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Discrimination of Insulation Defects in a Gas Insulated Switchgear (GIS) by use of a Neural Network Based on a Chaos Analysis of Partial Discharge (CAPD)

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Abstract - In this work, experimental investigation is carried out in order to design and fabricate the UHF sensor that is able to detect the partial discharges produced from 10 artificial defects introduced into the real scale 70kV GIS mock-up under high voltage within a well shielded room. As well, in order to verify the on-site applicability of our method, the newly proposed CAPD (chaos analysis of partial discharge) is combined with spectral analysis for identifying the nature of 10 artificial defects under investigation. The PD pattern recognition of each defect has been fulfilled by applying our ANN software. The result indicates that the recognition rate reaches up to 80% by the newly proposed method while the traditional PRPD analysis method allows us to obtain 41%.

In consequence, it can be pointed out that the proposed method seems likely to be applicable to the real GIS at the site.

Keywords: Chaos, Gas Insulated Switchgear, Partial Discharge, Pattern Recognition.

1. Introduction

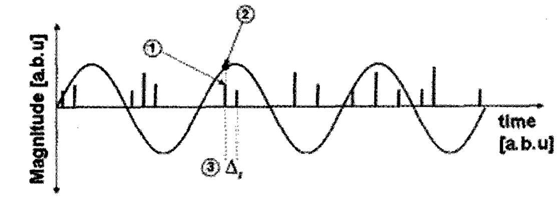
Various PD detection and analysis methods have been widely used for over three decades, for which the PD pattern analysis has been traditionally made by the so-called "PRPD analysis" method in which the PD phenomena has been assumed to be a simple stochastic phenomena [1-6]. However, the PD phenomena could be one of the deterministic dynamic systems that are determined by various physical parameters. And thus, we have suggested a plausible method for PD analysis, named "CAPD method", based on the chaos theory, which has been largely employed for analyzing deterministic dynamical systems [7-12].

In our concept, as a consequence of electrical overstressing in a small region inside the insulation, an extremely rapidly progressing electric discharge may occur and give rise to a local accumulation of space charge which, in turn, will change the local electric field. Thus, this will have considerable influence on the initiation and development of subsequent discharge pulses. Therefore, successive pulses cannot be considered independently of previous discharges. In this regard, its mathematical model can be described by either nonlinear difference equations or nonlinear differential equations using several state variables obtained from the sequentially measured time data for PD signals.

These variables can provide rich and complex behavior for the detectable time series, for which Chaos theory can be employed. In this respect, a new analysis method, named 'Chaotic Analysis of Partial Discharges (CAPD)', is well proposed [7-12].

2. CAPD (Chaos Analysis of Partial Discharge) combined with a spectral analysis as a novel tool for the PD pattern analysis

In the concept of CAPD, three Normalize-Differenced Quantities (NDQs) are emphasized as follows: differences in magnitude between consecutive normalized PD pulses (p_t), differences in amplitude between two normalized voltage values when partial discharges take place (v_t) and normalized differences of timing between two consecutive pulses (T_t) [7-12].



① Magnitude of discharges: p_t
② Applied voltage at which discharge occurs: v_t
③ Time interval between two consecutive PD pulses: Δ_t

Fig. 1. Fundamental parameters of CAPD analysis method

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Fundamental concepts of the CAPD parameters and analysis procedures are shown in Fig. 1 and in Fig. 2, respectively.

These parameters can be calculated from measured PD data using equation (1) through equation (6). In the CAPD analysis procedures, 2-dimensional attractors are used for the feature map as shown in Fig. 3 and, in addition, relative power spectral data can be combined with a feature map for the time-frequency joint analysis as indicated in Fig. 4. These feature maps and relative power spectral data are used as input vectors of an artificial neural network for the PD pattern classification.

Normalized quantities:

$$v^*_{vp} = \frac{v_t}{v_{t\max}}, (-1 \le v^*_{vp} \le 1) \qquad (1)$$

$$p^*_t = \frac{p_t}{p_{t\max}}, (0 \le p^*_{vp} \le 1) \qquad (2)$$

$$\Delta^*_t = \frac{\Delta_t}{T}, (T = 1/f) \qquad (3)$$

Normalized differenced quantities:

