AN EXPERIMENTAL SETUP FOR INSOLATION FAULT DETECTION OF XLPE CABLES

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Abstract

Insulation coordination is one of the most critical issues in high-voltage electrical installations. The smallest defect in the insulation will cause major problems in the near future. Timely insulation failure diagnosis can prevent life-threatening occupational accidents. Insulation fault diagnostics create maintenance costs for the business but prevent much larger costs that are highly likely to occur in the long run. This paper presents an experimental setup to detect insulation problems of XLPE cables. The experimental setup is composed of a coupling capacitor, voltage divider circuit, High-Voltage transformer, coupling device, and coaxial cable. The specimen of XLPE cable is connected from the high-voltage side of the transformer and the data is collected from the measuring device connected at the end of the coupling device. The paper presents different test results for different XLPE cable specimens tested on the presented system. It is possible to test different medium or high-voltage cables using the presented experimental setup.

Keywords: *partial discharge, insolation fault detection, XLPE cable, high-voltage*

1. INTRODUCTION

In the realm of electrical cable technologies, cross-linked polyethylene cables (XLPE) have garnered widespread recognition and application across diverse industries, owing to their exceptional properties. These cables are highly regarded for their capacity to withstand high electrical stress, providing a dependable solution for a myriad of applications. Notably, their impressive thermal stability ensures sustained performance even under the most demanding operating conditions. Moreover, XLPE cables exhibit remarkable resistance to moisture and chemicals, making them a fitting choice for underground and underwater installations, where exposure to harsh environmental factors is unavoidable. The versatility of XLPE cables extends beyond traditional industrial setups and extends into emerging sectors, such as renewable energy projects, facilitating the efficient transmission of power from sustainable sources. As a result, these cables have become an ideal choice for modern industrial installations, owing to their superior insulation characteristics.

Despite their advantageous attributes, insulation faults, also known as insulation defects, pose a significant challenge to the integrity and performance of these cables. These faults can arise from various factors, including manufacturing imperfections, mechanical damage during installation or operation, environmental conditions like temperature fluctuations and moisture, as well as the natural aging process over time. Three primary types of insulation faults partial discharge, voids formation within the insulation material, and water trees development each present unique challenges that demand vigilant monitoring and maintenance to uphold the cable's reliability and longevity.

To address these concerns effectively, early detection of insulation faults is crucial in preventing potential damage to XLPE cables and ensuring the safety of personnel and assets. Identifying these faults at their early stages allows operators to take immediate corrective actions, resulting in significant cost savings associated with cable replacement and minimizing downtime. Furthermore, effective fault detection enhances power transmission systems' overall reliability and longevity. To achieve this paramount objective of timely fault detection, it is imperative to employ advanced diagnostic techniques that can efficiently identify any abnormalities or defects present within XLPE cables. Various methods such as partial discharge measurement, thermal imaging analysis, dielectric spectroscopy, and acoustic emission monitoring have been extensively used for this purpose. Among these methods, partial discharge measurement has been frequently used in the studies carried out to date.

In the domain of high-voltage XLPE cables, a thorough comprehension of partial discharges necessitates meticulous observation and precise measurements (Joseph, Mohan & Thiruthi Krishnan 2019). In this pursuit, researchers have employed various numerical techniques to simulate XLPE cables within computer environments, enabling the analysis of partial discharge events. Notably, during the 1990s, scientists devised diverse methodologies centered around the reflection time differences approach (Mashikian, Bansal & Northrop 1990). Among the prominent methods available in the literature, the amplitude-frequency mapping method advanced by Cavallini et al. (Cavallini, Montanari & Puletti 2007), the phase difference-based proposal by Mardiana and Su (Mardiana & Su 2010), and the pulse rise time and transfer function (RTTF) method introduced by Sheng et al. (Sheng et al. 2015) stand as noteworthy examples. Accompanying these numerical analyses, electromagnetic investigations are frequently facilitated using software like ANSYS and EMTP. While these analyses yield promising outcomes, it is imperative to reinforce them with experimental studies and thoroughly deliberate their accuracy. In recent times, Khan et al. (Khan et al. 2020) have presented an advanced finite element-based computational algorithm, effectively modeling and analyzing various voids to measure partial discharge in cavities and voids, irrespective of their shapes and sizes. To study and analyze the partial discharge behavior, the KB statistical properties extracted from the simulated KB signal are utilized. To validate the efficacy of their proposed modeling approach, Khan et al. also conducts a comparative study between simulated and experimental results. Pattanadech and Nimsanong (Pattanadech & Nimsanong 2014) offer a comparison of four statistical classification models for CR classification. These models encompass the k-nearest neighbors (k-NN) model, the probabilistic neural network (PNN) model, as well as the PCA-KNN and PCA-PNN models, which employ principal component analysis (PCA). Furthermore, a fault diagnosis method based on kNN for a converter transformer is proposed. To collect the KB signals, Liu et al. (Liu, Zhang & Yao 2013) design four types of artificial greaseproof paper insulation faults and utilize an Ultra High Frequency (UHF) antenna. The collected UHF signals are subjected to multiscale wavelet packet transform to calculate energy coefficients, which are then employed in the kNN algorithm to recognize characteristic parameters. The diagnostic capability of the proposed algorithm is compared with the KB mode recognized by BPNN (Back Propagation Neural Network), demonstrating its superior suitability for converter transformer fault diagnosis.

