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The Application of Partial Discharge Detection for the condition assessment of XLPE Power Cables

Abstract. *Partial discharge (PD) detection is an important means in the condition-based maintenance of high voltage apparatus including cross-linked polyethylene (XLPE) power cables. In this contribution, we introduce the recent work in Shanghai municipal electric power company on the condition-based maintenance of XLPE power cables. As to how to carry out the PD detection in different circumstances, three schemes are laid out in brief. Particularly, a novel idea of partial discharge joint detection method, which is based on multiple sensors, or the high frequency current transformer (HFCT) coupling technique, ultra high frequency (UHF) and acoustics emission (AE) partial discharge detection technique, is proposed. Use more than one kind of coupling techniques, the reliability of onsite PD detection and diagnosis can be improved significantly.*

Streszczenie. *Przedstawiono metody wykorzystania wyładowania niezupełnego do testowania stanu kabli typu XLPE. Wykorzystano różne czujniki, jak np. wysokoczęstotliwościowy transformatorowy czujnik prądu czy czujniki emisji akustycznej. (**Metody wykorzystania wyładowania niezupełnego do testowania stanu kabli typu XLPE**)*

Keywords: XLPE cable; Partial discharge; Condition-Based Maintenance; HFCT; UHF; AE
Słowa kluczowe: kable XLPE, wyładowanie niezupełne, testowanie stanu kabli

1 Introduction

XLPE power cables play a significant role in the urban power network. The safe operation is vital to the stability for power grid. Once the cables break down, power failure will occur immediately. From the field photos, samples of failure cables and domestic major cities' power cable repairing records in China, we found that there were certain causes for the failures of power cables, comprising external force destruction, intrinsic defect of cable accessories, quality problems of cable laying and cable production. The corresponding proportion was 58%, 27%, 12% and 3% respectively.

High frequency current transformer coupling technique for online partial discharge (PD) measurement of power cables is commonly used to detect the PD signals. Time of flight between PD pulses arriving at opposite ends of the cable is used to locate PD source, or defects [1]. Recent working reports on PD detection technique indicate that defects in XLPE power cables will change the distribution of electromagnetic field and radiate electromagnetic wave [2] and acoustic emission [3] when PD occurs. The work published in [4] introduces a new joint detection method on PD detection and localization in GIS, with better behavior on anti-interference and defect location.

This contribution lays out three PD detection schemes for different condition or circumstance. Under different conditions, namely, onsite PD detection, online PD monitoring and field acceptance PD testing, different detection scheme may be considered, for feasibility of one scheme is justified in one case, may not in another. Especially, an onsite PD detection instance is provided, demonstrating the value of multiple sensors, or using more than one kind of coupling techniques in detecting PD.

2 PD detection schemes of XLPE cables in different circumstances

When partial discharges occur in the power cables, the induced high frequency current will flow to the ground through the earthing stripe. The HFCT is clamped around the power cable terminals or the earthing stripe to couple the PD pulse current which flows through the cable outer shielding[5,6].

The partial discharges occur in the power cables will also generate electromagnetic and AE signals. The AE signals propagate to the surrounding media quickly, which can be detected by the AE sensors attached outside the cables. The sensors couple the AE signals and transform them to the electric signals, which can be used to measure and locate the PD sources. The UHF based PD detection method was proposed by the CEGB in the early 1980s [7]. It has been applied in the production and operation process of GIS successfully. The principle of UHF method is sensing the electromagnetic waves generated by the PD and acquiring the detail information which could be used in the pattern recognition and defect location. AE and electromagnetic signals attenuate quickly when they propagate in the power cables. Recently, the two methods are applied in the situation of short distance detection such as PD detection on the power cable joints or terminations.

For single kind of PD sensor, it is prone to be influenced by outside interference. However, if we use more than one kind of sensors, such as adopting UHF and HFCT sensor at the same time, the trouble may be shot to a great extent, for the interference that can confuse the UHF sensors can hardly puzzle the HFCT sensors, and vice versa.

Further,Neural network, Frequency analysis and wavelet based algorism [8,9] are used for PD detection and diagnosis. In the PD monitoring system the characteristic trend can be derived to describe the insulation degradation procedure.

2.1 Scheme for onsite PD detection of the power cables in operation

Scheduled periodical maintenance of XLPE power cables is indispensable in the normal operation. The conventional methods are ocular observation, infrared temperature measurement and so on. However, for the tme being, the HFCT sensor becomes a widely used detection tool since it is non-destructive, and unsaturated at high frequency.

For these cases, onsite PD test should be done, detecting PD without interruption of the power grid. How to carry out onsite PD detection? It is a question easy to answer but hard to pracise, for mono-sensor is apt to be influenced by outside interference, whatever kind of sensor we use.

