E3S Web of Conferences **390**, 06030 (2023) https://doi.org/10.1051/e3sconf/202339006030
AGRITECH-VIII 2023

Concerning partial discharge detection in cable lines using high-frequency sensors

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Abstract. Partial discharges result in cable line faults that can occur in defective insulation systems made of rubber, polyethylene, XLPE, and flexible PVC. Insulation defects may occur due to disruptions in their production process, cable installation, and operational conditions. Therefore, the diagnostic and monitoring of partial discharge occurrence in cable insulation help prevent emergencies in damaged cable line sections. Partial discharge registration is a non-destructive diagnostic method that helps assess the cable line condition and localize the detected defects. There are various methods of operational monitoring and partial discharge cause analysis based on operative partial discharge sensors. The assessment of cable line condition depends on the efficiency of signal detection and processing by the sensors used. This article reviews the problems of detecting and localizing partial discharges in cable lines and junction boxes using HFCT and UHF sensors. Having analyzed the capabilities of these sensors, we believe that the combined usage of HFCT and UHF sensors is the best method of detecting and localizing partial discharge within the entire cable system (lines and junction boxes).

1 Introduction

In the energy sector, the prompt detection and elimination of electrical equipment faults help reduce emergency downtimes and prevent accidents, while a system of scheduled/preventive maintenance is reduced to performing repairs based on the current technical condition. Therefore, operating companies currently use various diagnostic and non-destructive methods to control both the shutdown and operating electrical equipment. The development and introduction of new, as well as the improvement of the existing non-destructive methods for the diagnostic and control of electrical equipment, aim to improve the reliability of power supply to consumers.

Partial discharge (PD) registration is one of the most advanced diagnostic methods for cable lines. It helps assess the cable line condition, localize the defects detected, and, using the measured parameters, determine the PD level and location.

Currently, the relevant problems for cable lines with different insulation types include the study of PD and the development of methods to separate their signals from noise interferences, as well as the dependencies of discharge parameter changes over time for the forecasting of electrical insulation properties and the residual operating life.

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https://doi.org/10.1051/e3sconf/202339006030

PDs are observed in the defects of hard insulation (paper, polyethylene, rubber, PVC), water and gas "inclusions" formed during the destruction of the insulation material, and in cable junction boxes if they are not installed properly [1–3]. Insulation defects may form because of the disruptions in cable production and installation procedures, as well as the insulation wear due to environmental factors. While such inclusions are practically absent in cables with impregnated paper insulation if their production and operation procedures are observed, they can be observed in cables with rubber, polyethylene, XLPE, and flexible PVC insulation.

PDs have several development stages, including reversible destruction, unstable temporary PD attenuation stage, and the stable process resulting in progressing insulation destruction. When PDs occur, cable insulation experiences electromagnetic, electrical, chemical, thermal, optical, and acoustic phenomena.

The statistics show that up to 85% of the cable line faults can be attributed to PD [1, 2]. Therefore, the monitoring and subsequent analysis of PD occurrence in XLPE-insulation cables help prevent emergencies in damaged cable line sections. Currently, there are several aspects of researching PD: the dependency of PD parameters and sine form and pulse impacts [4, 5], temperature and treeing processes [6, 7], and the insulation wear mechanism [1, 8–10]. For instance, the authors of [1] note that viewing PD as an insulation wear mechanism is necessary to forecast the disruption of the insulation and assess its residual life, while the shape and frequency of the PD signal help establish its cause and location [11].

2 Partial discharge detection methods

According to GOST R 55191-2012 [12], PD are measured to determine their parameters, intensity, and voltages for occurrence and attenuation. The electrical method based on the measurement of charges in metering system elements caused by the PD in the insulation is one of the most popular quantitative assessment methods (electrical, electromagnetic, and acoustic) used for the registration of PD in cable lines [13]. The electrical methods of detecting and localizing PDs in cable line insulation are based on the measurement of current impulse in a controlled cable line. The key PD parameters in the electrical method include the seeming partial discharge, PD repetition rate, average current value, and the phase angle of the impulse. The seeming charge registered by the PD registration system is part of the full charge that is instantaneously supplied to the electrodes. The voltage between them changes like during the real PD for a short time.

