CAPD기법을 이용한 부분방전 현상 해석에 관한 연구

Analysis of Partial Discharge Phenomena by means of CAPD

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Abstract

PD phenomena can be regarded as a deterministic dynamical process where PD should be occurred if the local electric field be reached to be sufficiently high. And thus, its mathematical model can be described by either difference equations or differential equations using several state variables obtained from the time sequential measured data of PD signals. These variables can provide rich and complex behavior of detectable time series, for which Chaos theory can be employed. In this respect, a new PD pattern recognition method is proposed and named as 'Chaotic Analysis of Partial Discharges (CAPD)'for this work. For this purpose, six types of specimen are designed and made as the models of the possible defects that may cause sudden failures of the underground power transmission cables under service, and partial discharge signals, generated from those samples, are detected and then analyzed by means of CAPD. Throughout the work, qualitative and quantitative properties related to the PD signals from different defects are analyzed by use of attractor in phase space, information dimensions (*Do* and *D2*), Lyapunov exponents and K-S entropy as well. Based on these results, it could be pointed out that the nature of defect seems to be identified more distinctively when the CAPD is combined with traditional statistical method such as PRPDA. Furthermore, the relationship between PD magnitude and the occurrence timing is investigated with a view to simulating PD phenomena.

Keywords: CAPD, Partial Discharge, XLPE power cable

1. Introduction

In a PD phenomena occurring in insulating materials, space charges from the previous discharges that could be remained near the discharge site affect the ignition of the following discharge. Therefore, the successive pulses cannot be considered without the effect of the previous discharge. From this reason, correlations between consecutive pulses should be considered especially in the early stage of insulation aging, where space charges play a decisive role. However, since the pulses are superimposed within finitely fixed phase windows of the applied voltage in PRPDA method [1-3], it could be remarked that information about the correlations between consecutive pulses could be hardly deduced [4]. But for the proposed CAPD method, the basic quantities related to discharges during local insulation degradation are collected through continuous thousandsof cycles of the applied voltage to get the information on the correlation between consecutive pulses.

The basic quantities are consists of three quantities obtained in accordance with the occurrence of discharge during continuous applied voltage cycles. Three quantities are the magnitude of discharge (p_i), the applied voltage when discharge occurs(v_i) and the differences of discharge timing (Δ_i) as can be seen in Fig. 1. Especially, Δ_i plays an important role in CAPD to get informationon the timing of discharge could be

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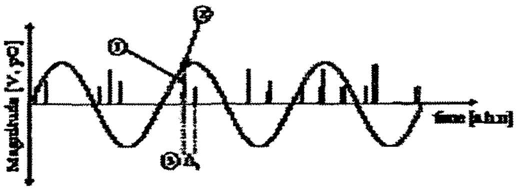
affected by space charge from the previous discharges [5-6]. Afterwards, the one-dimensional time series of *NDQs*can be embedded in larger dimensional phase space (phase space reconstruction or delay coordinate embedding), in order to find out the presence of converging bounded subset (strange attractor) [7-8]. Finally, in the embedded phase space, the specific qualitative and quantitative characteristics of the three *NDQs*are thoroughly examined.



① Magnitude of discharge p_i

② Applied voltage when discharge occurs v_i

③ Differences of discharge occurrence timing Δ_i

Fig. 1. Basic quantities for CAPD

2. Experiments

Fig. 2 shows the block diagram of the PD detection system. All of the experiments is conducted under the condition based on the standard IEC60270[9] with 60Hz PD free transformer(manufactured by Hafely Ltd.). And circular current transformer (CT) type transducer is adapted to detect PD signals. And the preamplifier acts as a broadband AM demodulator [10]. Then PD signals are digitalized by use of digital oscilloscope and transferred into PC through GPIB interfacing port.. Six types of artificial defect are preparedto model defects in an

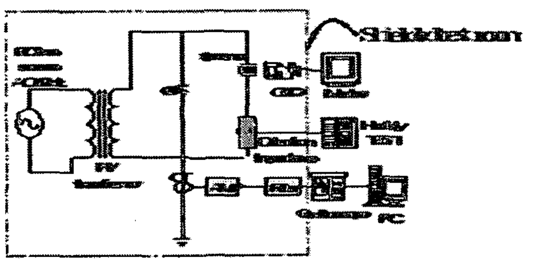


Fig. 2. block diagram of detection system

underground power transmission cable and accessories for joint as shown in Table 1.Every 2 minutes, the applied voltage was stepped up by 1 kVfor generating PD from artificial defects. And then, the experiment was continued at the voltage of 120% of the voltage at which the first PD is detected.