Therefore, aiming for a better behavior, more than one kind of sensors should be adopted. And in our opinion, HFCT,AE and UHF sensors could be put into practice simultaneously, if necessary and feasible. Because in this manner, the diagnosis result of every sensor can be confirmed by each other, and the reliability of onsite PD detection may be improved significantly, if results derived from different sensors are identical. As illustrated in Figure 1, it is a portable PD device, consisting three kinds of PD sensors, mentioned previouly.

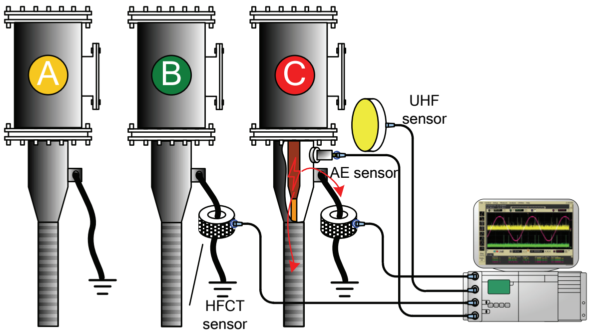

Fig.1 Schematic diagram of onsite PD detection system for cables

Among three kind of sensors, HFCT sensor is prevalent in onsite detection process, made by placing the winding on a long, flexible former and then bending it round the conductor. An ‘air-cored’ HFCT sensor is placed around the cable in a toroidal mode as shown in Figure 2. The magnetic field produced by the current induces a voltage on the coil. The output voltage is proportional to the rate of change of current. The upper frequency of the voltage can achieve about 50MHz.

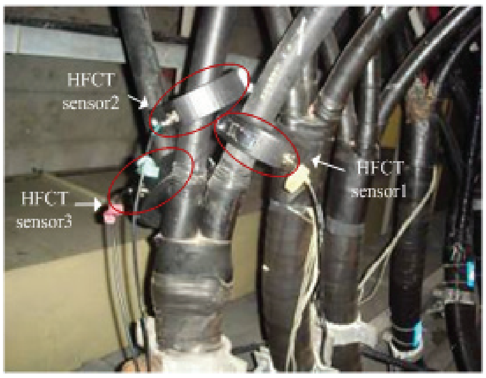

Fig.2 Onsite PD detection of cables in field

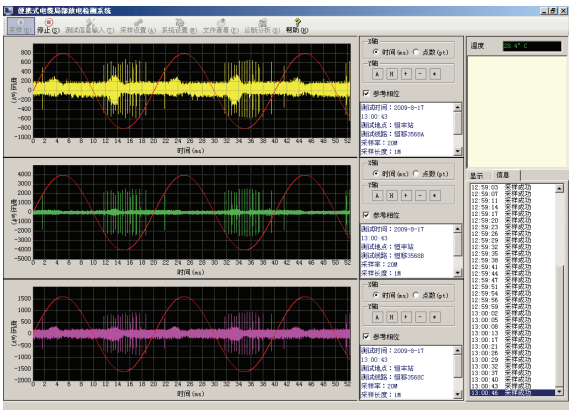

Fig. 3 Main software interface of some portable detection device

A portable device was developed for the synchronized partial discharge detection of power cables and cable accessories in operation with multiple sensors. The raw data detected onsite are processed by succssive denoising, pulse extraction, fingerprint construction, diagnosing algorithm. The main software interface of the program is illustrated in Figure 3.

Once suspicious partial discharge is found in the periodical checking of the power cables, it is of great significance to make an effective maintenance scheme to confirm and locate the PD source ASAP. It is important to ensure the safe operation of the system and remove the potential fault immediately. The experience of patrol indicates that the partial discharges can be effectively captured by using the multiple HFCT sensors which improve the reliability of the partial discharge diagnosis.

Multiple sensor tlgether with automatic diagnosis program, it improves the efficiency of maintenance for the power cables and insures that the cables are all in good condition.

2.2 Scheme for PD detection in field acceptance test of power cables

How to capture the PD of the power cables in field acceptance test effectively has been the focus for the utility. A unique set of system is needed for the PD detection of power cables while doing HIPOT withstand testing.

PD detection helps to find insulation defects in field acceptance test of power cables which is a complement to the HIPOT withstand testing for after-laying power cables. UHF and AE methods have better behavior in anti-noise and PD source location. Similarly, if we incorporate HFCT sensor with UHF and AE sensor, the ability of removing noise will be improved significantly. Therefore, a measuring system which adopted the HFCT, UHF and AE sensors [10, 11] was raised, as depicted in Figure 4.

