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Research Article

The Design of Partial Discharge On-Line Monitoring System for XLPE Power Cable

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Abstract: Partial discharge detection is an important means to assess the situation of XLPE power cable's insulation. This study has developed an on-line monitoring system which applies to the medium voltage XLPE cable on partial discharge, described its working principle, components of hardware, software designing and program implementation in details. Through monitoring the partial discharge signal in grounding lines of the XLPE cable's shield, the system integrated assess the situation of XLPE cable's insulation. The results of running show that the system is stable and reliable.

Keywords: High frequency current sensor, medium voltage XLPE cable, on-line monitoring system, partial discharge

INTRODUCTION

With the continuous development of China's power industry, XLPE cables are increasingly used in power grid construction (Zhu *et al*., 2009; Li *et al*., 2010). XLPE cable has remarkable characteristics, including high insulation strength, low dielectric loss factor, great anti-acid and alkali resistance and effective anti-corrosion properties. The core of cable can work at high temperatures as well as the volume is small, easy installation and maintenance (Zhang and Yan, 2012). But after the limited years, it often has accidents caused by insulation breakdown. Because of its high-voltage and large capacity, each incident may cause significant economic losses. In order to protect the security and stability of the distribution network, monitoring XLPE cable insulation condition has become the urgent problem. Some countries as early as the 1960s began to study the detection of XLPE cable insulation weaknesses and aging monitoring technology, especially in Europe, the United States, Japan and other developed countries have accumulated some experience (Xue *et al*., 2011; Zhou *et al*., 2009), online monitoring for XLPE cable partial discharge is one of the hot spots of the research.

There are many methods to detect cable faults, such as the DC component method, the loss of current harmonic component method, partial discharge method; *et al*. Partial discharge method is effective for on-line monitoring system in practice. The partial discharge of cables often produces current pulses, electromagnetic radiation and ultrasound phenomenon. Based on different physical quantities, it can apply the electromagnetic coupling method, UHF and ultrasonic method to detect the partial discharge. Electromagnetic coupling method is currently the most widely used method (Guo *et al*., 2010), due to the high sensitivity, easy installation and no electrical directly connections to cables.

This study presents the design of PD online monitoring system for XLPE cable. The system with using wireless communication technology takes advantage of the electromagnetic coupling method to achieve remote online monitoring.

THE PRINCIPLE AND STRUCTURE OF THE SYSTEM

The principle of cable partial discharge detection with electromagnetic coupling method is that the magnetic coupling device detects current pulse signal in the cable grounding wire through the sensor attached around the earth screen of the cable. The system can guarantee the security of the measurement, due to the measurement circuit separates from the high voltage part. The principle is shown in Fig. 1.

The system uses a modular design. The entire system consists of three parts, including the front-end signal sampling module, data acquisition module and system back-end software module, the overall structure is shown in Fig. 2.

THE HARDWARE STRUCTURE OF THE SYSTEM

Front end signal sampling module:

- **Partial discharge sensor:** The partial discharge

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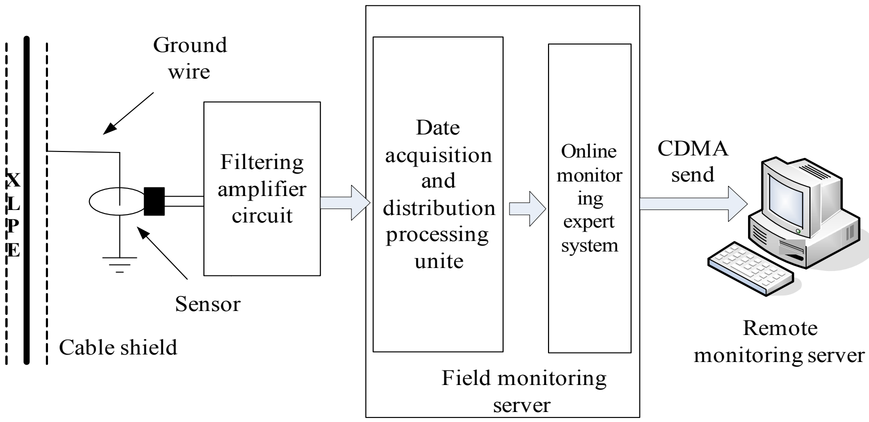

