Partial discharge classifier based on wavelet theory

Yuxin Yun1,*, Xiaoxiao Zhao2 and Yanjie Zhang2
1State Grid Shandong Electric Power Research Institute, Jinan, China
2State Grid of China Technology College, Jinan, China

*Corresponding author e-mail: 15966635503@139.com

Abstract. The excursion of fractal parameters is the main obstacle to the application of classifiers trained by fractal-parameter-based features. In order to solve this problem, the characteristics of fractal parameters are studied based on partial discharge ultra-high-frequency signals mathematical models. One solution to this problem based on symlets wavelet has been put forward. And the result of implementation to signals with different signal-to-noise-ratio shows that it’s a promising approach to expand the applicability of the classifier.

1. Introduction

Usually, the test of partial discharge (PD) fault in gas insulated substation (GIS) is operated in the laboratory where the noise level is relatively stable. Because of the excursion of fractal parameters caused by the difference of signal to noise ratio (SNR) of input signals, the classifier trained by the data obtained through PD experiment in laboratory can only be applied at some certain noise level [1-3]. What’s more, it is difficult to simulate the actual GIS electromagnetic environment in the laboratory. Therefore there are some problems in getting PD signals with same noise content as the actual PD signal in GIS. On the other hand, it’s easy for simulation study to gain the demand signals, but the excursion of fractal parameters is still the problem that restricts the translation from theory to practice.

This paper is divided into two parts. Firstly, mathematical model of the PD ultra-high frequency (UHF) signal in GIS is analyzed with the study of computation methods of fractal dimension and lacunarity. Secondly, a solution method of restrain the excursion of fractal parameters of PD signals in GIS is proposed.

2. UHF signal mathematical models of PD fault in GIS and the fractal parameters

The mathematical models of UHF signals of PD fault in GIS are the foundation of the simulation research of GIS PD faults and its pattern recognition [1]. And the excellent performance of the fractal theory in feature reduction has made it widespread used in pattern recognition.

2.1. Mathematical models for simulation study

The researchers of literatures [1, 2] have done much work on the modeling of the UHF signal of GIS PD faults. And the studies show that several types of PD signals captured by sensors are quite different from each other, but they will become much more similar after normalized. In this paper, the methods mentioned in references [1, 2] are adopted to build the normalized mathematical model of the PD UHF signals caused by several typical GIS insulation defects, and the simulation result is shown in Fig. 1.
The correctness of the mathematical model obtained has been proved in references[1-3]. Moreover, in order to simulate the actual signal input of the pattern recognition system (as shown in Fig.1) in a better way, some white noise is usually added into the mathematical model. Take the PD signals caused by electrode gap defect for example, the simulating waveforms are shown in Fig.2.

According to the nature of the signals, different types of signals are defined as follows:

Type N: caused by the defect of needle protrusion fixed to the conductor; Type P: caused by free metal particles defect; Type M: caused by the defect of metal contamination of the insulator and Type G: caused by electrode gap defect.

All the signals used in this paper are obtained from the adjusting of the mathematical models, except for the parameters of the first discharge wave crest.

2.2. The computation methods of fractal parameters

2.2.1. Box dimension. Box dimension method is also called the covering method. Define the used box size as $\delta$, the corresponding number of box needed to cover the waveforms as $N(\delta)$, As mentioned in the reference [4], the relationship between $\delta$ and $N(\delta)$ is:

$$N(\delta) = L_0 \delta^{-D}$$  \hspace{1cm} (1)
where \( L_0 \) is constant. Obviously \( N(\delta) \) has a negative power law relationship with \( \delta \).

And (1) can be rewritten as:

\[
\log N(\delta) = \log L_0 - D \log \delta
\]

(2)

The box dimension \( D \) can be estimated by doing the least square fit on \( [\log(\delta) - \log(N(\delta))] \).

2.2.2. Lacunarity. Because the fractal dimension alone is insufficient for purposes of discrimination, Mandelbrot introduced the term called lacunarity \( \Lambda \), which quantifies the denseness of an image surface [5].