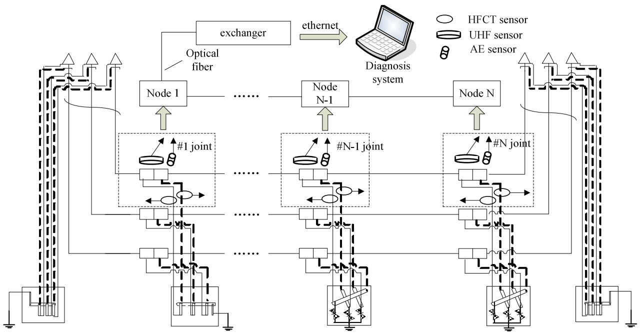

Fig.4 Schematic diagram of PD detection system in field acceptance test

The system has been put into practice successfully in the field acceptance test of some 220kV cable line, as demonstrated in Figure 5.

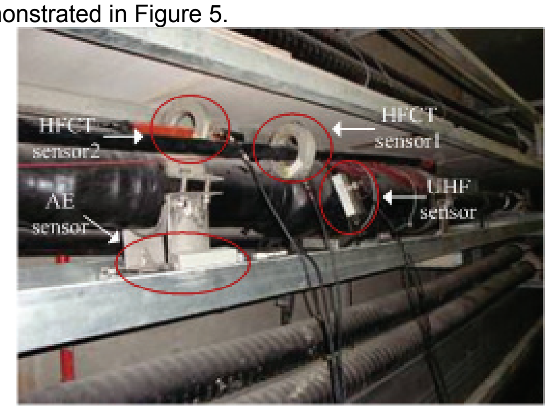

Fig.5 PD detection of the 220kV power cables during HIPOT withstand testing

The software of field acceptance PD testing system differs form that of onsite PD detection system, for the former is used in the offline condition while the latter is not applicable. The software used in field acceptance case supports multiple channels, far more than that of onsite detection system, sampling data continuously and simultaneously, illustrated in Figure 6.

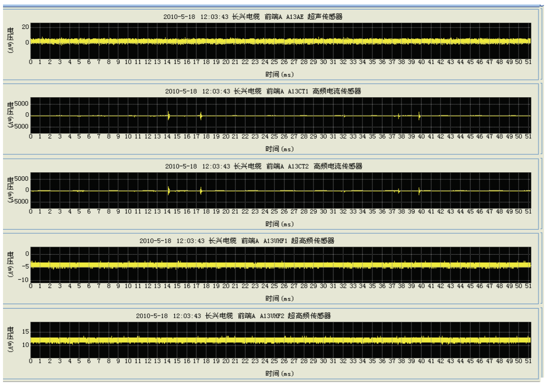

Fig.6 Main software interface in the field acceptance test

2.3 Scheme for on-line monitoring of the power cables

There exists a development process of partial discharge in the power cables, from initial defect to final breakdown. For these cases, it is beneficial to capture the potential insulation defect by applying online monitoring of the power cables [12, 13], the sketch map of system is illustrated in Figure 7.

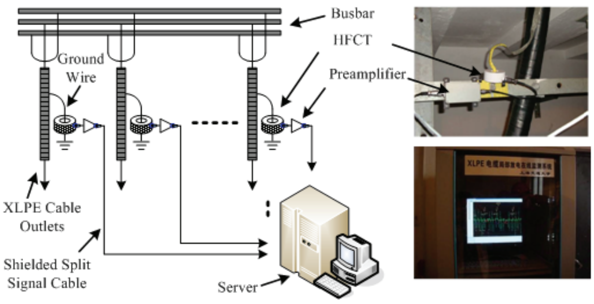

Fig.7 Schematic diagram of online PD monitoring system for cables

The online PD monitoring system for cables shown above was installed in two 35kV substations in Shanghai city. The sensors were installed around the earthing stripe of the power cables. The online expert system running on the servers could realize the realtime diagnosis for the power cables, the characteristic parameter trend curves, covering 5 months' period, are illustrated in Figure 8.

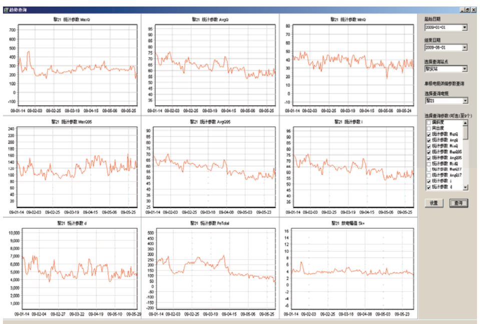

Fig.8 Various characteristic parameter trends of PD

3 An onsite PD detection case of XLPE power cables

In the past years, we have tested over 150 power cable lines in 30 substations in Shanghai as far as PD was concerned. Several potential insulation defects were found and have been effectively and correctly treated in time. Some potential dangers were removed and the disaster accidents were prevented.