$$V_t = v^*_t - v^*_{t-1}, (-2 \le V_t \le 2) \qquad (4)$$

$$P_t = p^*_t - p^*_{t-1}, (-1 \le P_t \le 1) \qquad (5)$$

$$T_t = \frac{\Delta^*_t}{\Delta^*_{t\max}} \qquad (6)$$

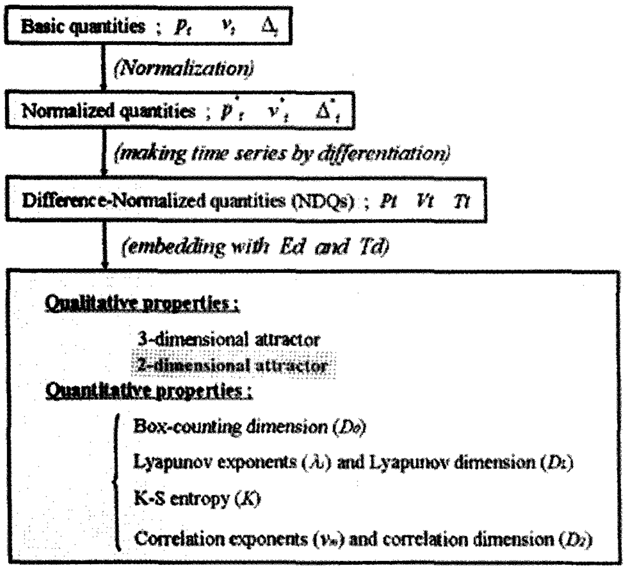

Fig. 2. Sequential procedures for the CAPD analysis using 2-dimensional attractors

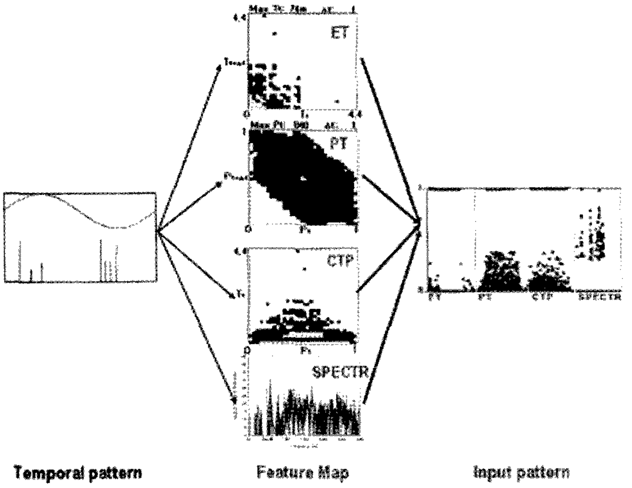

Fig. 3. Making feature vectors for the input of an artificial neural network

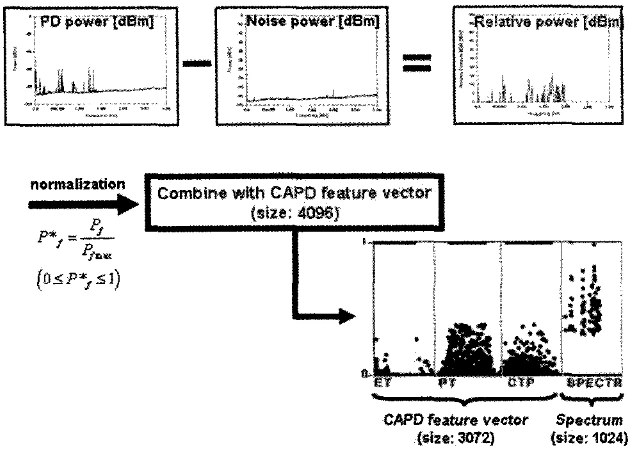

Fig. 4. Combining of feature vectors with relative power spectrum data

3. Experimental

According to IEC60270, all the experiments were conducted using a PD-free transformer (Haefely Ltd.) inside a well shielded room (-20 dB in the radio frequency range) for less interference from external noise as shown in Fig. 5. Ten artificial defects have been put under investigation since they are reported to be the most vital defects of the GIS under service. In addition, the UHF sensor has been designed and fabricated to detect the partial discharges generated from the above defects introduced into the real scale 70kV GIS mock-up under high voltage. Moreover, in order to verify the on-site applicability of our proposed method, the proposed CAPD (chaos analysis of partial discharge) is combined with the spectral analysis method in order to identify the nature of the above 10 defects. PD pattern recognition has also been fulfilled by our artificial neural network software.

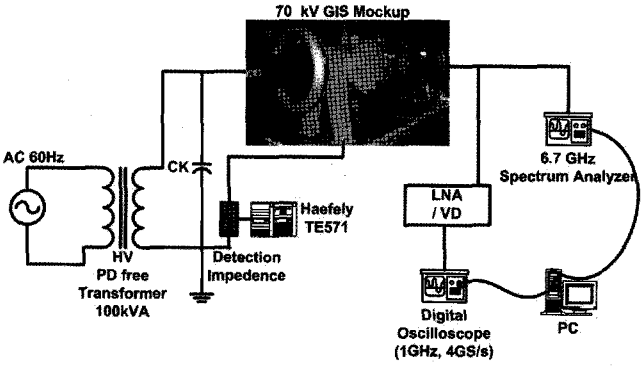

Fig. 5. Experimental block diagram

Self designed UHF Coupler:

An internal UHF coupler was designed and realized and then embedded into the inner part of the hatch cover plates for higher sensitivity due to its screen effect.

