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Study of signal processing and feature extraction method for partial discharge in subway DC cables

***Abstract**. In the contribution, some preliminary work on insulation subway cable was reported. Accordingly, the paper mainly deals with two problems, focusing on denoising algorithms, associated with various outside interferences existing in the field, and feature extraction method, regarding the evaluation and diagnosis results. Three distinctive categories of interferences were classified, 4 time interval based discharge diagrams were formed, 22 statistical operators were calculated out and further fingerprint of DC discharge was constructed.*

***Streszczenie.** W pracy analizowano izolację podziemnych kabli DC. Opracowano algorytm odszumiania wpływów interferencji zewnętrznych pól elektromagnetycznych. Przedstawiono główne kategorie interferencji, zaproponowano statystyczne operatory do ekstrakcji danych. (**Przetwarzanie sygnału i ekstrakcja danych w podziemnych kablach DC**)*

Keywords: partial discharge, signal processing, feature extraction
Słowa kluczowe: wyładowania niezupełne, przetwarzanie sygnałów.

Introduction

The DC feeder cable was one of the key devices for the safety operation of subway system, and its insulation condition affected the power supply of rail traffic greatly. It was well known that partial discharge (PD) was the most effective means discovering the insulation defect before it came down. And by detecting the DC PD occurring in subway cable and analyzing the PD data, we could monitor the insulation condition continuously and take necessary measures preventing it from break down [1]. In the contribution, a preliminary investigation of issues existing in PD monitoring of subway DC cable was carried out. The issues could be classified into two main categories: one is signal processing and the other feature extraction. In the subway cable operation field, there existed various outside interferences, involving discrete spectrum interference (DSI), white noise as well as pulse-shaped Interference, resulting from radio broadcast, rectifying equipments, etc. PD was electrical phenomena with weak energy density, usually overwhelmed by noise. Therefore, for analyzing the PD data with relatively reliable results, the outside interferences must be suppressed to an acceptable level[2]. In addition to this, DC PD was significantly different from alternating current (AC) PD, classical phase resolved PD pattern (PRPD) was no more applicable, and features reflecting the essence of PD must be extracted [3,4].

The organization of this contribution is as follows. Section 2 gives a short introduction to PD online monitoring system. Section 3 explains the signal processing procedure and how to suppress the various interferences. Section 4 discusses the time resolved PD diagram and feature extraction method. And the final section draws the conclusion and points out the work in the future.

PD online monitoring system

PD is the cause of insulation deterioration and aging. PD in DC cable is closely related to insulation material, and it can characterize the internal defect and reflect the potential weak spot. Detection of PD is based on various physical phenomena occurring in the discharge process. For the subway DC cable, which is direct buried without armor in Shanghai City, PD is detected from the cable by installing a high frequency current transducer (HFCT) around the out sheath. Fig.1 illustrates the basic principle that is used for PD detection[5].

PD signal is originally detected by PD sensor, or HFCT, and then it is pre-filtered, which was aimed at suppressing some circumstance interference with large magnitude. The pre-filtering procedure is usually carried out by a analogy band-pass filter with the frequency scope falling in our interests. The filtered signal is reshaped before it is transmitted to data acquisition unit (DAC). Data acquisition unit consists of two parts: channel deploying unit and A/D convertor. The former is used to deploy the multiple data streams and the latter digitize the PD data. Therefore, digitized PD signal is sent to the monitoring center and tend to be analyzed.

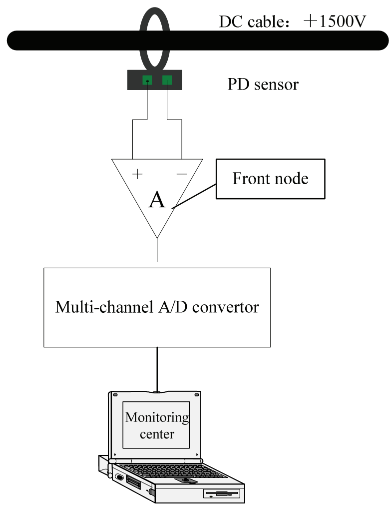

Fig.1. Principle of PD detection system for DC cable.