Here is a typical case of PD test of cables.

The three-core cable, ranking 35kV, lied in a 220kV substation. When operators made onsite PD test as scheduled. Suspicious signals of partial discharges were captured around the power cable's accessories. The HFCT and UHF sensors were installed on the cable as shown in Figure 9.The three HFCT sensors were installed on phase A,B,C of the three-core cable respectively, and one UHF sensor was placed just beside the cable termination.

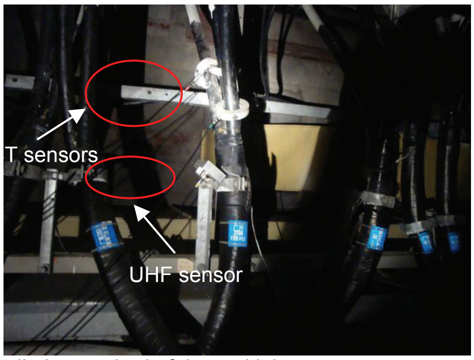

Fig.9 Installation method of the multiple sensors

As shown in Figure 10, signals coupled by 1 UHF sensor and 3 HFCT sensors were listed in sequence: UHF,HFCT A,HFCT B and HFCT C from top to bottom.

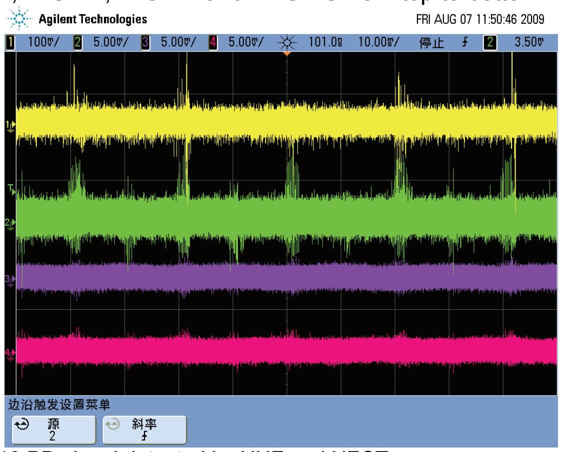

Fig.10 PD signal detected by UHF and HFCT sensors

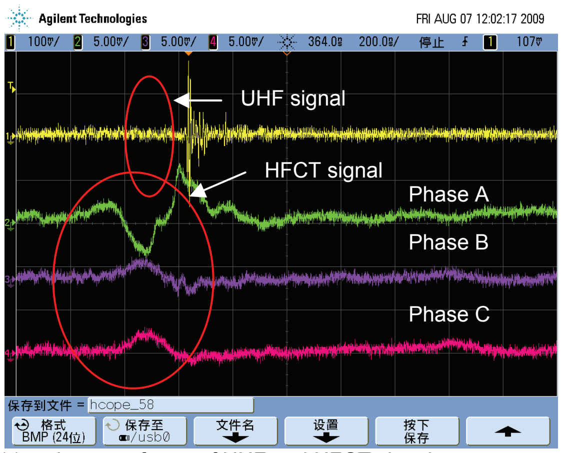

Fig.11 pulse waveforms of UHF and HFCT signals

Zoom in the signal illustrated in Fig.10, expanding the signal in time domain. we could get the UHF and HFCT pulse waveforms in dedail, depicted in Fig.11. From the

waveforms it can be observed that:1) first, UHF and HFCT signals are in agreement with each other; 2) second, the polarity of 3 HFCT signals are inconsistent;3)the amplitude of HFCT A is greater than the other two HFCT sensors and the polarity of the former disagrees with the latter.
Based on the analysis above, we could see that there should exist just one discharge source and the source was located on the phase A of the cable termination.

As shown in Figure 12, the cable tank containing suspicious cable was opened. There was an apparent discharge trace on the phase A of the cable termination. And the diagnosis result previously inferred was confirmed.

Fig.12 Photos of defective cable termination

4 Conclusion

1)PD testing can be carried out regarding three aspects: a) for online monitoring case, only HFCT sensor is proper and an online monitoring system is indispensable; b) for onsite detection case, multiple sensors is perpered, as mono-sensor is apt to be affected by outside interference, the multiple kinds of PD sensors can improve the reliability of onsite PD detection and diagnosis result. Besides, only portable detector is suitable; c) for field aceptance test case, mainly for high voltage cable joints, multiple sensors should also be applied simultaneously.

2)For demonstrating the effectivity of multiple sensrs,an onsite PD detection instance is provided, including the verification process. In the case,it can be derived that, besides detecting PD the same with UHFsensor, HFCT sensors can asists in PD location in the case of discriminating which phase is defective.

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