PD Pulse Detector:

In this work, instead of the conventional method considering the magnitude of the partial discharges, the displayed PD patterns related to the defects are mainly considered. And thus, a commercialized PD detector has been employed to detect only the envelope of the fast damping PD signals, just as does the logarithmic video detector. This allows us to demodulate the PD signals (ranging from 0.3 GHz to 2.5 GHz) into those in reduced range from 20MHz to 80MHz. According to its specification [8], the amplifier operates in logarithmic mode by which the PD magnitude does not correspond to that of the actual one.

Software for PD Measurement and Analysis:

Our software enables us to obtain all the necessary data both in time and frequency domain simultaneously, by which time–frequency joint analysis can be achieved. Its related analysis algorithms are well described in detail. [8].

Artificial Defects:

For the modeling of insulation defects in real GIS condition, ten different types of artificial defects, as presented in Fig. 6, are prepared and then put under investigation under the same experimental condition. The length and width of metallic particles (aluminum) are 10mm and 2.5mm, respectively.

Experimental Conditions:

A real scaled 70kV model GIS, in Fig. 5, consists of several important parts: HV bushing for the high voltage application, a small chamber reserved for the artificial defects to generate the PD signals under investigation, and two spacers. Four windows allow us to observe the physical phenomena taking place inside the GIS through a digital camera that is placed at a fixed position in front of the main window. The diameter of the aluminum inner conductor and metal outer tank are 80mm and 270mm, respectively and the pressure of the SF_6 gas has been maintained to be $3kgf/cm^2$.

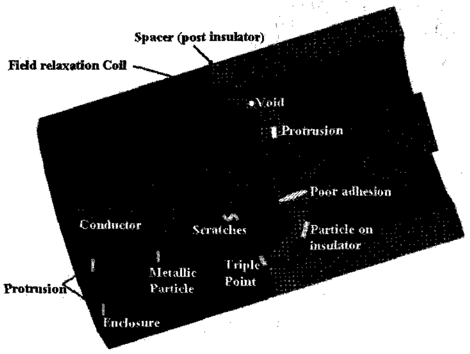

Fig. 6. Modeled defects in GIS

Our UHF coupler was mounted at the inner (surface) part of the outer chamber hatch plate to detect the PD signals that are transmitted through the RG400 double insulated coaxial cable, SMA and N type connector. Since the coupler output value cannot be precisely transformed into the Pico Coulomb unit, the PD occurrence is measured simultaneously according to IEC60270 using HAFLEY TE571.

A/D conversion and spectral data, obtained by a digital storage oscilloscope (LC574AL, bandwidth 1GHz, 2Gs/sec) and a spectrum analyzer (Agilent E7402A, 30Hz-3GHz), are transferred to the personal computer through the GPIB interfacing port (max transfer rate: 4MS/s). The frequency of the external noise at the laboratory has been well analyzed for its discrimination.

4. PD pattern recognition by use of CAPD feature map

In order to verify the on-site applicability of our proposed CAPD method, its rate of success for PD pattern recognition has been compared with that obtained by the conventional PRPD method. Considering the case of wrong phase information, time-shifted PD data are provided based on the properly collected sound data.

Successful recognition rates for the given 10 artificial defects are summarized in Table 1, showing that the recognition rate is up to 80% by our method while the conventional method allows only a 41% recognition rate. From this result, it can be pointed out that if time-shifted PD data are used for PD pattern recognition, the CAPD method can afford a more reliable result than the PRPD method.

Table 1. Successful recognition rate by use of CAPD and PRPD result for the input of an identical artificial neural network.

Insulation defects		Number of patterns	Successful recognition rate [%]	
			CAPD	PRPD
1	Fixed Protrusion at the conductor	100	86	43
2	Conductor triple point	100	89	34
3	Fixed protrusion at the enclosure	100	87	42
4	Enclosure triple point	100	79	33
5	Floating electrode	100	86	35
6	Particle in a spacer	100	98	39
7	Spacer fixed particle	100	67	33
8	Freely moving single particle	100	75	54
9	Freely moving multi particle	100	83	65
10	Void in a spacer	100	93	38
11	External corona from outside of GIS	100	64	45
12	Motor operational noise	100	54	33
Averaged successful recognition rate [%]			80.1	41.2

5. Concluding remarks

In this paper, a novel analytical method named the 'CAPD' is proposed for the PD pattern analysis and verified for its on-site applicability. Based on the results, it can be pointed out that the feature vectors from different defects have different aspects. In addition, for the cases where the accurate phase of the operating voltage is unavailable to any on-site engineers, CAPD result can afford more reliable recognition of defect than the conventional PRPD method.

However, elaborate investigations are now under preparation to provide a sufficient database for the pattern recognition algorithm combined with the CAPD method to identify the nature and the location of defect introducible into the GIS.

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