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# Research on Partial Discharge Localization in XLPE Cable Accessories Using Multi-Sensor Joint Detection Technology

***Abstract**. A multi-sensor joint detection technology was proposed based on the theory of the high frequency current transformer (HFCT) method, Ultra-high frequency (UHF) method and acoustic emission (AE) method. An experimental partial discharge (PD) testing was applied on XLPE cable with artificial defect signals. The experimental results show that the multi-sensor joint detection technology will help to identify the PD signals from the interference noises and improve the localization accuracy.*

***Streszczenie.** Zastosowano wielosensorową metodę badania wyładowania niezupełnego: wysokoczęstotliwościowy transformator prądu oraz metodę emisji akustycznej. Badania przeprowadzono na kablu ze sztucznym sygnałem defektu. Umożliwiło to wydzielenie sygnału z szumów i poprawe dokładności pomiaru lokalizacji. (**Badania lokalizacji wyładowania niezupełnego w kablu XLPE przy użyciu techniki multiczujnikowej**)*

**Keywords:** XLPE cable; partial discharge; Multi-Sensor; HFCT; UHF; AE
**Słowa kluczowe:** kabel XLPE, wyładowanie niezupełne.

## Introduction

As the extensive application of Cross-linked Polyethylene (XLPE) cable in power grid, power accidents caused by insulation faults in cable equipments are increasing constantly. Meanwhile, the cable laying method is mainly concerned with underground, which brings problems on state testing and fault localization in cable systems. Therefore, how to judge the cable insulation situation effectively and locate the fault site accurately is of great practical significance [1].

Insulation faults occur more often in cable accessories. And the existence of insulation faults, can lead internal partial discharge (PD) to occur. Through the partial discharge testing in XLPE cable accessories, we can indirectly access the XLPE cable insulation status. In this paper, we proposed a XLPE cable on-line testing method which based on multi-sensor joint detection technology, in order to realize the partial discharge localization in XLPE cable accessories. Multi-sensor joint application makes each sensor advantages, enhances the anti-interference capability and the detection efficiency of cable PD testing, and has a very good practical value.

## Partial Charge Detection In XLPE Cable

Partial discharge is an electrical phenomenon that occurs in the internal local area of electrical insulation, when only part of the insulating material is conducted under the electric field [2]. By measure the signals emitting from PD areas in XLPE cable accessories, like sound, light, electric signals and chemical signals, we can accomplish the PD test and the PD localization.

High frequency current transformer (HFCT), which can detect high-frequency signals along the pulse path by connecting them around the cable earth strap or the cable core, is a common method of cable PD detection [3]. The frequency band of a HFCT sensor is usually from hundreds of kHz to dozens of MHz, which is generally believe can obtain the PD signal effectively. HFCT sensor can install easily, so it is thought to be a noninvasive, safe and reliable test method.

Using HFCT sensor to implement the PD localization in XLPE cable is mostly applied by Time Domain Reflectometry (TDR) method [4]. TDR method determines the PD site by calculating the time differences between direct pulse and reflection pulse of one single PD signal [5, 6] and by combining with its propagation speed. This is illustrated in Figure 1.

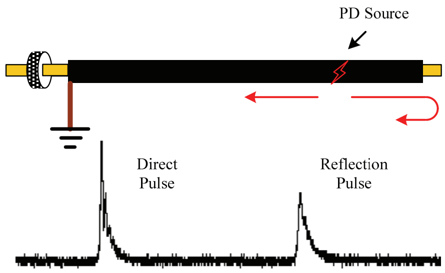



Fig.1. TDR method of PD localization in XLPE cable

In the field test, simple TDR method generally only applies to short cable PD detection, due to external interference and special transmission behaviors of the high frequency signals, such as attenuation, frequency dispersion and reflective properties. Because the insulation fault occurs more often in cable accessories, we can also apply Arrival Time Analysis (ATA) method to locate the fault cable joint by using multiple HFCT sensors. When PD pulse arrivals at specified sensors, ATA method calculates the time differences of their arrival-time and then accesses the PD site. Long distance cable systems are suit for ATA method in PD detection, with attaching HFCT sensors around each cable joint and using synchronous sampling technology. And to determine the direction of PD source, only two HFCT sensors are needed, by connecting them around one specified cable joint.

Ultra-high frequency (UHF) method, in XLPE cable, obtains electromagnetic PD signals by UHF antennas which placing around cable joints [7]. The frequency band of electromagnetic PD signals is usually from hundreds of MHz to several GHz, which is allowed to avoid low frequency noises and interferences effectively. So, UHF method is considered to have higher detection sensitivity.