VOSS defines lacunarity \( \Lambda \) as follows [6]:

\[
\Lambda(\delta) = \frac{m^2(\delta) - (m(\delta))^2}{(m(\delta))^2}
\]

(3)

where

\[
\begin{align*}
& m(\delta) = \sum_{m=1}^{M} mP(m, \delta) \\
& m^2(\delta) = \sum_{m=1}^{M} m^2P(m, \delta)
\end{align*}
\]

(4)

\( M \) is the number of possible points within the box, \( P(m, \delta) \) is defined as the probability that \( m \) points existed within a box of size \( \delta \), in which case a point is centered on the image surface. \( P(m, \delta) \) is normalized as below, for all \( \delta \).

\[
\sum_{m=1}^{M} P(m, \delta) = 1
\]

(5)

It can be found that both the lacunarity and box dimension are the functions of the box size \( \delta \). According to the gathered effects of fractal parameters, 43.84 sampling intervals are used as the solution size of lacunarity in this paper. When the same size of box is used, the more severe the signal changes, the bigger the box number \( N \) becomes. As well as the box dimension. Then it can be concluded that the box dimension can describe the noise level of the signal to a certain degree.

3. The influence of Wavelet denoising technique to the excursion of fractal parameters

Mathematical model is idealized and abstracted from actual signal, usually there are certain deviations with the actual situation. A certain amount of noise is often added into the mathematical model to simulate the actual signal. But the amplitude and frequency of the noise differs greatly in different environment, so it is difficult to take noise information into consideration. In addition, noise has a great influence on the distribution of fractal parameters which is widely used in feature extraction. And the excursion of fractal parameters caused by white noise signal worsens classification effects of fractal parameters greatly, which leads the simulating research at loose ends. This chapter focuses on the influence of input signal’s SNR to the distribution of its fractal parameters and a solution based on wavelets transfer theory is put forward.

3.1. Relationship between input signal’s SNR and the distribution of fractal parameters

Different fractal features are extracted from those signals whose SNR is 17dB, 15.2dB, 14dB and 13dB, and the results are shown in Fig. 3. Because of the big differences among the PD signals caused by high voltage conductor metal protrusions insulation defects, free metal particle flaws,
insulator metal pollution defects and insulator gap defects, it is easy to tell apart if some other features are added. So in order to discuss their gathered effects, we draw them in different diagrams.

And the fractal parameters as signal SNR by large to small are gathered in the chart from left to right.

From Fig. 3, it’s easy to observe that with the improvement of the noise level of the signals, the box dimension of PD signals begin to increase. And the fractal feature at different noise levels appears to be gathered in different areas. We train a three layer-BP neural network classifier based on the partial discharge signals whose SNR is 14 dB, with each layer of the network having six neurons. In addition, features used in neural network training include the similarity between the input signal and the four standard fault signals, fractal parameters of the input signal itself (box dimension and lacunarity). Altogether, there are six features. Every classifier is tested and the result is shown in Table 1.

![Fractal parameters' distribution of polluted PD UHF signals in GIS](image)

**Figure 3.** The fractal parameters’ distribution of polluted PD UHF signals in GIS.

| SNR | 17dB | 15.2dB | 14dB | 13dB |
|-----|------|--------|------|------|
| Type N | P | N | N | N |
| Type P | P | P | P | P |
| Type M | M | G | M | M |
| Type G | P | G | G | M |

Obviously, the obtained BP neural network classifier obtained is unable to work properly, when the noise level of the signal input for the pattern recognition system changes.

It is concluded that the fractal parameters of PD UHF signals with different SNR have different gathered areas, therefore it is difficult to design a unified and excellent classifier based on the fractal parameters at a certain noise level. That is to say, the designed classifier based on signals with certain SNR is not applicable to other conditions (signals with different SNR).

### 3.2. Symlets wavelet and its application in restraining the excursion of fractal parameters

If the fractal parameters of signals at different noise levels have similar aggregation effect with signals under same SNR by some kind of processing, the design of classifier will be greatly simplified, and its range of application will be extended greatly. At the same time, the problems will also be readily solved. Therefore we have a variety of signal processing methods tested and find that the wavelet denoising method can make this idea into reality.

Symlets wavelet is a kind of discrete sequence wavelet transforming method based on multiresolution analysis and the theory of sampling filter. The first person who put forward the theory is Inrid Daubechies, and it is an improvement for Daubechies (db) wavelet. Symlets wavelet method is based on time domain compactly supported orthonormal wavelets, and it retains the advantages of db wavelet and indicates better symmetry, which makes it successfully avoid signal distortion in signal decomposition and reconstruction[7]. Symlets wavelet is usually expressed as sym \( N \) ( \( N = 2, 3, \ldots, 8 \)).
When making decision, the performance and filter length factors should be considered, such as the discontinuity of symlets wavelet filters; the shortage of symlets 2 wavelet filters, and the vulnerability to the outside impact[8].

The general process of wavelet de-noising method can be described as follows. First, the input signal is decomposed; Second, threshold of the high frequency coefficient is quantified; Third, the signal is reconstructed in use of low frequency coefficient and the handled high frequency coefficient[9].