Fig. 1: System principle diagram

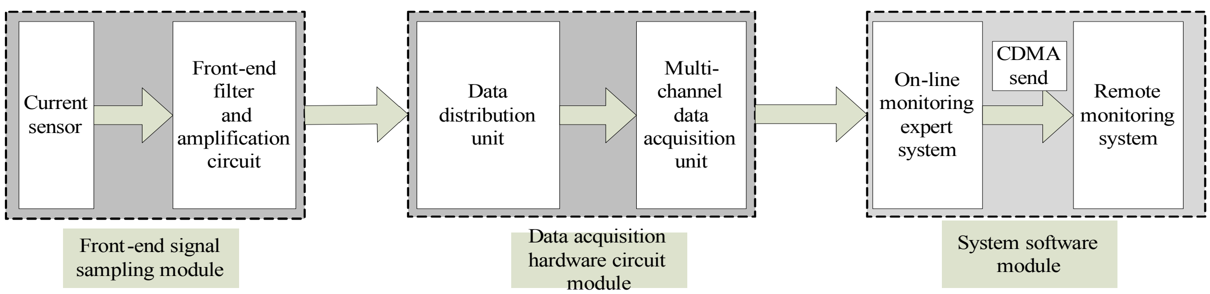

Fig. 2: System structure diagram

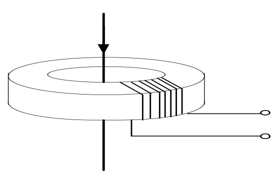

Fig. 3: Schematic diagram of current sensor

Fig. 4: Current sensor photo

pulses in the XLPE power cable have short duration which can be as short as nanoseconds and such pulses' spectrum is so wide that its energy is distributed from tens of kilohertz to more than one gigahertz. Taking all the pulses' characteristics into consideration, our sensor must possess wide working frequency band as well as suitable response sensitivity in order to assess the XLPE power cable's partial discharge.

Partial discharge sensor is a Rogowski coils current sensor with broadband (Hashmi *et al*., 2011). The magnetic core uses ultracrystalline, characterized by high saturation magnetic induction and high permeability. The Rogowski coil current sensor's structure is shown in Fig. 3. When alternating current flows through the measured conductor, the coils can induce current from the magnetic field produced by the primary alternating current.

To determine the width of sensor's frequency band, we have to consider the interference signal on site. According to a large number of test results, the frequency of interference signal is mainly below 1MHz so that we determine the current sensor's working frequency is from 1MHz to 25MHz. The system's current sensor's photo is shown in Fig. 4.

- **Preceded filter amplifier circuit:** The main function of the preceded filter amplifier circuit is primary signal processing. Aiming at amplifying the signal without distortion, we devise our signal processing circuit as a differential amplifier with a 160MHz response frequency bandwidth. At the same time, this circuit is set as a two stages