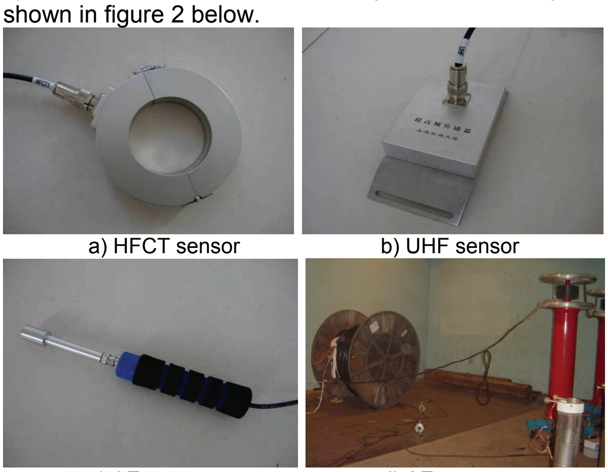
UHF signals attenuate sharply, when they propagate in XLPE cables. So, if we obtain the PD signal by an external UHF sensor attaching on the cable joint surface, we can be assure that the PD source is near the joint area. In order to determine the PD site accurately, the method of time difference can be used [8]. This concept had been discussed formerly in TDR method or ATA method by calculating the time difference of signal arrival-time, when electromagnetic PD pulse reached specified UHF sensors.

Acoustic emission (AE) sensor setting up around the cable joint can get the AE signals emitting from the PD source. AE sensor mostly is made of piezoelectric crystal and its frequency band is around dozens of kHz to hundreds of kHz as usual. During the AE testing, there is no electrical connection between the AE sensor and the cable, so AE method has very good performance on anti-electromagnetism interference [9].

Air coupling AE sensor is suit for PD detection in XLPE cable, which can obtain the discharge signal in the air near the PD source. Multi-sensor plan is meanly considered in XLPE cable AE testing, for the detection range of AE sensor is not very far. So the method of time difference can also applied in AE testing to locate the PD site.

## Multi-Sensor PD Joint Localizaiton Technology

Simplex PD testing method can often be sensitive to external signal interference in the field test [10]. A multi-sensor joint detection technology in this paper will be proposed using HFCT method, UHF method and AE method, in order to accomplish the partial discharge localization in XLPE cable accessories. The application of multi-sensor technology can distinguish PD signals and external interferences, so it can enhance success rates of the PD localization and improve the accuracy of diagnosis system [11]. PD sensors used in joint detection system is shown in figure 2 below.



c) AE sensor d) AE sensor

Fig.2 Photos of UHF, HFCT, AE sensors and experiment scene

Considering the electrical and mechanical structure of XLPE cables, we can set-up the joint detection system. During the joint detection, HFCT sensors are connected around the cable earth strap or the cable core near the cable accessories. The UHF sensor and AE sensor are placed around the cable joints or cable terminals. Figure 3 below shows the schematic of PD joint detection method in XLPE cable accessories.

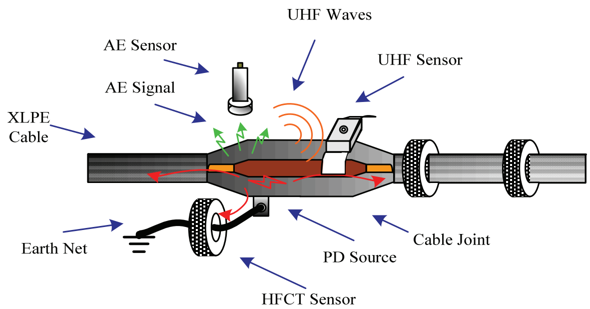



Fig.3 Schematic of PD joint detection method in XLPE cable accessories

To locate the PD source in XLPE cable accessories using these three types of sensors, the specific procedures are as follows:

1) Firstly, set-up UHF and HFCT sensors to give a preliminary test on each cable joints or cable terminals, and find out whether there are partial discharge occurred.
2) Secondly, give a further test on those suspect cables. Use two HFCT sensors to determine the direction of the PD source.
3) If the PD occurred on the side of cable accessories, locate the PD site using HFCT and AE sensors by joint detection technology.

## Experimental Reasearch

In order to validate the effectiveness of multi-sensor joint technology in XLPE cable PD detection, we give an experimental research on real XLPE cables using artificial defect signals, and locate the PD site.

1. Reflected Wave Test

The propagation speed of high frequency pulse in XLPE cable should be obtained first, before the localization experiment. The parameters of experimental cable are of 15kV voltage level, 35 $mm^2$ cross-sectional and 300 meters long.

Figure 4 shows the experimental circuit of reflected wave test. Generate a PD pulse on the cable core using pulse signal generator PG. The cable on remote end is open and the earth screen is grounded well. HFCT sensor is connected around the cable core.