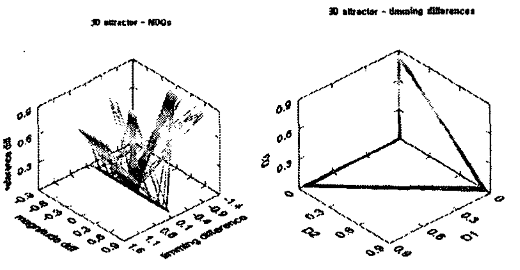
Table 1. Artificial defects

defect type	model	note	notation
Needle to plane in air	contact noise (corona)	tip radius: 100μm	I
Metal to EPDM sheet in air	contact noise (surface discharge)	diameter: 10cm	II
Needle defect	Defect in a cable insulation	tip radius: 100μm electrode gap: 3mm	III
Cavity	Defect in a joint	diameter: 1000μm fulfilled gas: air	IV
Metallic substance	Defect in a joint	length: 1000μm height: tens of μm	V
Insulating substance	Defect in a joint	length: 1000μm height: tens of μm	VI

3. Results

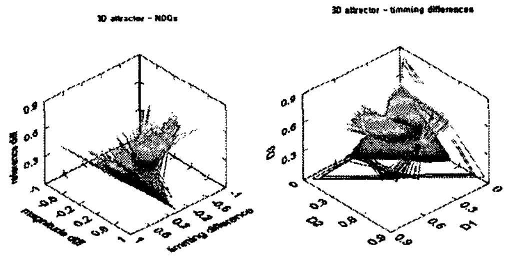
3.1 Qualitative information for the NDQs

By means of proper phase space reconstruction (embedding), it is possible to investigate the presence of chaotic characteristics, such as self-similarity and periodicity by drawing attractor based on the embedded time series, which can be also represented by non-integer fractal dimension [7-8]. In sequence, it is preferable to ascertain the presence of strange attractor, by means of appropriate phase space reconstruction. With this reason, it is required to determine the "embedding dimension(*Ed*)" and "time delay (*Td*)" in order to come out correct embedding. Accordingly, to compute *Ed* and *Td*, False Nearest Neighbors (FNNP) methods [11] and autocorrelation function [12] were used, respectively. Especially, if a computed *Ed* is lager than 10, *Ed* was assumed to be 10 inorder to avoid overflow during calculation. All of computation was performed for each *NDQs* of each defect and for the *Tt-Pt-Vt* trajectory of each defect. However, the strange attractors of *Tt* and *Tt-Pt-Vt* are shown as examples. These 3-dimensional strange attractors are shown in Fig. 3 using those *Ed* and *Td* values in Table 2, respectively. It can be said that the presence of strange attractorin a phase space indicates the existence of fractal structures in its phase space. Furthermore, the strange attractor of *Tt* of each defect shows a very distinctive shape from each other. This distinctive shape will result in different quantitative properties e.g. Lyapunov exponent, correlation dimension and etc.