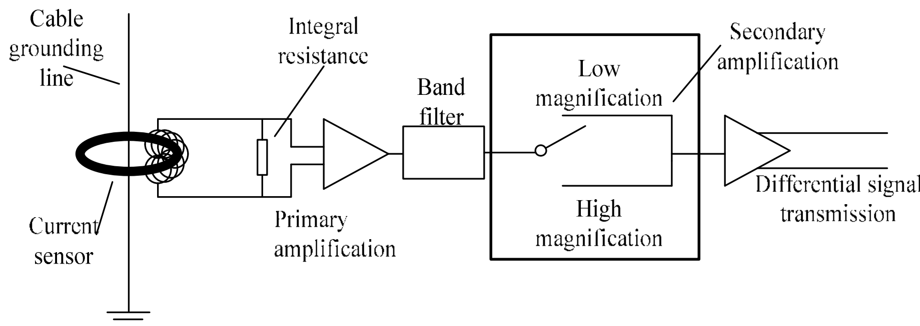

Fig. 5: Partial discharge signal amplification process chart

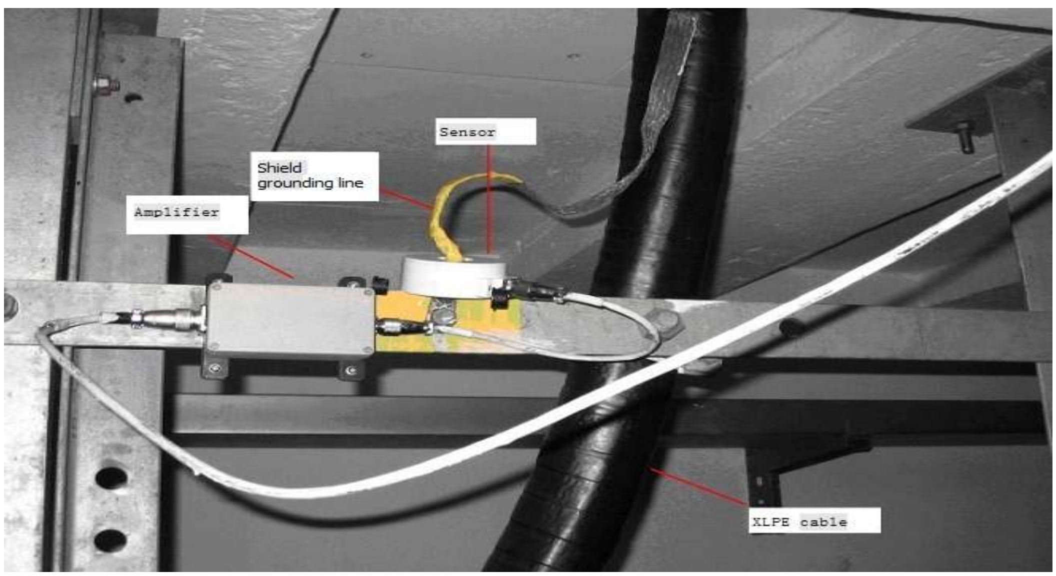

Fig. 6: Sensor and amplifier installation diagram

programmable amplifier circuit. It is very convenient to change the amplification using software. Meanwhile, the pass band is 1~25MHz to filter the interference signal effectively. Since the signal of partial discharge is so weak and has to be transmitted to the acquisition system through multicore cable, the system uses two stages of amplification and a transmitting way of differential signal with shielding to improve the anti-noise ability and transmitting capability. The partial discharge signal's amplification process is shown in Fig. 5. Figure 6 is sensor and amplifier installation diagram.

Multi-channel data acquisition module: This module includes data channel converting unit and data acquisition unit. Data channel converting unit is signal distribution circuit. Because the system's data acquisition card can only collect signals from 4 routes when the system can monitor partial discharge signals from 30 routes, we need signal distribution circuit to distribute the multi-channel signals. Whenever background software sends signals to switch the channel, the signal distribution circuit will gate and send out 4 routes output signals. The hardware of data acquisition module uses high-speed data acquisition card with PCI bus interface, whose continuous sampling rate can be as high as 50 MHz. After four independent A/D conversion channels gather the 4 routes partial discharge signals which are sent to data acquisition card, the data acquisition card will digitalize the amplified analog signals and put the results into the memory.

THE SOFTWARE SYSTEM

Background software system architecture: The system's background software is mainly used to process