The greatest efficiency during the operational control of cable line insulation is achieved with the continuous changing of PD. Therefore, the measurement and the subsequent analysis of the discharge process are performed by various sensors connected to the monitoring device. Sensor type selection depends both on the electrical equipment (cable line) parameters and the task set.

There are numerous offline and online PD detection methods that have their advantages and drawbacks. Focus on an online operational control method for cable line insulation as it facilitates the continuous measurement of PDs. Currently, there are several methods using operative PD measurement sensors tailored for power cables and junction boxes [11, 14]. Testing normally involves the usage of PD detection methods based on broadband measurements with different sensor types [15]. For instance, a high-frequency current transformer (HFCT) sensor is used to detect and localize along with the Time Domain Reflectometry (TDR) method [11]. The reflectometry method provides that the voltage impulse passes with a set speed from the end of the cable to the defect where some of it is reflected. The time between the sending and reception of the reflected impulse helps determine the location of the defect relative to the cable end from which the signal was sent [2].

The authors of [16] note that HFCT sensors are effective within a frequency range of 3-30 MHz. They can be used in a bilateral connection of the cable shield and the ground to capture high-frequency current impulses that are distributed to the ground [2]. The high-frequency transformer (HFCT sensor) captures these impulses and sends their parameters to the PD meter (Figure 1). The advantages of these sensors include the simplicity of installation on cable lines in operation. HFCT sensors placement depends on the technical capability, and they can be installed in two ways: directly on cable insulation or on the ground lead. The first option facilitates high accuracy of PD measurements, and the second one is used when using the first one is impossible. The drawbacks include the high level of noise in PD measurements and the attenuation of the direct and reflected charge impulses when connected to the distribution grid. Besides, HFCT sensors cannot be used to localize two PD sources in power cables [11].

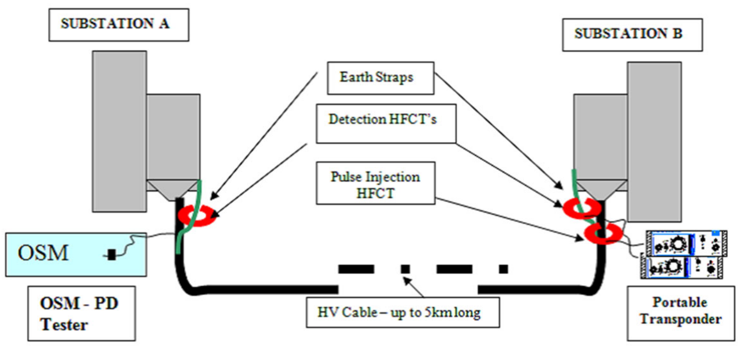

Fig. 1. Double-ended method of PD detection in a cable line using HFCT sensors [14].

The authors of [16] proposed a method based on the ultra-high frequency (UHF) sensors to detect PDs within a range of (300-3000 MHz) that are resilient against noises and interferences and highly sensitive to PDs. The authors of the experiment described in [11] study the PD activity responses generated in the power cable in the UHF and HF ranges using the HFCT and UHF sensors. Similarly to using the HFCT sensor with reflectometry, the UHF sensor also employed the trend method. Based on their research results, the authors of [11] suggested using the two options described above simultaneously to detect, localize, and improve the analysis of PDs in power cables.

The authors of [17] reviewed the detection and localization of PDs in high-voltage cross-connected cable systems using HFCT sensors. The coupling effects of high-voltage and cross-connected lines make it harder to localize the PD signal because the impulses registered by HFCT sensors include signals from the jackets of three conductors. The research on impulse data showed that the location of the PD source is related to impulse polarity and values registered by HFCT sensors. Therefore, the authors suggest installing HFCT sensors around the cross-connected lines and next to junction boxes to localize and monitor PD signals (Figure 2).

