

Research Article

Research of PD on-line Monitoring System for DC Cable

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Abstract: In order to monitor the insulation of XLPE cable of rail system, an On-line Partial Discharge (PD) Monitoring System applied for 1500V DC cables of Shanghai Traction Substation is described, including its hardware and software structure. After installed, this system successfully detected one PD signal. The results demonstrated that this system worked stably and reliably.

Keywords: DC cable, on-line monitoring, partial discharge, traction substation

INTRODUCTION

Rail transportation, one of the public transportation tools, is directly related to the safety of passengers. Many factors influence its operation safety. Power supply is one of the main factors and its key system is DC power supply. Thus monitoring the safety status of DC cable is very important. Partial discharge is the main reason of the cable insulation aging. On-line PD signal monitoring is an effective method for diagnosis of cable insulation (Zhou *et al.*, 2009; Haiqing *et al.*, 2009). Common Partial discharge detection methods include differential, directional coupling and electromagnetic coupling. The electromagnetic coupling method does not have to set a coupling capacitor in the high-voltage side to obtain PD signal, so measuring circuit does not have direct electrical connection, which can successfully suppress noise (Ming-Jie and Yan, 2012). This system detects partial discharge signal in the method of electromagnetic coupling, aiming at evaluating the cable insulation condition.

This system uses the wideband current sensor and high-speed data acquisition card to obtain partial discharge signals; uses the data system and the analysis and diagnosis system for acquisition and control of signals and analysis of data; finally make a comprehensive evaluation on discharge of the cable and give an effective warning of the cable which is possible to have insulation problems.

HARDWARE OF SYSTEM

Figure 1 shows the hardware structure of the on-line discharge monitoring system for subway DC cable. The system is divided into three parts including the

wideband current sensor, signal distribution box and server. The wideband current sensor is installed in the underground cable. The signal distribution box and server are installed in the collection server cabinet in control room.

Wideband current sensors: As in Fig. 2, the wideband current sensor is installed in the underground cable. The sensor's structure looks like pliers, bringing convenient disassembly and installation. Usually, six cables make up a group, each of them covered by a current sensor. There are five groups in total. The sensor has internal electromagnetic coupling magnetic core and amplifying and filtering module. Because the band of city rail DC cable discharge signal is wide, ranging from tens of kHz to tens of MHz and there is large amounts of broadcast interference signal (Feng *et al.*, 2006; Hashmi *et al.*, 2011), this system choose the Rogowski Coil to acquire partial discharge signals in its band. Amplifying and filtering module has 2 built-in analog switches. It has a function of 4-level amplifying. Based on the amplitude of sampling signal, we can magnificate it by software either 10 times or 100 times.

It greatly simplifies the front-end acquisition module and improves the stability and reliability of the system to integrate magnetic core and amplifying and filtering module with the sensor. Figure 3 shows the amplitude-frequency characteristic curve of sensor. The sampling frequency band of sensor is 1.6 to 10 MHz. The amplitude-frequency response curve is flat in this band, consistent with the need of system monitoring.

Signal distribution box: Figure 4 shows the hardware function of system. The number of subway substation cable is generally 25 or so. In order to leave some margin and prevent emergency of monitoring lines, the