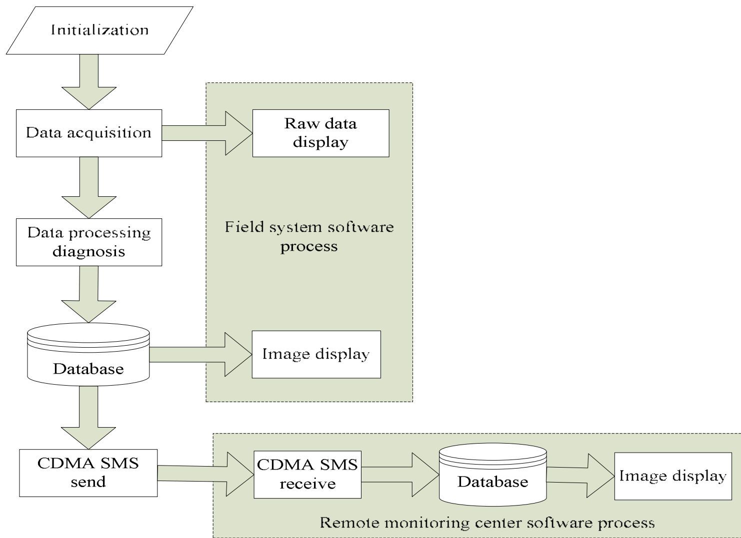

Fig. 7: Software system structure

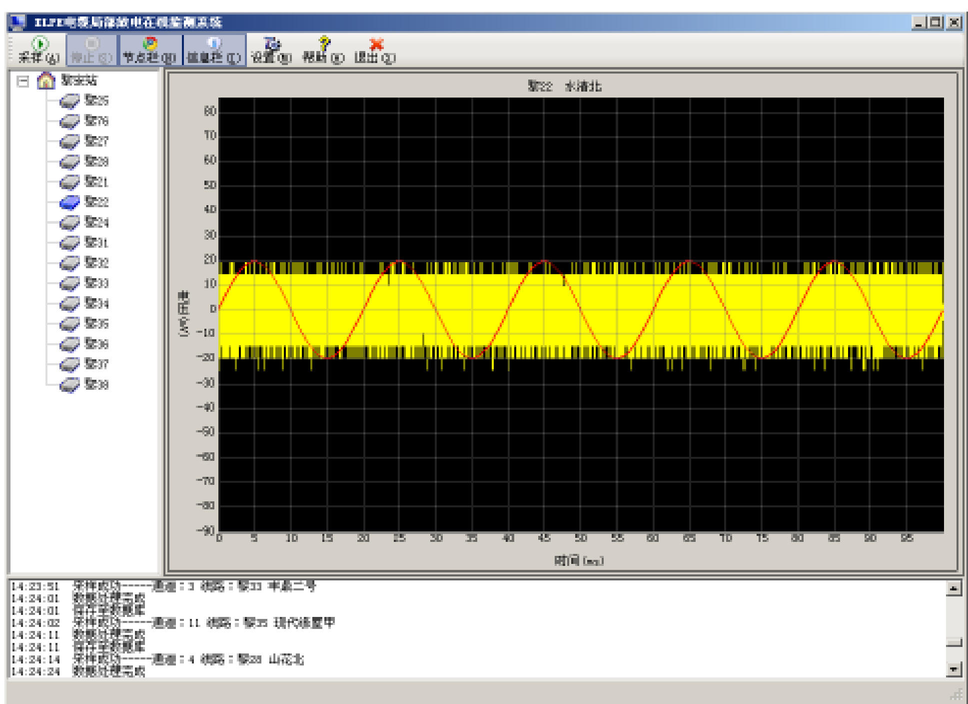

Fig. 8: Software main interface of system

the sampling signal, analysis and collect the characteristic parameters and store them in the SQL database. At the same time the map of every characteristic parameter is displayed on the software main interface of system. After the characteristic value is sent to the remote monitoring center by CDMA module, the remote monitoring is realized. Taking every cable's history data into concern, the remote monitoring center will do horizontal relation and vertical trend analyses so that we can judge severity of the cable discharge and give the diagnosis. Figure 7 illustrates the software system structure.

Software main interface of system is shown in Fig. 8. In this figure we can see cable number and original detection data, respectively in the left bar.

Data processing: There are several interferences in on-site partial discharge measurement, chiefly including

