The Development of Mobile On-line Partial Discharge Monitoring System of XLPE Cable

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Abstract. The existing on-line monitoring systems of cable are poor in mobility, cost performance and networking mode. Aiming at these deficiencies, a mobile on-line partial discharge monitoring system of XLPE cable is designed and developed in this paper. Besides the analysis of partial discharge pulse and diagnosis for cable insulation, the system features on flexible networking modes. The paper describes the hardware theory, development process details and significant parameters. And the architecture and interface of the system’s software are also demonstrated. A series of test and installation proves that, this is a flexible, stable, reliable system which can satisfy the requirement on on-line partial discharge monitoring of XLPE cable.

1. Introduction

With the continuous development of China's power system, XLPE cables are widely used in transmission and distribution networks of various voltage levels because of their good insulation, low dielectric loss coefficient and high temperature resistance [1]-[2]. However, the insulation layer of some XLPE cables in operation is aging gradually, and the failure rate is rising dramatically [3], which seriously threatens the safe operation of the power grid.

Traditional cable preventive test will not only cause power outage loss, but also damage the cable and accelerate the aging of cable insulation [4].

In order to effectively avoid the risk of traditional off-line detection, cable on-line monitoring technology has become a research hotspot. The existing on-line monitoring methods mainly include [5] DC component method, loss current harmonic analysis method, partial discharge method and so on.

Partial discharge (PD) is an important characterization of insulation defects. Therefore, the insulation status of equipment can be timely and accurately grasped by measuring partial discharge of equipment [6]. Therefore, PD method is a commonly used on-line detection technology. According to the different physical quantities, partial discharge detection includes electromagnetic coupling method, ultra-high frequency method and ultrasonic method [7]-[9]. The electromagnetic coupling method is the most widely used cable partial discharge detection method at present.

Based on the electromagnetic coupling method of Cable Partial discharge, a series of on-line monitoring systems have been put into use [10]-[12]. However, these systems generally have some shortcomings, such as inconvenience in installation, poor fluidity, single networking mode and low cost-effective ratio, which severely restrict their application scope. In order to solve the above
problems, based on the existing on-line detection system of electromagnetic coupling method, a cable partial discharge on-line monitoring system with convenient installation, high fluidity and flexible networking is developed in this paper, which integrates multi-channel data acquisition, database and Internet of Things technology. This system can be used in Multi-substation mobile. It can be used in series, parallel and ZigBee wireless ad hoc networks according to the need. It improves the cost ratio of the system and expands the application scope of the system. It has important practical significance.

2. System overview

2.1. Hardware Architecture

Based on the principle of electromagnetic coupling, the mobile XLPE cable partial discharge on-line monitoring system extracts the partial discharge pulse signal of the cable through a sensor sleeved on the cable terminal grounding wire. The signal is amplified and extracted by multi-channel data acquisition system. After data conversion, it is networked by optical fiber or ZigBee and uploaded to portable diagnostic center. The insulation status of cable is analyzed and evaluated by on-line cable analysis and diagnosis software system.

The whole system consists of signal sampling module, detection front-end, detection terminal and portable diagnostic center. There are up to 32 detection channels in the four detection front-ends, which can monitor multiple cable lines or multiple intermediate joints of a cable line. In order to improve the fluidity of the system, the functional components are modularized in the design. The components can be flexibly connected according to the detection requirements. The system architecture is shown in Figure 1.

![Figure 1. Structure of Monitoring System](image)

Among them, signal sampling module includes high frequency current sensor and high frequency amplifier, detection front-end contains 8-channel high-speed data acquisition system and data conversion module, four detection front-end is networked with detection terminal through optical fiber or ZigBee, and differentiated by different IP. Finally, detection terminal uploads data to portable diagnosis center through RJ45 port.

2.2. System Networking Technology

This system can be based on the need of optical fiber network and ZigBee wireless network.

In the aspect of optical fiber networking, if multiple cables are required to be detected simultaneously, the system can make optical fiber parallel networking for four detection front-ends. After data conversion, the detection front-end communicates with the detection terminal through multi-mode dual-fiber optical fiber. The detection terminal completes networking and uploads data, and completes up to 32 cable monitoring. If a cable is multi-point tested, the system can connect four detection front-ends in series with the detection terminal, and connect four detection front-ends in turn through multi-mode dual-fiber optical fibers. The data is also uploaded by the detection terminal to complete the multi-point detection. The schematic diagram of the optical fiber network of the system is shown in Figure 2, where the solid line is the optical fiber parallel network connection mode and the dotted line is the optical fiber series network connection mode.
This system is based on ZigBee technology of the Internet of Things. It connects multiple detection front-ends with the detection terminal. The detection front-end is the wireless network terminal node and the detection terminal is the wireless network coordinator. The system wireless network schematic diagram is shown in Figure 3. Open the wireless communication mode, the detection front end and detection terminal can be self-organized network. This networking method is suitable for complex site detection, complementary to optical fiber networking, and expands the scope of application of the system.

3. Introduction of System Hardware

3.1. Signal Sampling Module

3.1.1 High Frequency Current Sensor. In order to extract this signal, the sensor should have the following characteristics: wide operating frequency bandwidth, high sensitivity, good transient response and good linearity [13]-[14].

The system uses Rogowski baseline coil sensor as high frequency current sensor [15]. The structure of the sensor is shown in Figure 4 [16]. When the measured conductor passes through the high frequency pulse, the coil can induce high frequency current, and the pulse signal can be extracted through the integral resistance and signal conditioning circuit.