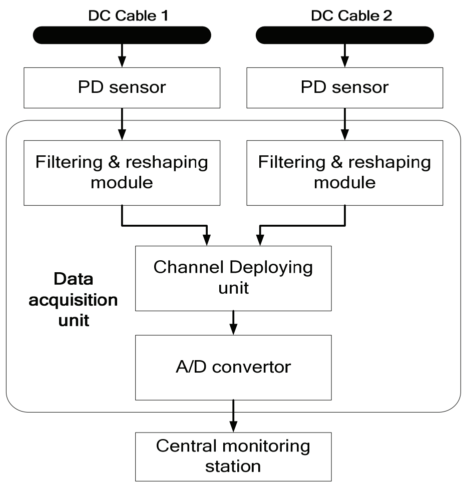

Fig.2. Scheme of PD detection system.

The monitoring system operating on site was illustrated as Fig.3.

Fig.3. Online PD monitoring system for subway cable.

Signal processing of PD data

The interferences existing in the field involves three typical categories: DSI, white noise and pulse-shaped interference.

DSI usually come from radio, communication system, etc. Its distinctive feature is that, after Fast Fourier Transform (FFT), it converges in a finite narrow band in the frequency domain.

White noise commonly results from electronic devices, etc. Its amplitude is random and its frequency spectrum scatters widely.

Pulse-shaped interference is usually generated by rectifying equipments. The research results showed that rectifying pulses had good periodicity and synchronously, appearing in all parallel cables.

The flowchart of signal processing of PD data is depicted in Fig.4.

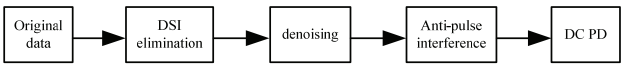

Fig.4. Procedure of PD pulses extraction.

The characteristic of aforementioned three kinds of interferences are obviously different. Numerous research results have shown that, it is impossible to remove all these interferences with just one algorithm. Instead, to suppress the interference to an acceptable level, more than one method should be adopted. And therefore, for certain interference, corresponding effective algorithm should be used. Besides, it should be emphasized that the sequence of suppressing these three kinds of interferences should follow this rule: firstly, eliminate DSI, next, suppress white noise, and finally, remove pulse-shaped interference.

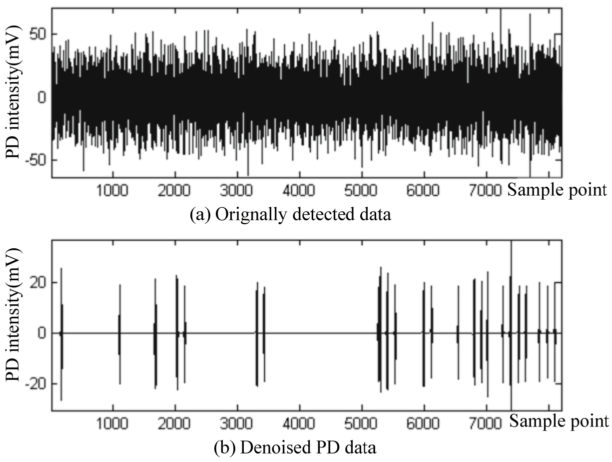

Fig.5. Denoising of PD data.

The DSI should be eliminated at first, because the amplitudes of DSI are usually far higher than useful PD pulses. The common methods for DSI suppression reported previously include FFT based algorithm, FIR filtering, IIR filtering, wavelet based scheme, adaptive filtering, etc. Among all these methods, the most used is FFT based algorithm, which is a simple FFT procedure incorporated with a frequency window for selecting the main frequencies of DSI and cancelling them.

Next, we should consider how to suppress the white noise. Thanks to the birth of wavelet, we can solve this problem easily, with a properly selected mother wavelet function and a thresholding method reported. In most cases, the performance of wavelet based thresholding method is satisfactory.

The final step is to remove pulse-shaped interference. Pulse-shaped interference is the most difficult to treat with, for it shows similar characteristics to PD pulses, both in time domain and frequency domain. Until now, many efforts have been devoted to this trouble, however, with little achievement to our knowledge. For the moment, the commonly used method is to use a shifting time window cancelling the pulses falling in the window and keeping the rest. In addition to this, statistical method is usually adopted, due to the significant difference between the repetition rate of PD pulses and stochastic interference pulses.