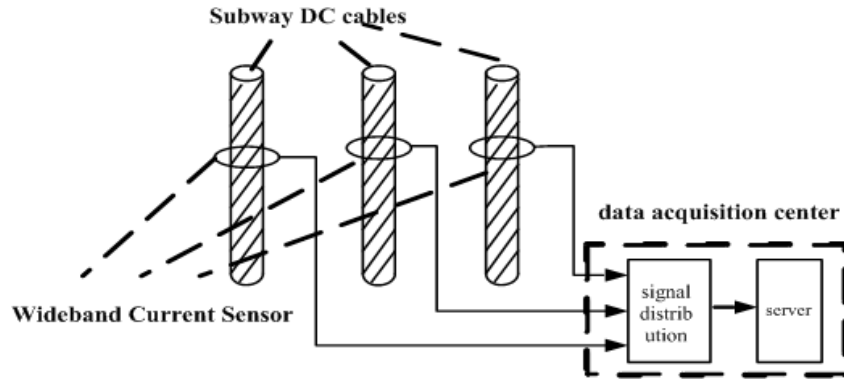


Fig. 1: System hardware structure



Fig. 2: Sensors' installation diagram

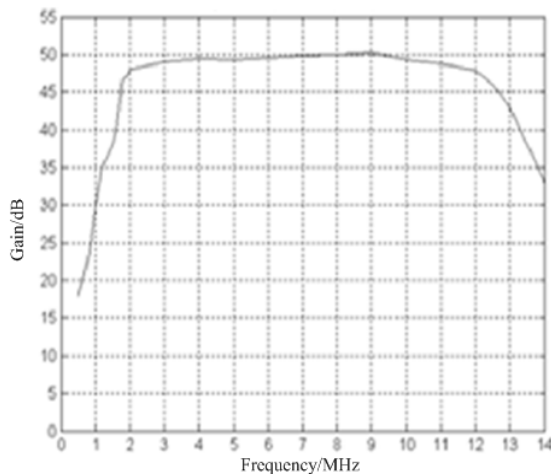


Fig. 3: Amplitude-frequency characteristics of sensor

hardware system is designed with 30 cables. At present, the system can support up to 30 partial discharge signal acquisition. In order to simplify the structure of system and reduce the cost, we use only 1 piece of 4-route high-speed data acquisition card, we need signal distribution box to allocate channels for 30 discharge signals. Each time 4 channels of signals are transmitted.

There are 5 analog switches in signal distribution box, controlling 30 channels, respectively. The analog multiplexer is controlled by the background software through the parallel port. Four channels of signal are transmitted to the data acquisition card each time.

Server: As in Fig. 4, high-speed data acquisition card is installed in the server. Acquisition card has 4 mutually-independent A/D conversion channel, processing the amplified analog signal in digital way and storing the results in a memory. Channels synchronize with each other by clock and trigger bus. This method can ensure each channel to be triggered and recorded at the same time.

Background processing software reads data from the specific channel through system bus and controls the parameters and state of acquisition channel.

The server cabinet is installed on the scene as in Fig. 5: The partial discharge signal collected by current sensor is transmitted through shielding line to the signal distribution box and server for processing.

SOFTWARE OF SYSTEM

The online cable monitoring software system is composed of data acquisition and control system and the analysis and diagnosis system. The whole structure is shown in Fig. 6.

Data acquisition and control: Data acquisition and control system mainly includes parameter setting, sampling control and self-diagnosis module.

Parameter setting module has a function to set parameter, data storage format, path and so on.

Sampling control module is mainly used to complete the communication between computer and data acquisition card, controlling the sampling channel of acquisition card and executing the corresponding sampling command.

Self-diagnosis module is responsible for monitoring server and network. When the system is abnormal, it reset immediately and automatically.

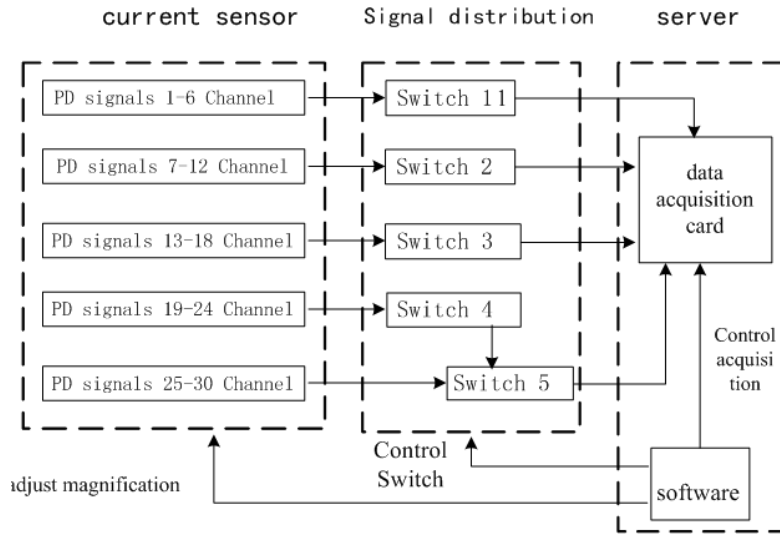


Fig. 4: Hardware function block diagram



(a) Face

(b) Back

Fig. 5: On-site installation of monitoring center

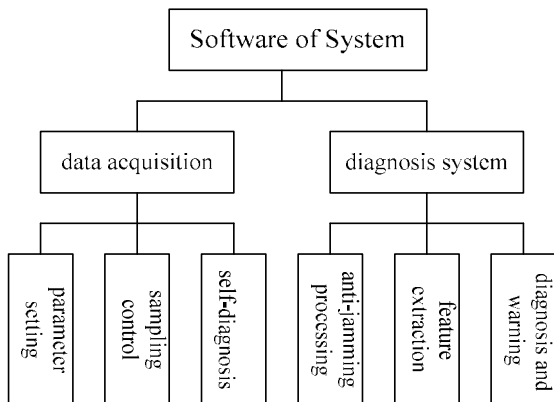


Fig. 6: System software structure

As in Fig. 7, a display interface for data acquisition and control program is used to display the time domain waveform, data file information and sampling state of sampling data. Each data file has its corresponding specific cable. Click the file name and the interface will display the corresponding time domain waveform of sampling data.