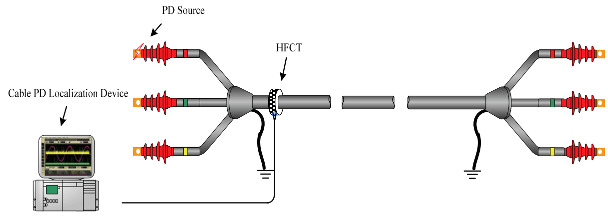



Fig.4 Signal reflection experiment in XLPE cable

The simulate PD pulse generated by pulse signal generator PG travels outwards in both direction along the XLPE cable core and cable earth screen. The first pulse (direct pulse) to arrive at the measurement end is the pulse which has travelled directly to that end. The reflected pulse which originally sets off in the opposite direction is then reflected back from the remote end back to the measurement end. Calculate the time differences between the direct pulse and the reflected pulse allows the PD site to be located. In the actual signal processing, the starting point of PD pulse is often hard to recognize, for the distortion of pulse signal during its transmission. AIC (Akaike information criterion) method is an effective solution to deal with this problem, and is benefit to improve the accuracy of localization.

AIC method, which is first proposed by Hirotugu Akaike, a Japanese statistician, is a measure of the goodness of fit of a statistical model to a set of observations [12]. AIC method extracts characteristic function CF from PD pulse waveforms. The form of function CF is as follows, which shows the relationship of the pulse amplitude and the frequency.

(1) $$CF(i) = |x(i)| + R|x(i) - x(i-1)|$$

Where x(i) is the discrete series of input sensor signals.

According to the CF curve, we can select a small area around the starting point. Then calculate the AIC value of each point. The AIC function is as follows:

(2) $$AIC(k) = k \cdot \ln(\sigma_{1,k}^2) + (N-k-1) \cdot \ln(\sigma_{k+1,N}^2)$$

Where k is an index ranging from 1 to N, and $\sigma^2_{m,m}$ indicates the variance from index m up to and including index n.

Seek the minimum point of AIC curve, and its time component indicates the starting point of PD pulse [13].

In this paper, AIC method is used to help analyzing experimental data. Figure 5(a) shows PD waves accessed from HFCT sensor in the reflected wave test, and their AIC curves are shown in figure 5(b).

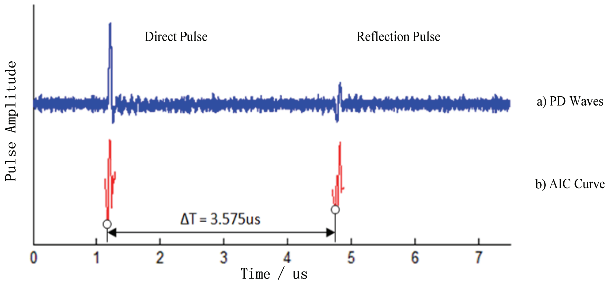



Fig.5 PD pulses in XLPE cable and AIC results

With reference to the AIC results, the time difference between direct pulse and reflected pulse is 3.575us. As the cable length is 300 meters, we can get the propagation speed of PD pulse in XLPE cable: $v = \frac{2\times 300m}{3.575us} = 167.8us$

The test result is accord with general record which is 160-180m/us.

2. PD Source Direction Discrimination

When suspect fault was found in XLPE cable joints or cable terminals during the PD detection, we can set-up HFCT and UHF sensor to give a further examination. The direction of PD source is allowed be determined by ATA method using two HFCT sensors.

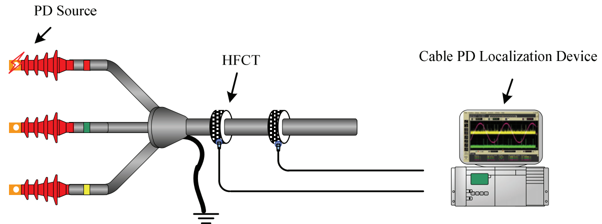



Fig.6 PD experiment in XLPE cable using two HFCT sensors

In this paper, we set a PD fault on the cable terminal, and connect two HFCT sensors around the cable core near that side as shown in figure 6. The distance between two HFCT sensors is near 10 meters. Figure 7 shows the signals from these two sensors, and the AIC analysis results are shown in figure 8.