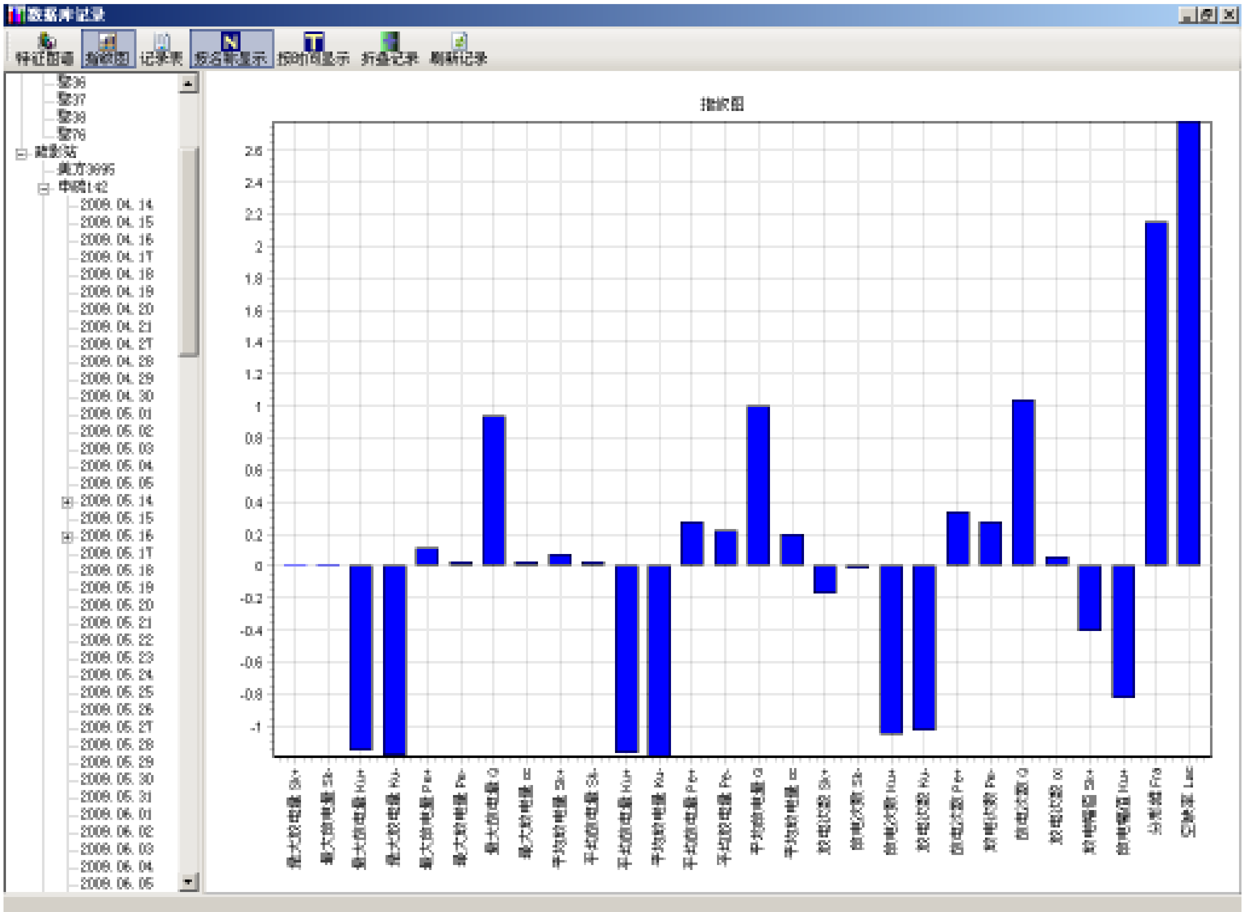

Fig. 9: Fingerprint of partial discharge

periodical narrow-band noise and white noise. In order to obtain distinct partial discharge signal, the software system has to perform filtering process on original data. In allusion to periodical narrow-band noise, FIR band-pass filtering and FFT filtering algorithm are used in the system. When it comes to white noise, the system relies on the wavelet filtering algorithm. By digital filtering process the signal-to-noise ratio can be greatly increased, which lays the essential foundation of further feature extraction, analysis and assessment.

Discharge's characteristic map and fingerprint: Characteristic map of partial discharge consists of 5 two-dimension maps, including the distribution of maximum discharge phase and the distribution of average discharge phase and one three-dimension map of Φ-Q-N. The fingerprint of partial discharge is made up of 26 characteristic parameters, mainly including standout, degree of skewness, the number of local peaks, degree of asymmetric and so on. Figure 9 is a fingerprint of partial discharge.

(a) Right side (b) Reverse side

Fig. 10: On-site installation of monitoring center

RESULTS AND DISCUSSION

The system develop by our research group has been installed in several transformer substation in Shanghai. And the system is monitoring tens of cable lines' partial discharge on line. Figure 10 shows the site installation of server.

Fig. 11: The remote monitoring center interface

Currently, the system is under good condition. The Fig. 11 shows the remote monitoring center interface of Shuying station. According to the results of monitoring, every cable's insulation state is normal. None unusual discharge is found.

CONCLUSION

This study introduces the development process on on-line monitoring systems of XLPE cable partial discharge and on-site running conditions of such system. The system has following characteristics:

- Partial discharge sensor is separated from amplifier so that it's convenient for installation and maintenance.
- This system can monitor 30 cables at the same time, which satisfies the need of monitoring the media voltage cables' partial discharge in transformer substation.
- This system's software system uses CDMA data transmission method and realizes the function of on-line detection of cable's partial charge. It can estimate the on-site cable's running condition in time and give reasonable early warning information.

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