Data diagnosis and analysis: Data analysis and diagnosis system mainly includes the anti-jamming processing, feature extraction, diagnosis and warning module.

- **Anti-jamming processing:** Anti-jamming processing module is mainly used to suppress the

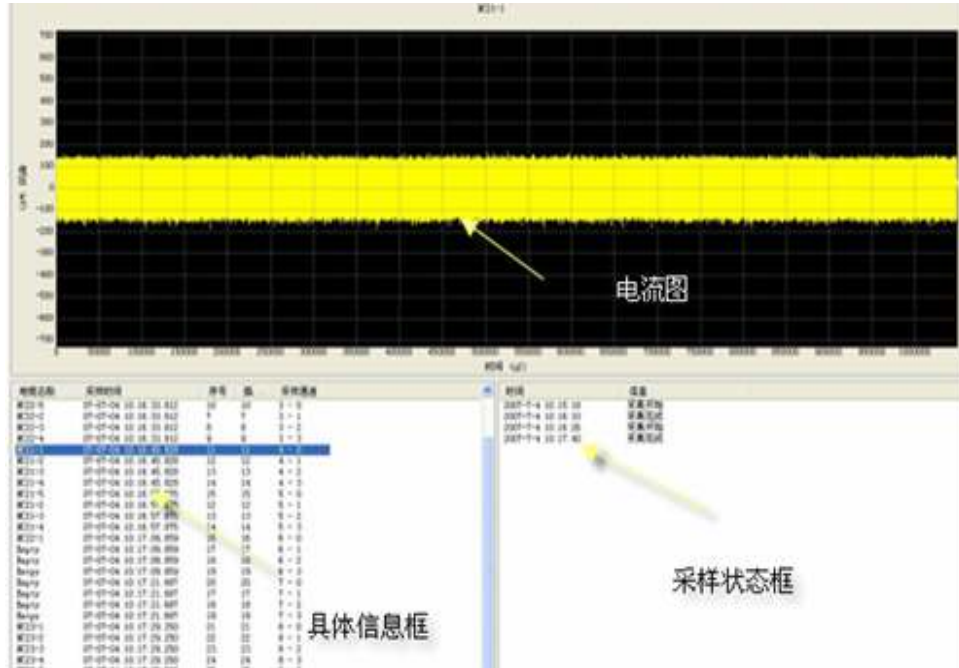


Fig. 7: Data acquisition program window

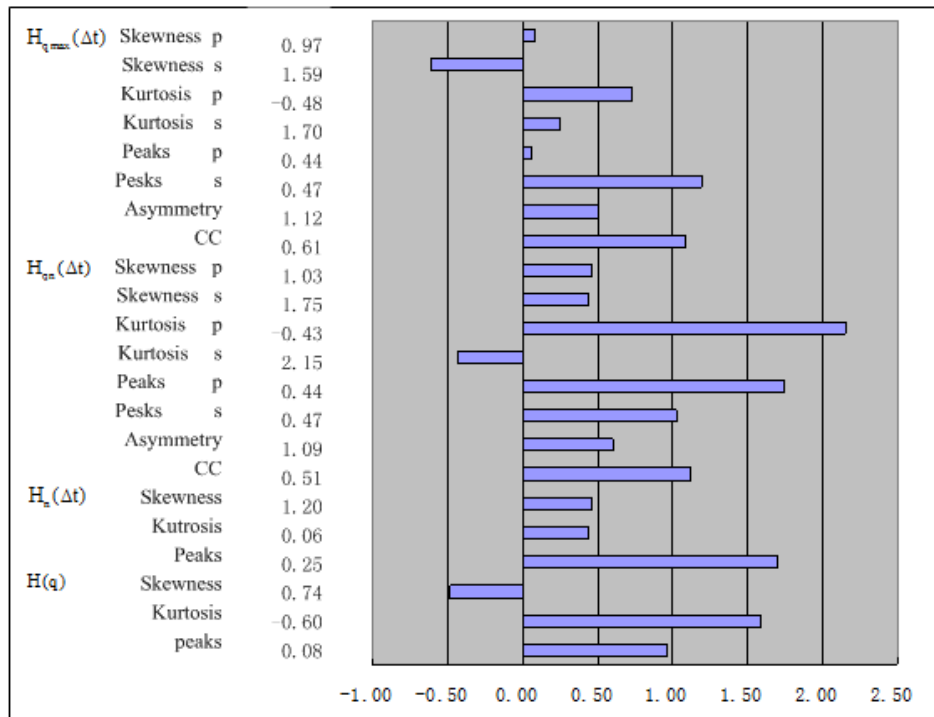


Fig. 8: Fingerprint of DC partial discharge

background noise and line coupling noise in original testing data.