In this paper, symlets wavelets function is used to decompose the input signals into five layers. the principle of minimaxi is adopted to choose the soft threshold and adjust the threshold according to the high frequency coefficient of each layer. So that the input PD signal is denoised automatically. The fractal parameters of the signals in chapter 3.1 handled in this way are shown in Fig. 4.

Obviously, the fractal parameters of PD signals denoised by wavelet de-noising method have good clustering effects. It seems that wavelet de-noising method is a good way to solve the migration phenomenon of fractal parameters among signals with different SNR. In order to test its performance in the classifier designing, the denoised signals of 14dB SNR is used to train the same BP neural network classifier as chapter 3.1, with same features. The trained classifier identifies signals with different SNR and the signals has been denoised by wavelet de-noising method. The identification results are shown in Table 2.

From above, it is easy to conclude that wavelet denoising can transform the partial discharge signal from inferior level of the different signal-to-noise ratio to the same noise level. So that pattern recognition research of partial discharge signal at one single noise level can be conducted. Only after some processing of the partial discharge signals of other noise level, it can be put into the same classifier for classification.

Pattern recognition obtained by this method can be put into application only after addition of the same digital filter link in the actual system and some simple adjustments, which will greatly reduce the development difficulty, time and cost. At the same time, all sorts of filtering method can only deal with the signal within a range of SNR. When out of the range, it will lead to signal distortion, causing the similarity coefficient characteristics effect worsen. As a solution, we need to extract other features to ensure the accuracy of training. So it is necessary to improve the application of wavelet transform to enlarge its working range of SNR.

| Type  | Input SNR | 17dB | 15.2dB | 14dB | 13dB |
|-------|-----------|------|--------|------|------|
| Type N| P         | N    | N      | N    | N    |
| Type P| P         | P    | P      | P    | P    |
| Type M| M         | G    | M      | M    | M    |
| Type G| G         | G    | G      | G    | G    |

Table 2. Result of classification

![Figure 4. The fractal parameters’ distribution of denoised UHF signals of PD fault in GIS.](image-url)
4. Conclusion

Wavelet denoising method can cluster fractal parameters of the PD signals with different SNR, which makes the designed classifier’s application range more extensive. Through adding the same digital filter link in the actual system, the designed classifier can be put into practical application only after some small adjustments, which can decrease the differences between the theoretical results and the practical applications. Fractal parameters can reflect the noise content of signal to a certain extent, and the good filtering effect can be got when they are used as feedback parameters of digital filter. In order to obtain round-up effect of the fractal parameters, some other parameters should be added to control filter parameters together.

References

[1] Ju Tang, Qian Zhou, Zhongrong Xu, Mingjun Liu and Caixin Sun, “Establishment of Mathematical Model for Partial Discharge in GIS using UHF Method,” Proceedings of the CSEE, Vol.25, No.19, 2005, pp.106–110.
[2] Qian Zhou, “Study on Mathematical Model and Pattern Recognition for Ultra-high Frequency Partial Discharge signals in GIS,” Chong Qing: Chongqing University, 2007, pp.23-29.
[3] L. Satish and W.S. Zaengl, “Can Fractal Features be Used for Recognizing 3-d Partial Discharge Patterns?” IEEE Transactions on Dielectrics and Electrical Insulation, Vol.2, No.3, 1995, pp.352–359.
[4] S. Chen, J. M. Keller and R. M. Crownover, “On the Caculation of Fractal Features from Images,” IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol.15, No.10, 1993, pp.1087-1090.
[5] B. B. Mandelbrot, The Fractal Gemetry of Nature, Freeman, New York, 1983, pp.86-95.
[6] R. F. Voss, “Random Fractals: Characterisation and Measurement,” in Scaling Phenomena in Disordered Systems, eds. Roger Pynn and Arne Skjeltrop, New York: Plenum, 1985, pp.1-11.
[7] C. H. Kim, H. Kim, Y- H. Ko, S. H. Byun, R.K. Aggarwal, and A.T. Johns, “ A novel fault-detection technique of high-impedance arcing faults in transmission lines using the wavelet transform,” IEEE Trans. Power Del., Vol. 17, No. 4, 2002, pp. 921-928.
[8] Zhongwei Li, Li Cheng and Weiming Dong, “Study of Symlets wavelet amplitude algorithm,” Electric Power Automation Equipment, Vol.29, No.3, 2009, pp.102-107.
[9] Jiecheng Xie, Dali Zhang and Wenli Xu, “Overview on Wavelet Image Denoising,” Journal of Image and Graphics, Vol.7(A), No.3, 2002, pp. 207-217.