The aim of this study is to establish an experimental setup to detect insulation problems of XLPE cables. The experimental setup consists of a coupling capacitor, voltage divider circuit, high voltage transformer, coupling device and coaxial cable. In this context, the experimental setup and the dataset used are presented in the second part of the study. The third section discusses the results obtained. Finally, the conclusion is summarized in the fourth section.

2. PARTIAL DISCHARGE PHENOMENA

In medium and high voltage systems, the integrity of insulation and the reliability of insulated equipment are critical aspects that directly influence the operational efficiency of the power grid. Partial discharges (PDs) have emerged as a primary cause of aging, degradation, and failure in insulation materials, contributing significantly to approximately 85% of equipment failures within these voltage ranges. Although partial discharge represents the most common fault encountered in insulation materials, insulation breakdown faults also play a substantial role in overall insulation failures. The underlying factors giving rise to partial discharges in medium and high voltage insulation are multifaceted, encompassing aspects such as surface contamination, material irregularities, voids, flaws, presence of air bubbles in liquid insulation, floating particles in gas insulation, and mechanical failures in the insulation material. These diverse activities associated with partial discharges gradually deteriorate the equipment over time, often progressing from an incipient fault condition to complete failure, leading to sudden power network outages (Refaat & Sham 2018).

The consequences of inadequate equipment maintenance or unexpected failures can be significantly high, underscoring the crucial role of insulation materials as the backbone of any electrical system. As a result, their use has become increasingly widespread in power generation, transmission, and distribution systems operating at medium and high voltages. According to IEC 60270, partial discharge is defined as "a localized growth of dielectric breakdown in an area within a solid or fluid dielectric insulation system under medium or high voltage stress." The occurrence of partial discharge is observed at any point in solid, liquid, or gaseous insulation systems where the electric field strength exceeds the insulation material's breakdown threshold. Generally, partial discharges can be categorized into three main types: internal discharges, surface discharges, and corona discharges. Internal discharges mainly occur within cavities of solid insulations and are formed through the electrical treeing process. Surface discharges, referred to as streamer discharges, initiate in regions with high tangential field strength along the interface. When the applied voltage is increased, discharges occur around the surface. Additionally, corona discharge occurs when corona emerges in a high electric field, particularly at sharp edges, such as at the end terminations of power cables (Refaat & Sham 2018).

The detection and localization of partial discharges in medium and high voltage cables present significant challenges. As a result, substantial research efforts have been dedicated to developing techniques for measuring and monitoring partial discharges as a preventive tool to protect high-voltage equipment from complete damage. These detection methods rely on measuring changes in various physical properties influenced by environmental variables, such as acoustic emission, radio waves, light, and heat. Chemical, acoustic, optical, and electrical measurements are employed in these techniques to accurately detect and assess the presence of partial discharges.

3. MATERIALS AND METHODS

3.1. Experimental Setup

High-voltage experiments are carried out in a laboratory environment. Experiments are realized using the coupling capacitor system in accordance with the IEC 60270 norm. The circuit diagram of the experimental setup is presented in Fig. 1.

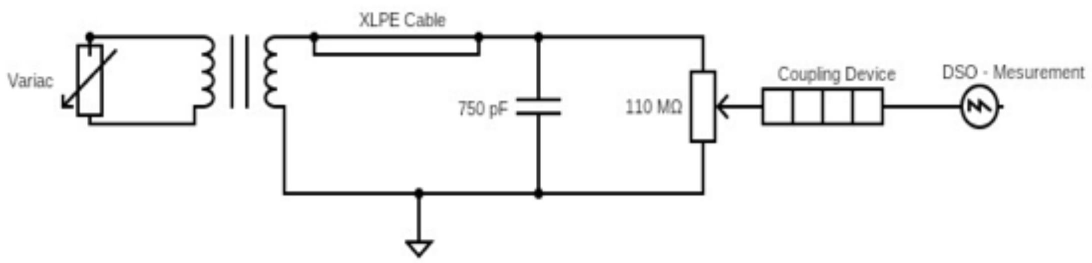

Figure 1. Circuit Diagram of the Measurement System

First, various defects are figured out on the cable samples of equal lengths with a cross section of 95 mm2, prepared by cutting from the same cable. Copper cable is preferred for experiments since it is widely utilized. These defects are introduced to simulate the weak regions within the XLPE cable insulation system, which are susceptible to deterioration and potential insulation failure. A sample of XLPE cable and the PD test system in the laboratory is shown in Fig.2.