Varieties of noises exist in the PD monitoring field. Typical interferences are divided into three categories: white noise, discrete spectrum interference and pulse

interference. These interferences have huge difference in time-frequency characteristics between them. It is tough to eliminate the interference with a single method, so different filtering methods should be used according to the type of interference (Fan and Cai, 2007). Therefore, this system uses three techniques of

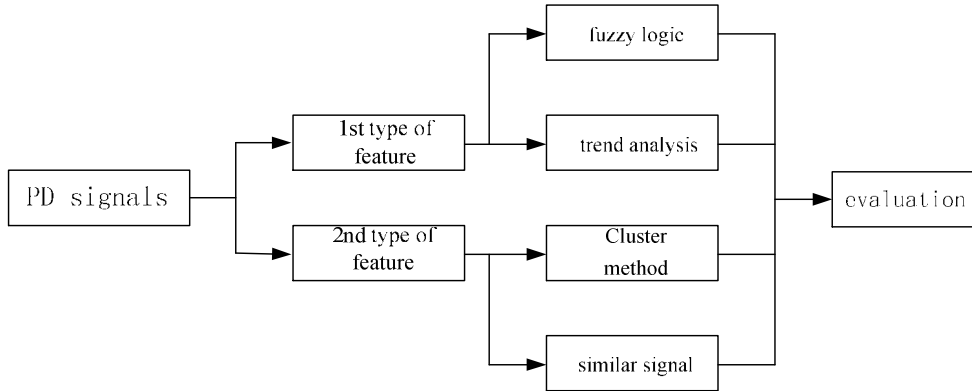


Fig. 9: Flow chart of PD diagnosis

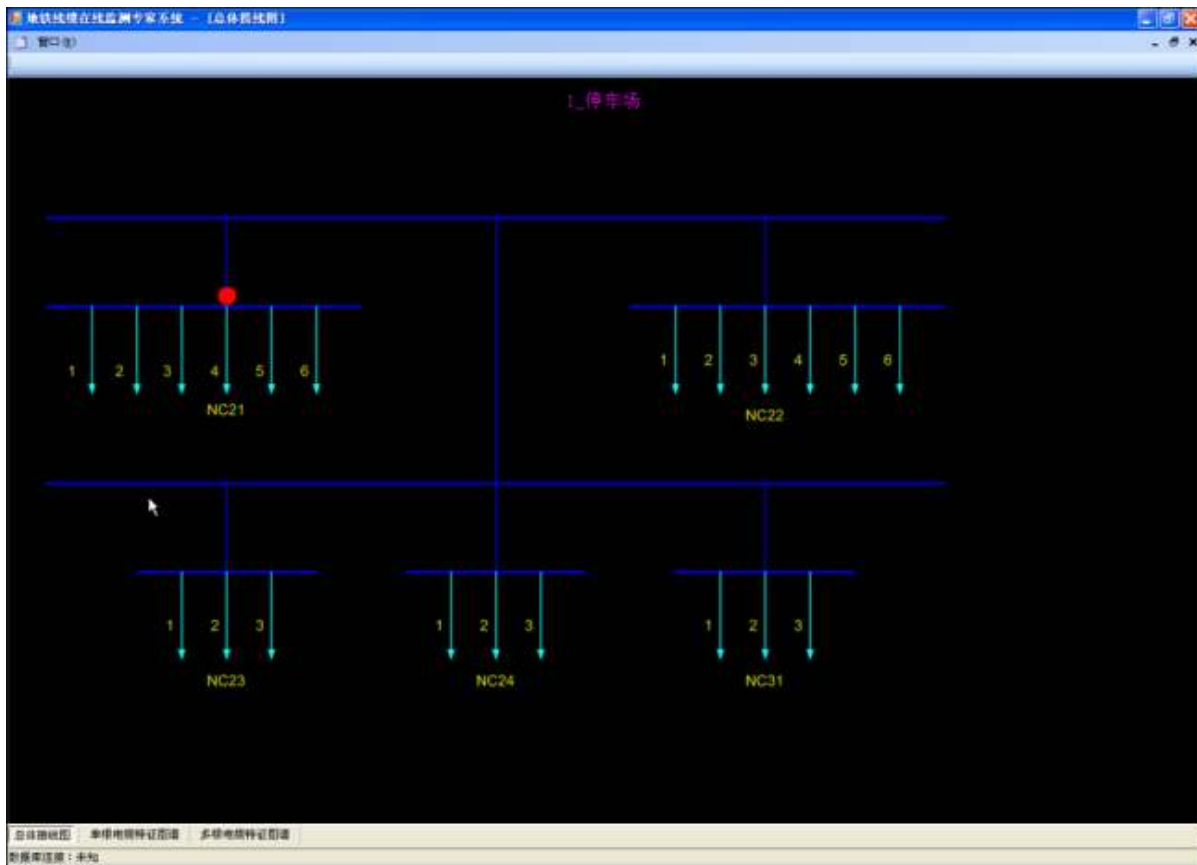


Fig. 10: Alarm window of the monitoring system

wavelet filtering, FFT filtering and neural network filtering to, respectively suppress the typical interferences.

- Discharge feature extraction:** At present, the online monitoring system for subway cable partial discharge extracts two PD characteristic parameters. The first one measures the discharge level, mainly used to analyze the development trend of discharge. In total, 9 feature parameters are extracted, including the maximum value, the

average value of discharge pulse and pulse number etc. The second one shows the discharge mode, mainly used to analyze the stability of discharge mode. In total, 22 feature parameters are extracted, including skewness and projection etc., used to build the PD fingerprint, as in Fig. 8.

- Diagnostic assessment and prewarning:** The diagnosis and treatment of PD is fairly complex, requiring a combination of professional knowledge and intelligent diagnosis techniques. Years of research shows that, in current condition, it is

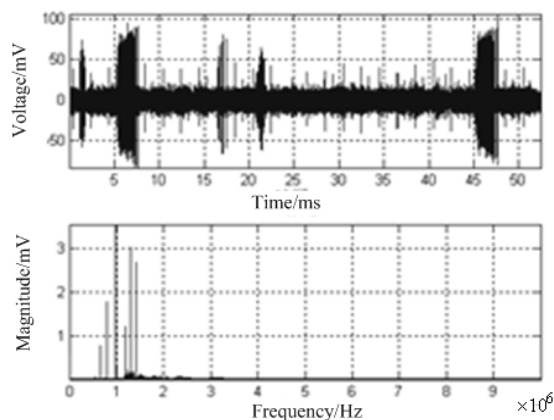


Fig. 11: PD signal and its frequency spectrum

impossible to use a single method to complete partial discharge diagnostic task. A variety of technology is needed to build a comprehensive diagnosis system.

