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Partial Discharge Analysis - A Deterministic Approach

***Streszczenie.** (**Analiza wyładowań niezupełnych – podejście deterministyczne**) W artykule tym przedstawione jest deterministyczne podejście do analizy i modelowania wyładowań niezupełnych. Opieramy się tu na teorii deterministycznych systemów nieliniowych wrażliwych na warunki początkowe. Obserwowana seria impulsów wyładowań niezupełnych traktowana jest jako dyskretny wielowymiarowy układ dynamiczny. W ten sposób można osiągnąć mniejszy błąd w przewidywaniu serii wyładowań w porównaniu z metodą stochastyczną. Ponadto uzyskana informacja o błędzie przewidywania może być użyta do klasyfikacji źródeł wyładowań.*

***Abstract**. In this paper we explore deterministic approach to PD data analysis. The work is inspired by the theory of processes or dynamical systems that are deterministic, non-linear and sensitive to initial conditions. We consider the observed sequence of PD events as a multivariate discrete dynamical system. We demonstrate that the deterministic prediction of PD sequences is possible and that the error of prediction is smaller than the one obtained with a linear stochastic model. Further, we demonstrate that the error of prediction can be used in classification of PD sources.*

Słowa kluczowe: wyładowania niezupełne, układy nieliniowe, modelowanie, klasyfikacja.
Keywords: partial discharge, non-linear systems, modelling, classification.

Introduction

The analysis and modelling of partial discharge (PD) process is important in providing the means for quantification, classification, and ultimately, better understanding of the PD phenomena and its effects on insulation degradation and the reliability of the insulation system.

There exist attempts to model the PD process based on physical principles, for example the algorithmic model of Patsch and Hoof [1] or the stochastic model of Heitz [2].

For engineering applications it is often sufficient, and also interesting, to model the observed data instead of attempting to describe the process on the basis of the ‘first principles’.

It is common in engineering modelling to describe signals in terms of an input-output system. Partial discharges can be also seen as a response of an insulation system to the sinusoidal excitation, as shown in Figure 1.

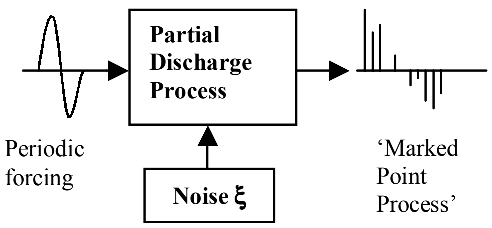

Fig.1. Input-output representation of partial discharge process

In traditional experimental setting, PD events are observed as current pulses induced in the high voltage electrode by the electric discharge. The peak value of the current and its time relative to the phase of the applied 50 Hz voltage are normally recorded. The temporal information is not preserved since PD pulses are presented in the form a phase-resolved pattern within one sinusoidal cycle. Subsequently, statistical measures are used to characterise the process.

In our work, we are interested in the time relationship, or ‘dynamics’, in the sequences of PD events. In particular, we are inspired by the theory of processes which are non-linear, deterministic and sensitive to initial conditions.

It seemed surprising that an irregular in appearance process can be generated by a deterministic algorithm when it was first demonstrated over 50 years ago by Ulam and von Neumann [3]. Later, it was shown that for a deterministic process to generate ‘apparently stochastic output’ it is required that its rules of motion are non-linear and sensitive to initial conditions. The chaos theory was born.

An order may emerge from such irregular process if the trajectory of its motion is embedded and observed in space of sufficient dimension. In this context, stochastic process can be seen as a dynamic process of infinite dimensionality. Intuitively, one can see even from this brief reasoning that statistical tools may not be most efficient in analysing data of finite dimensionality and vice versa. In the following sections we demonstrate that such is the situation with sequences of partial discharge pulses.

Deterministic dynamic model

If a dynamic process is governed by non-linear rules of motion which are sensitive to initial conditions, non-linear correlations must exist within its output variables. These correlations can be often discovered by simple means, such as observation of geometrical patterns in the time delay plots, for example. However, if substantial random component is present in the signal the pattern may be obscured and trajectory plots in two or three dimensions may fail to reveal existing correlations. Therefore, we investigate predictability of PD data as a tool for revealing determinism, for good predictability indicates presence of determinism.

There may be also a question whether the non-linear dynamics approach is valid in the case of PD process, which is a ‘point process’, i.e. consisting of discrete events which are irregularly spaced in time. We believe that the method can be justified on the basis of work by Sauer [4] and as shown in our previous work [5]. Consequently, we propose to analyse the PD data as a 2-D, phase-magnitude map of the following form:

$$PD_{ph}(n+1), PD_m(n+1) = f\left[PD_{ph}(n), PD_m(n), \cdots, PD_{ph}(1), PD_m(1)\right] \qquad (1)$$

Using this map, we employ local linear model [6] in multi-step prediction of partial discharge magnitudes and phases.