Figure 2. Measurement System in the Laboratory

Partial discharge detection is a crucial aspect of assessing the insulation defects in cross-linked polyethylene cables (Qian et al. 2019). These defects can lead to potential insulation failure and compromise the reliability of the power grid. To evaluate the state of XLPE cables without interrupting power supply, on-site or online detection of partial discharge signals is performed. This allows for the early detection of cable degradation and facilitates timely action to address potential failures. One commonly used method for PD detection in power cables is the high-frequency current method. It allows for the identification and analysis of PD signals, providing valuable insights into the condition of the XLPE cables.

3.2. The Dataset

The test scheme shown in the previous section made measurements from XLPE cable samples with different imperfections. As a result of these experiments, in which measurements were obtained, time series PD signals for various defects were obtained and recorded. In this way, the data set was created. PD signals are raw data. The data is obtained from the coupling capacitor measurement system without filtering or feature extraction. The data are usually indistinguishable, as seen in Figure 3. The signal of each different sample corresponds to another fault on the cables. These faults correspond to defects that are likely to occur in real life. Assembly errors, errors that may arise in cable production, are among these error types.

4. EXPERIMENTAL RESULTS

In this paper, six different types of assembly defects are figured out and tested under 15 kV medium voltage level in the high voltage laboratory. These six defects are defined accordingly in Table 1.

No	Defect Label	Defect Description
1	*Defect 1*	Well-Prepared
2	*Defect 2*	Scratched
3	*Defect 3*	Nail Dipped
4	*Defect 4*	Needle Tip Gap
5	*Defect 5*	Badly Stripped
6	*Defect 6*	Deep Scratched

Table 1. Labels and descriptions of the defects created

Each defect presented in Table 1 has been created by considering insulation failures that may occur in real life. In this context, for Defect 1 type, no defect was created and the cable was prepared normally. For the creation of Defect 2, a cut was made in the cable insulation. For the creation of Defect 3, a nail was driven into the cable insulation. To create Defect 4, a pinpoint gap was created in the cable insulation. To create defect 5, the semiconductor part of the cable insulation was badly peeled off. Finally, to create Defect 6, a deep cut was made in the insulation section of the cable.

Following the creation of defective cables prepared by considering six different possible scenarios, PD measurements of each cable were carried out using the experimental setup. For this purpose, each cable was connected to the experimental setup and a medium voltage level below 15 kV was applied equally to all cables. Finally, PD data were collected and recorded using the measuring device connected to the end of the coupling device. Figure 3 shows the PD signals collected for each defect and their comparison.