After completing the anti-interference procedure, now, we can obtain the relatively pure PD data (see Fig.5) and it is time to extract PD pulses for sequent analysis.

Feature extraction of DC PD

A Time resolved PD diagram

For AC PD, distributions and density functions of the basic parameters q and Φ (charge and phase) are used to describe and discriminate patterns from various defect types. For DC PD, the basic parameters q and Δt have been used to build distributions and density functions. The following distributions were created [6]:

1. Hn(Δt), indicating the number of PD pulses observed as a function of Δt, the time interval between successive discharges
2. Hqmax(Δtpre) and Hqmax(Δtsuc), representing the maximum PD magnitude as a function of Δtpre or Δtsuc,
3. Hqn(Δtpre) and Hqn(Δtsuc), describing the mean PD magnitude as a function of Δtpre or Δtsuc, and
4. H(q), representing the discharge density.

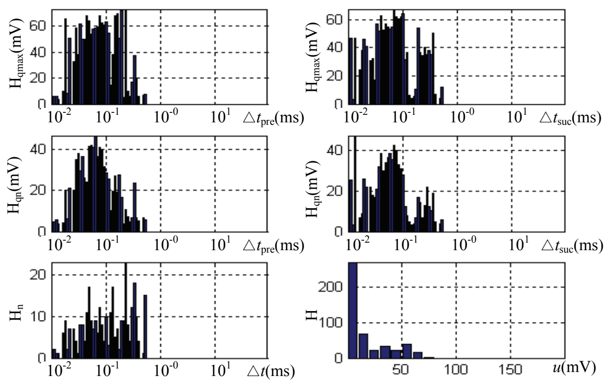

Fig.6. Distributions of q and Δt, used for describing PD pattern.

B Construction of DC PD fingerprint

Fig.5 gives examples of a set of these distributions.

The distributions in Fig.6 each have a characteristic shape correlated to the defect type. These shapes can be described by a set of statistical moments. These moments are identical to those used in ac discharges, including *skewness*, *kurtosis*, *asymmetry*, etc. A set of 22 statistical operators is calculated and forms a fingerprint of the discharge [6], as listed in Tab.1. Fig.6 shows the fingerprint of discharges in cable, the distributions for which are illustrated in Fig.5.

Table I Statistical parameters of DC discharge diagram

Statistical operator	Discharge diagram			
	$H_{qmax}(\Delta t)$	$H_{qn}(\Delta t)$	$H_n(\Delta t)$	$H(q)$
Sk-pre	√	√	√	√
Sk-suc	√	√		
Ku-pre	√	√	√	√
Ku-suc	√	√		
Pe-pre	√	√	√	√
Pe-suc	√	√		
Asy	√	√		
cc	√	√		

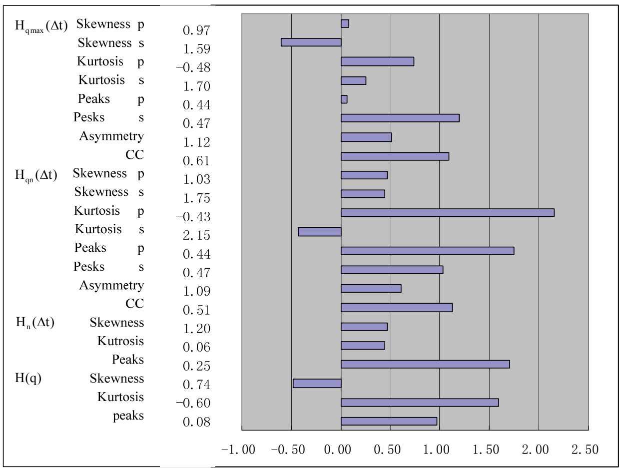

Fig.7. Fingerprint of the discharge source for the distribution.

Conclusion

PD detection and analysis is indispensable for insulation condition control. This article introduced some preliminary investigation of PD monitoring in 1500V subway DC cables.

a) An online PD monitoring system was developed and put into trial.

b) Basic methods concerning PD signal processing and feature extraction was investigated.

Based on the above work, future work on signature bank of typical defect in cable can be established

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