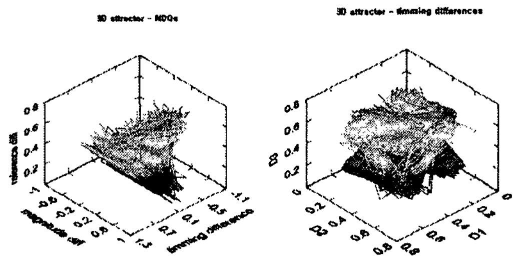
Tt-Pt-Vt *Tt*

(a) Defect I



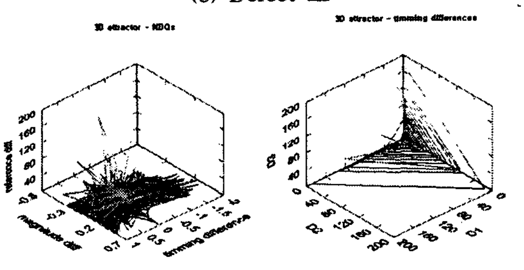
Tt-Pt-Vt *Tt*

(b) Defect II



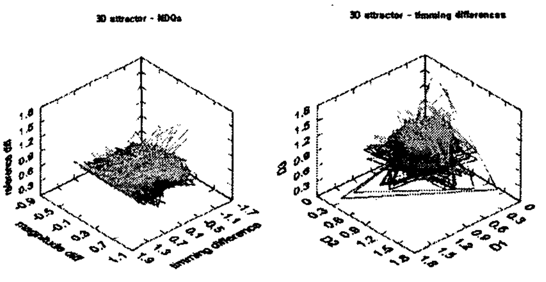
Tt-Pt-Vt *Tt*

(c) Defect III



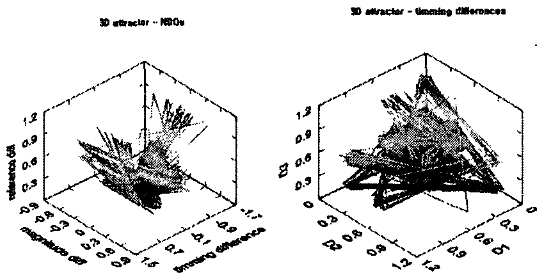
Tt-Pt-Vt *Tt*

(d) Defect IV



Tt-Pt-Vt *Tt*

(e) Defect V



Tt-Pt-Vt *Tt*

(f) Defect VI

Fig. 3. Strange attractors of *Tt-Pt-Vt* and *Tt* of each defect

3.2 Box Counting Dimension (*D0*).

3-dimensional box-counting dimension (*D0*: alternatively called the capacity dimension) was computed by means of the equation (1) for each NDQs and *Tt-Pt-Vt* trajectory of each defect. *D0* is very simple and convenient definition of the dimension set. However, it can definitely indicate whether the concerning attractor has a fractal orbit or not. For example, a point attractor has the value of 0 and a limit cycle attractor has the value of 1. If *D0* is lager than 1 and non-integer value, the concerning attractor could be considered as a fractal structure.

$$D_0 = \lim_{\varepsilon \to 0} \frac{\ln M(\varepsilon)}{\ln(1/\varepsilon)} \qquad (1)$$

In this paper, very useful information has been achieved from the result. As can be seen in Table 2, *D0* of *Vt* of defect I is 0 and *D0* of *Tt* of defect I is 0.4. This means that *Vt* has a point attractor and is not a fractal and *Tt*has a few point of basin in its phase space and has not a fractal structure in its phase space. Meanwhile, other NDQs have non-integer and lager than 1 *D0*values so that these NDQs have fractal structure in their phase space

3.3 Lyapunov Exponents Spectra, Lyapunov dimension (*DL*) and K-S Entropy (*K*)

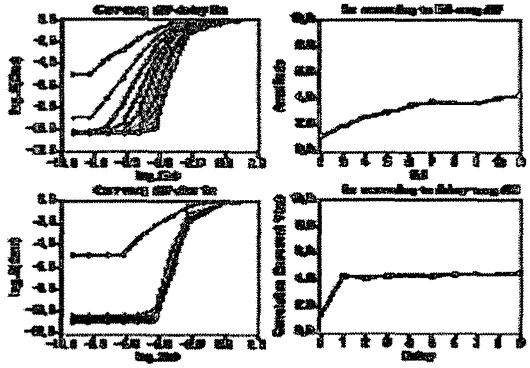
In order to calculate the degree of divergences for the trajectories in Fig. 3, Lyapunov exponents spectra has also been investigated as a function of the given time interval in Table 2 between two sequential center points. Among the different values of Lyapunov exponents corresponding to several given dimensions, the largest one (*L1*) is considered to determine the presence of chaos. For the positive one, the system could be considered to be divergent implying chaotic system. Otherwise, the system would be converged [14-15]. Then, the Lyapunov dimension (*DL*) and K-S entropy (*K*) can be calculated by means of the equation (2) and the equation (3), respectively [13]. All of the calculated results is indicated in Table 2.

$$D_L = j + \frac{\sum_{i=1}^{j}\lambda_i}{|\lambda_{j+1}|} \qquad (2)$$

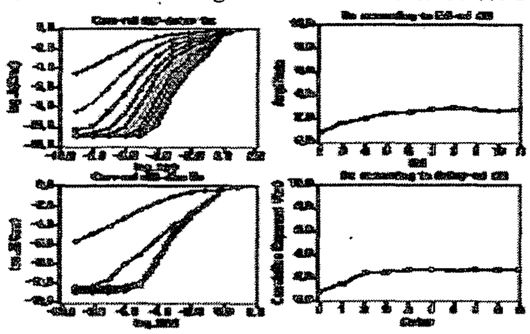
$$K = \sum_{i=1}^{k}\lambda_i \qquad (3)$$

