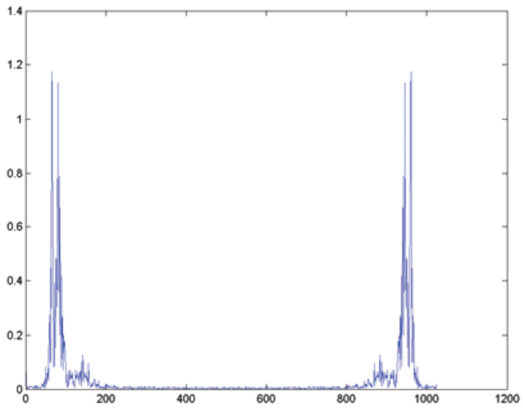

Fig. 1b. Partial discharge signal – homogenous insulation system, amplitude-frequency characteristics

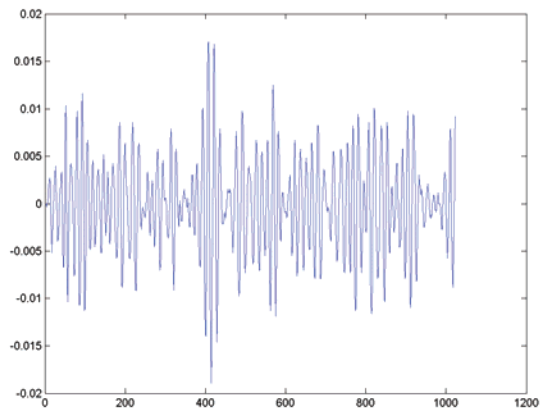

Fig. 2a. Artificially generated noise signal – homogenous insulation system, time domain

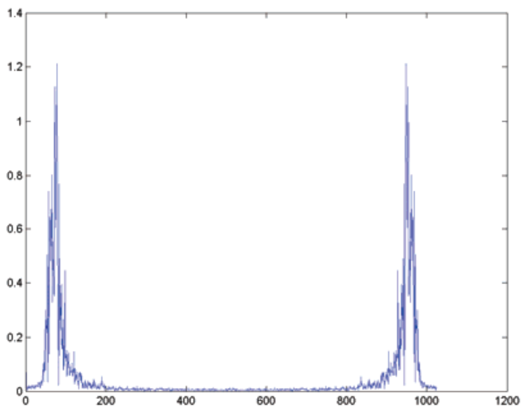

Fig. 2b. Artificially generated noise signal – homogenous insulation system, amplitude-frequency characteristics

When comparing the Fourier transform of partial discharge signal and the spectrum of the artificial noise signal we can see obvious differences in spectral element content. But we can not see the time position when these frequencies occurred in signal. Thus we cannot recognize possible reflected pulses which occur especially in complicated and non-homogenous complex insulation systems. Such recognition is useful also for signal shape analysis in time domain. This is possible with the help of wavelet transform. The wavelet transform graph gives us additional information about time distribution of spectral elements (time axis *b* in graph).

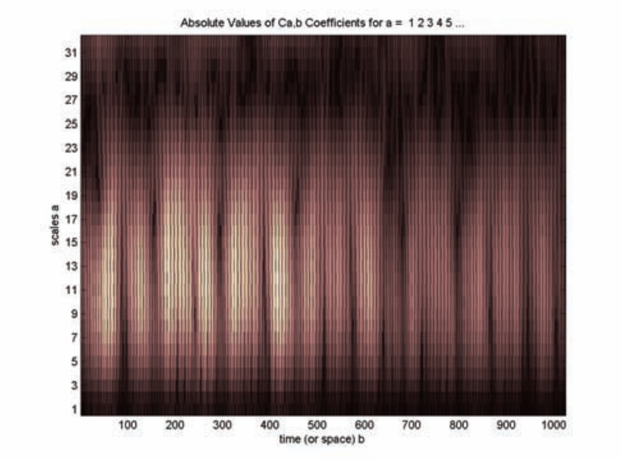

Fig. 3. Wavelet transform graph of the signal from fig. 1a.

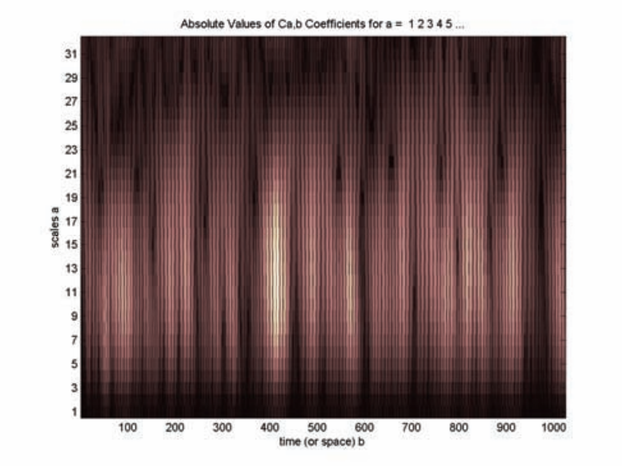

Fig. 4: Wavelet transform graph of the signal from fig. 2a.

We can see that in case of noise signal the energy is distributed more evenly in time. This e.g. results from the fact that the noise signal is a composite of many smaller successive pulses with approximately equal energy. On the other hand the pulse of partial discharge acoustic emission is a single-shot pulse with possible subsequent pulses with smaller energy that origin from reflected pulses.

Conclusion

The aim of this paper was to outline the differences and suitability of Fourier and wavelet transform form spectral analysis of partial discharge acoustic emission signals. The wavelet transform appears to be a very useful tool for non-stationary PD AE pulses analysis in time-frequency domain and it even gives additional information for signal shape analysis in time domain.

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