The authors of [16] analyze the technical details and practical usage of HFCT and UHF sensors to measure the PDs during the diagnostics of high-voltage equipment and XLPE cable line insulation. The advantages of each of the sensor types were analyzed and compared. For instance, the advantages of measuring PDs in the HF range using HFCT sensors include the fact that the sensitivity does not depend on the impulse shape and distance to the PD location. If the PD impulse propagates through the cable shield, it can be measured at a distance exceeding one kilometer [18]. For the practical measurement of PDs, the authors of [16] recommend using HFCT sensors with a bandwidth of 20 MHz. The location of defects in a cable system can be determined using the time-of-flight analysis with several HFCT

 https://doi.org/10.1051/e3sconf/202339006030

sensors installed. The advantages of PD measurement with UHF sensors include resilience against electrical interference, high sensitivity, and the capability of PD source localization in cables and accessories while detecting internal and external defects. We suggest an optimized electromagnetic detection method based on the combined usage of broadband PD sensors for measurements over HF and UHF ranges. We described a UHF-HF converter that allows for enjoying the advantage of UHF impulse capture, as well as recording and analyzing signals with the PD metering device with HFCT sensors. The efficiency of the proposed measurement methods was demonstrated in an experiment where several PD sources are measured simultaneously in a high-voltage setup comprising a XLPE-insulated 12/20 kV cable line connected to a gas-insulated substation with a plug-in terminal (Figure 3). Based on the above, the authors of [16] conclude that the usage of a PD detection sensor with an HF bandwidth facilitates the analysis of the signals measured by HFCT and UHF sensors.

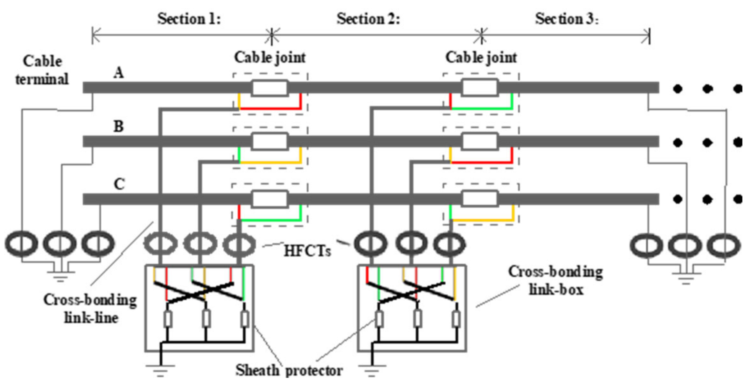

Fig. 2. Location of HFCT sensors for PD measurement in HV cross-connected cable systems [17].

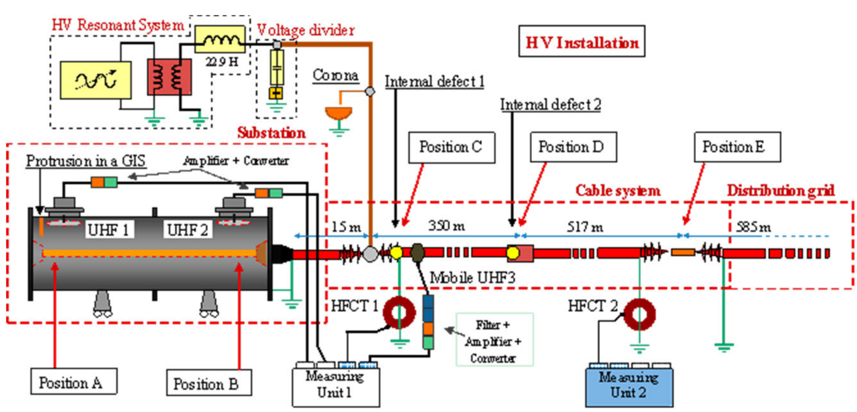

Fig. 3. Experimental setup for measuring multiple PD sources using HFCT and UHF sensors [16].

The simultaneous detection of PDs in the cable line [19, 20] and junction box housing require the usage of highly-sensitive capacitance TEV sensors that detect electromagnetic signals as voltage pulses along with the UHF sensors.

Despite the accuracy of these methods of PD detection and diagnostic in cable lines, operating companies face some problems [2] like the weakening of the generated PD signal impulse as it passes through the cable lines, the superimposition of noises from the external environment, and PD metering equipment, and the calibration of the detected PD signal to establish the defect size and type.

 https://doi.org/10.1051/e3sconf/202339006030

3 Conclusions

Having reviewed the materials above, we assume that the optimal PD signal detection and localization in cable lines and junction boxes require a combined approach using HFCT and UHF sensors.

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