In order to get more accurate evaluation results, we need to analyze two kinds of feature parameters separately, as in Fig. 9. The first type of feature parameters is mainly used for trend analysis, combined with fuzzy logic to evaluate the severity and determine the stability of the discharge level. The second type of feature parameters is mainly used for similarity analysis, combined with clustering method to cluster and analyze similar signal and determine the stability of discharge mode.

According to the final evaluation conclusion, monitoring system send warning information for cables that exceed the alarm threshold. As in Fig. 10, red dots, which appear in the monitoring alarm interface, indicate that a cable may have problem in insulation and it needs further safety inspection.

SITE OPERATION

At present, the subway DC partial discharge online monitoring system designed by our research group have been successfully installed in several Shanghai subway traction substations. According to the survey, they are running in good condition. During the operation of monitoring system, it successfully detected discharge abnormal signals in one cable. The time-domain waveform and spectrum are shown in Fig. 11. After on-site inspection, cable insulation deterioration was confirmed. Then workers replaced the cable and the display of monitoring system recovered.

CONCLUSION

Good site operation condition proved that this system can realize online monitoring of the cable insulation state, greatly reducing the security risks of power supply system.

This system has the following characteristics:

- Integration of amplifier and sensor simplifies the installation process and effectively improve the reliability of front running.
- Synchronous acquisition of 4 channels can support online monitoring of 30 cables, fully able to meet the current needs of Shanghai subway station cable monitoring.
- Comprehensive use of various intelligent algorithms on cable discharge diagnosis can give effective early warning information of the cable which has insulation problem, ensuring the safety of power system operation.

ACKNOWLEDGMENT

This study is supported by National High Technology Research and Development Program (863 Program) under Grant No. SS2012AA050803.

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