The field interference signal of substation is mainly concentrated below 1MHz, so the sensor is designed as a pass band from 1MHz to 25MHz, which can not only extract the pulse signal smoothly, but also reduce the environmental interference. Literature [16] explains in detail how to improve the sensitivity of sensors. On this basis, after design and testing, the high-frequency current sensor of the system chooses the super-crystalline alloy with high permeability and low loss as the core material, the integral resistance is 50 Ω, the number of coil turns is 7, and the diameter of coil wire is 0.8 mm. Figure 5 shows the relationship between transducer impedance and frequency. From the diagram, it can be seen that the high frequency amplifier has suitable transducer impedance in the frequency range of 1MHz to 25MHz.
3.1.2 High Frequency Amplifier. Because of the small amplitude of partial discharge pulse, in order to facilitate subsequent processing, the signal needs to be amplified by high frequency amplifier. In order to effectively improve the transmission and anti-noise ability of the system, the amplifier is designed with two-stage amplification and differential mode output. The signal processing process diagram of the sampling module is shown in Figure 6.

Figure 5. Relationship between Transmission Impedance and Frequency

Figure 6. Signal Processing of Sampling Module

3.2. Detection front end
The detection front-end is one of the core hardware of the system. Its power supply board is powered by eight high-frequency amplifiers. At the same time, the detection front-end has built-in 8-channel high-speed data acquisition system, which can pre-process the extracted pulse signal and extract the characteristic parameters, effectively reducing the amount of data transmission. In addition, according to the user's selected network mode, the detection front-end can convert RJ45 network signal to optical signal output through photoelectric conversion module or to ZigBee signal output through wireless module. If the detection system needs to be connected in series with optical fibers, the detection front-end has reserved an optical fibers serial interface, through which the signal of the front-end can be input to the detection front-end of this level, and then output from the detection front-end of this level to the next detection front-end. The detection front-end hardware is shown in Figure 7.

Figure 7. Hardware of Detection Front
3.3. Detection terminals and portable diagnostic centers
The detection terminal has the function of signal centralized unit. It can receive up to four optical signals from the detection front-end and form a network. At the same time, the detection terminal acts as a coordinator to support several detection front-end for ZigBee wireless networking. Finally, the detection terminal uploads the data input from multiple detection front-ends to the portable diagnostic center through RJ45 port.

The portable diagnostic center is based on a portable computer and connected to the detection terminal through RJ45 port. The on-line analysis and diagnosis software system of the built-in system can analyze the pulse data and diagnose and evaluate the insulation status of the cable. The overall effect of the system is shown in Figure 8.

![Figure 8. Photo of the System](image)

4. Introduction of System Software

4.1. Software Architecture
The supporting software of the system is based on SQL database technology. It can process the uploaded data under the condition of system optical fiber or wireless networking, analyse the characteristic parameters of pulse signal, display the characteristic atlas in real time and diagnose the insulation status of cable. In addition, the software supports data storage, historical data analysis, discharge trend viewing and other functions. The software of this system can make a comparative analysis of the lateral data of multiple cables and make a reasonable early warning. The system software architecture diagram is shown in Figure 9.

![Figure 9. Structure of Software](image)

4.2. Data processing and analysis
In this software, a variety of filtering methods are used to deal with the field noise, including FIR band-pass filtering and FFT filtering algorithm. The preliminary processed data are stored in the database, which is convenient for viewing at any time. The software can analyze the data in detail. The main interface can display the data information and the characteristic Atlas of the user’s attention in real time. The detection interface is shown in Figure 10.
In addition, the database of this software system can also query all historical data and its characteristic atlas, including maximum discharge, average discharge, $\phi$-$Q$-$N$ atlas, etc. If the user needs to analyze the trend of data in a certain period of time, the software provides relevant support to show the trend of single channel multi-eigenvalue and multi-channel same eigenvalue in a period of time.

The detection interface and the $\phi$-$Q$-$N$ atlas of detected signal is shown in Figure 11.

5. System testing and Application
The system has fully tested various functions, including signal extraction test, optical fiber parallel networking test, optical fiber series networking test and ZigBee networking test. The partial discharge signal is simulated by pulse generator, and the secondary pulse signal passes through the sensor through the analog grounding wire as shown in Figure 11.

In the test, the system achieves all the expected functions, the multi-detection front-end network is convenient and flexible, the system runs stably and reliably as a whole, the software data processing is normal, the pulse can be effectively identified, and the corresponding early warning can be made.

The system has been installed and tested in many substations in Shandong Province, and on-line partial discharge monitoring has been carried out on dozens of cable lines. In the process of field installation, the system shows strong fluidity, and the installation is convenient and the detection efficiency is high. In addition, the system makes use of the flexible characteristics of networking to detect partial discharge of several cable lines which are scattered and difficult to monitor. The test results show that the insulation status of each cable is normal and no abnormal discharge is found.
6. Conclusion
According to the electromagnetic coupling monitoring method of Cable Partial Discharge and the Internet of Things technology, this paper designs and develops a mobile XPLE partial discharge online monitoring system.

This system realizes the functions of cable partial discharge signal acquisition, processing and analysis, multi-detection front-end optical fiber networking and ZigBee wireless networking. It can fully analyze the pulse characteristics and make early warning. At the same time, aiming at the shortcomings of fixed installation location and poor liquidity of the existing online monitoring system, the system uses modular design method to improve the system liquidity, which greatly improves the system's high performance-price ratio, and has certain application value and significance.

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