3.4 Correlations Integral, Correlation Exponents (ν_m) and Correlation Dimension (*D2*)

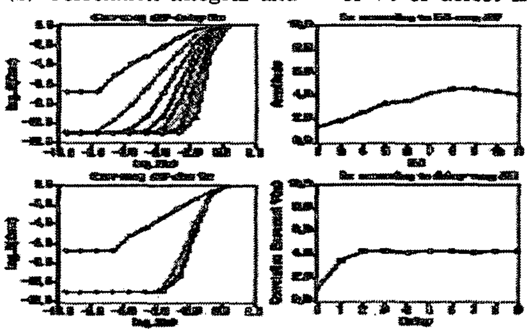
Correlation dimension (*D2*) value indicates the minimal number of variables needed to model chaotic system by nonlinear differential equation [13]. And, correlation dimension (*D2*)can be determined using correlation exponents (ν_m) resulted by correlation integral. Thus, in this paper, *D2* was computed by correlation integral by increasing Ed and the some of results are shown in Fig. 4.



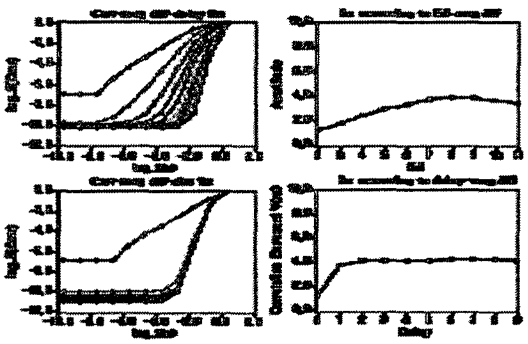
(a) Correlation integral and ν_m of *Pt* of defect I



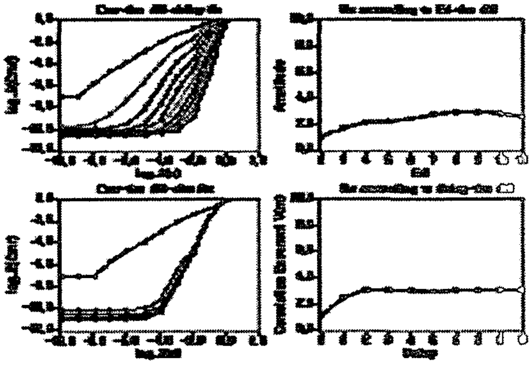
(b) Correlation integral and ν_m of *Vt* of defect II



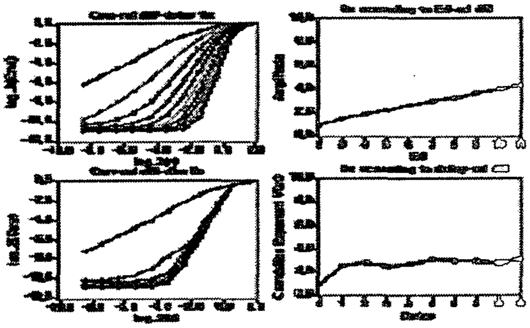
(c) Correlation integral and ν_m of *Pt* of defect III



(d) Correlation integral and ν_m of *Pt* of defect IV



(e) Correlation integral and v_m of *Tt* of defect V



(f) Correlation integral and v_m of *Vt* of defect VI

Fig. 4 correlation integral and v_m for each defects

4. Conclusion

Throughout the work, qualitative and quantitative properties related to the PD signals from different defects are analyzed by use of attractor in phase space, information dimensions (*Do*and *D2*), Lyapunov dimension (*DL*) and K-S entropy (*K*) as well. Based on these results, it could be pointed out that the time series from different defect seems to have different quantitative values according to the nature of defect. Shortly, a few remarks can be pointed out from results:

(a) From the result of 3-dimensional attractors and *Do* values in the phase space, it can be deduced that *Vt* of defect I has a point attractor and is not a fractal and *Tt*of defect I has a few point of basin in its phase space and has not a fractal structure in its phase space. Therefore, it can be noted that further chaotic analysis is not meaningful for these time series from defect I. Meanwhile, defect I has distinctive qualities from other defects in qualitative and quantitative properties.

(b) Thus, it can be said that the PD phenomena in the power apparatus is not merely random process but the chaotic process possessing obscure regularity behind its randomness

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