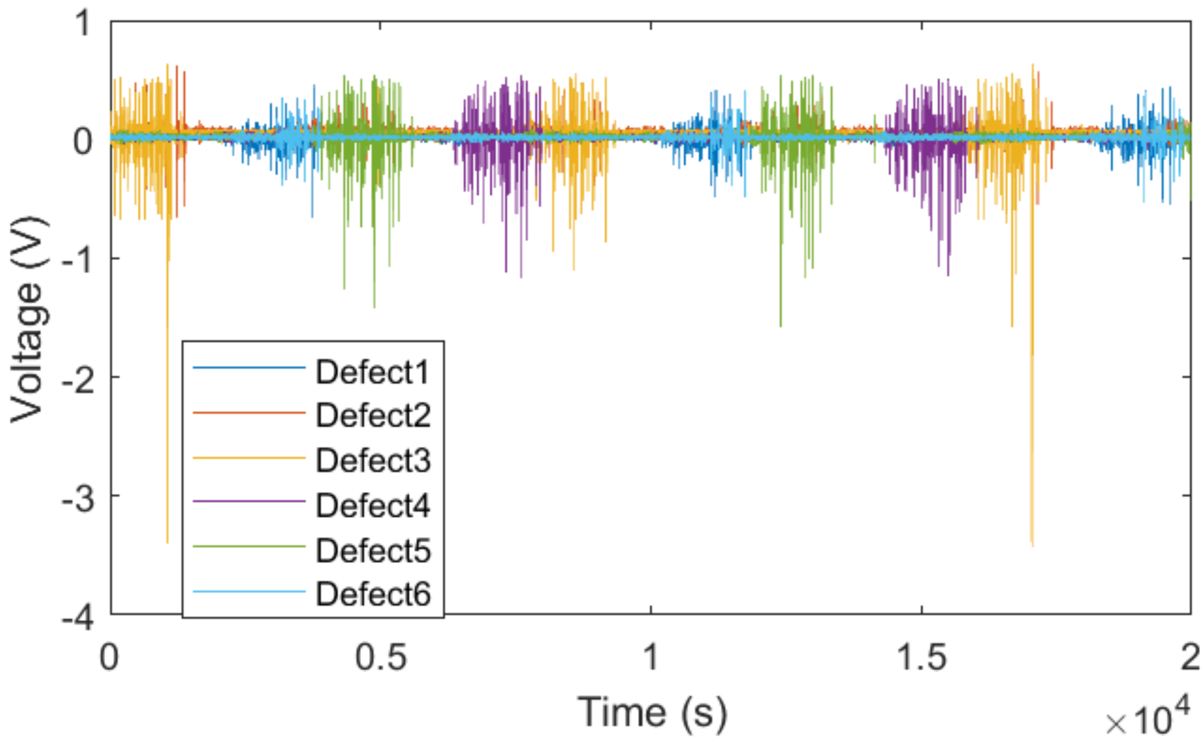

Figure 3. Comparison of the All PD Signal Varieties

As can be seen in Figure 3, the PD signal of each defect shows different characteristics. When the signal from the "well-prepared" cable, which is called Defect 1, is analysed, it can be seen that the voltage fluctuations occurring at certain intervals remain at very low levels. On the other hand, when the signal from the "nail dipped" cable, which is named as Defect 3, is analysed, it can be seen that the voltage fluctuations can reach quite high levels at certain intervals. In addition, although there are slight differences in the Defect 1 and Defect 2 signals, similar changes are observed. In addition to the graphical representation of the signals, certain statistical parameters frequently used in the literature were used to analyse the collected data. In this context, minimum, maximum, mean value, mode, standard deviation and range statistical parameters of the signals were calculated and presented in Table 2.

Statistical Parameter	Defect 1	Defect 2	Defect 3	Defect 4	Defect 5	Defect 6
Minimum	-0.6535	-0.6614	-3.425	-1.165	-1.575	-0.5276
Maximum	0.4646	0.6063	0.6299	0.5354	0.5354	0.4094
Mean Value	0.0163	0.0485	0.0415	0.0167	0.0216	0.0156
Mode	0.0157	0.0440	0.0393	0.0157	0.0157	0.0157
Standard Deviation	0.0157	0.0440	0.0393	0.0157	0.0315	0.0157
Range	0.0477	0.0494	0.1134	0.0753	0.0812	0.0330

Table 2. Statistics of The PD Signals

As can be seen from the statistical parameter results presented in Table 2, although each signal has similar parameter values, the signals can be separated from each other with certain parameter values. For example, Defect 3 differs from all other signals with a minimum value of -3.425 and a range value of 0.1134. Similarly, although the minimum, maximum, mean value, mode and range parameter values of Defect 4 and Defect 5 are very close to each other, the standard deviation parameter value of Defect 4 is half of Defect 5. As can be seen from these results, insulation failures in XLPE cables can be successfully detected with the help of the experimental setup created within the scope of the study.

In light of the experimentation conducted, it has been determined that the raw partial discharge data captured in time series format by means of the experimental setup holds significant potential for application in classifying and detecting faults. A future area of focus is to develop a deep learning algorithm trained on this PD dataset, which will enable efficient classification of insulation faults. By leveraging this approach, it becomes possible to identify and categorize various types of insulation anomalies accurately and expeditiously.

5. CONCLUSIONS

Partial discharge data is becoming increasingly popular in fault detection in XLPE cables. This data plays a crucial role in identifying potential insulation defects in cables and can be used to evaluate the state of the cables without interrupting the power supply. By detecting and analyzing PD signals, the early deterioration of the cable can be identified promptly, which ultimately enhances the power grid's reliability. One effective method for PD detection in XLPE cables is through the coupling capacitor. This technique involves placing an optical fiber coupling between the acoustic transducer and the test cable, which enables the detection of partial discharge and protects the system from flashover. In this paper, an experimental setup and XLPE cable samples are prepared and tested under high voltage in the laboratory environment. 1x95/16 copper XLPE cables were damaged during assembly, and defective cable samples were obtained. One undamaged and five damaged cables are listed as Defect 1-6. Raw PD data in the form of time series obtained after the experiments can be used in fault detection applications with any classification algorithm.

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