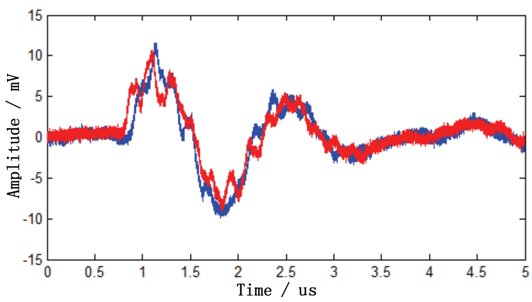



Fig.7 Signals from HFCT sensors

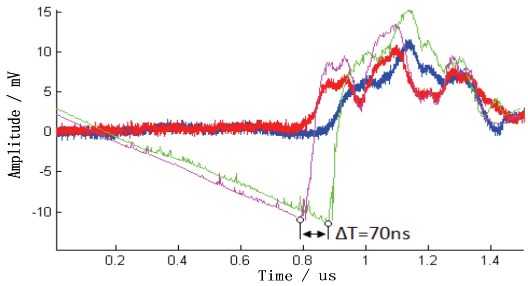



Fig.8 HFCT signals and AIC analyze results

From AIC analysis results, we can clearly see the time difference between the two HFCT signals, which the red one is before the green one. So the PD pulse was traveled from the cable terminal. With reference to the propagation speed which we had got from former reflected wave test (167.8m/us) and the time difference of the two HFCT signals (70ns), the exact distance of two sensor is allowed be calculated, which is $l = 167.8m/s \times 70ns = 11.8m$. The result is accord with the experimental setting.

3. Localization In XLPE Cable Accessories

If the PD site was affirmed in cable joints or cable terminals, HFCT and AE sensors can be used to locate the exact fault cable lines and the precise fault phase.

In this experiment, we simulate the PD signal with electrical ignition on an A-phase terminal in XLPE cable. Multi-sensor joint detection technology is used to locate the PD site as shown in figure 9.

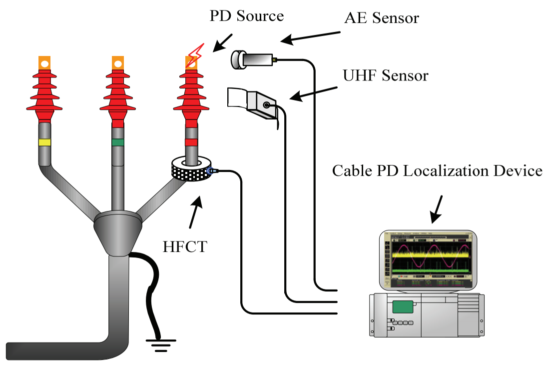



Fig.9 PD localization experiment in XLPE cable accessories

HFCT sensor is set-up around the cable core; UHF sensor and AE sensor are placing near the cable terminals, where the AE sensor is 31.4 centimeters away from the A-phase terminal. Figure 10 shows the signals obtain form each sensor. AIC method is taken to process the AE signal data. The result is shown in figure 10(c).

According to the analysis results, we can learn that the time difference between the HFCT signal and the AE signal is 912.6us. As introduced formerly, the AE sensor used air coupling type. AE signals travel 340m/s in the air, and we ignore its propagation path inside the XLPE cable (as we know the AE signals travel much faster in the solid than in the air). Then the distance from PD site to AE sensor is allowed be calculated. $l = 340m/s \times 912.6us = 31.03cm$. The result is accord with the theoretic calculation.

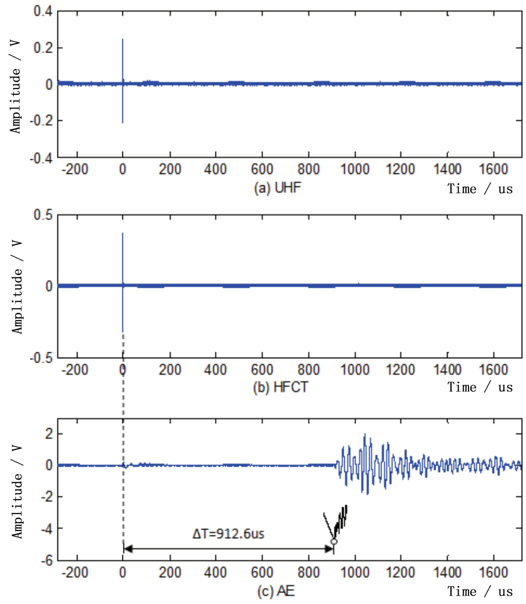


Fig.10 Signals from UHF, HFCT, AE sensors and AIC result

## Conclusiona

Multi-sensor joint detection technology, applying HFCT sensor, UHF sensor and AE sensor methods, is effective to accomplish the PD detection and localization on the XLPE cables. The joint detection technology can improve the efficiency of localization by comprehending multiple sensor information and implementing the PD localization step by step. The experimental research indicated that the application of multiple sensors has enhanced the accuracy and reliability of PD localization.

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