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Application of the UHF method for partial discharges measurement in high voltage cable lines

***Abstract**. The article presents the assumptions, characteristics and description of the implementation of a pilot installation of electromagnetic partial discharge sensors on the operating 110 kV high voltage cable line. The installation was intended to realize the measurement of partial discharges without switching off the line, by using an unconventional UHF method. The works described in the article were the first stage of the implementation of a complete on-line partial discharges monitoring system whose main objective is to increase the reliability of cable lines. The article also presents an analysis of received measurement results whose correct interpretation requires additional research work.*

***Streszczenie.** W artykule przedstawiono założenia, charakterystykę oraz opis realizacji pilotażowej instalacji elektromagnetycznych czujników wyładowań niezupełnych na czynnej linii kablowej wysokiego napięcia 110 kV. Instalacja miała na celu zrealizowanie pomiaru wyładowań niezupełnych bez konieczności wyłączania linii spod napięcia, poprzez wykorzystanie niekonwencjonalnej metody UHF. Opisane w artykule prace były pierwszym etapem wdrożenia kompletnego systemu monitoringu on-line wyładowań niezupełnych, którego głównym celem badań jest zwiększenie niezawodności pracy linii kablowych. W artykule przedstawiono również analizę otrzymywanych wyników pomiarowych, których prawidłowa interpretacja wymaga podjęcia dodatkowych prac badawczych. (**Zastosowanie metody UHF do detekcji wyładowań niezupełnych w liniach kablowych wysokiego napięcia**)*

Keywords: cable lines diagnostics, partial discharges, unconventional methods of partial discharges measurement, UHF electromagnetic method.
Słowa kluczowe: diagnostyka linii kablowych, wyładowania niezupełne, niekonwencjonalne metody detekcji wyładowań niezupełnych, metoda elektromagnetyczna UHF.

Introduction

The growing requirements of customers in the scope of continuity of electricity supply in connection with the regulatory model, newly introduced by the Energy Regulatory Office, require distribution companies to constantly develop their grids to improve the reliability of power supply. The new model of regulation was introduced to reduce the value of reliability indicators in Poland, which, despite the significant increase in investment outlays in the distribution grid in recent years, still significantly deviate from the European average. For example, in 2016 in Poland System Average Interruption Duration Index (SAIDI) was 272 minutes/recipient, and System Average Interruption Frequency Index (SAIFI) was 3.46 interruptions/recipient. The average values of these indicators for the European Union were in the same year at the level of 170 minutes/recipient in the case of SAIDI (at the lowest value of approx. 20) and 1.75 interruptions /recipient in the case of the SAIFI indicator (at the lowest value of approx. 2) [1]. According to the quality regulation, distribution companies are required to reduce SAIDI and SAIFI indices by 50% by 2020, adopting the base year for 2015 [2].

Despite the fact that the qualitative regulatory model is in force for a few years, distribution companies are still far from reaching the assumed goals, which is mainly due to the sensitivity of the existing energy infrastructure to various types of failures. The Polish Power Grid is still mainly an overhead grid, which makes it particularly sensitive to damage caused by atmospheric phenomena. An example of the scale of the impact of weather phenomena on the reliability of power supply is the year 2017, when rapid storms combined with strong winds caused extensive damage to grids, which resulted in a significant increase in reliability indicators (for some Distribution System Operators even more than 2 times compared to 2016) [3]. The 2017 events showed that despite multi-billion investment in grid infrastructure and solutions to limit the effects of malfunctions (including those described in [4] by the authors), the Polish electricity grid is still very sensitive to atmospheric phenomena, which can be the source of extensive failures covering hundreds of thousands recipients. These investments were also insufficient to fulfill the objectives of the quality regulation, resulting in the DSO having to pay the agreed penalties.

Due to the inefficiency of existing investments, currently a special emphasis has been placed on the reconstruction of existing overhead lines to the cable lines - insensitive to atmospheric phenomena threatening overhead lines. This trend has been visible in Poland for many years, but now it has become the main investment activity aimed at real improvement of the power supply reliability. The significance of the problem was confirmed by the latest report of the Supreme Audit Office "Protection of consumer rights of electricity" in which it was noted that without increasing the share of cable lines and accelerating work on the implementation of smart grids, traditional grids will still be sensitive to violent weather phenomena, and the Polish electricity energy recipient will still be waiting for the resumption of energy supplies much longer than recipients from other EU countries [5].

The intensification of the construction of new cable lines, combined with the need to improve the reliability of the power supply, makes it particularly important to ensure trouble-free operation of both newly established and already used cable lines. The significance of the issue increases as the rated voltage of the cable line increases - the higher the voltage level, the greater the consequences of potential damage.

Ensuring trouble-free operation of the cable line requires the use of appropriate methods to assess its technical condition. The main task of the assessment is to detect potential damages before they appear - both directly after construction of a cable line (acceptance tests) as well as during its operation (periodic inspections). The former standard for cable lines construction requires only voltage tests, consisting of supplying the line for a limited time with higher than operation value of voltage. This type of test is intended to lead to breakdown in places with a reduced level of insulation - if the breakdown occurs, the necessary repair works are carried out before the line is connected to the power system in order to ensure an adequate level of line insulation. The main disadvantage of this type of test is the fact that it only detects damage that leads to the breakdown of the insulation, while a large part of potential damage does not immediately take on the character of a complete discharge, leading to insulation breakdown only after a longer time. Many lines that pass the voltage test within a few years get damaged, which was not detected in the acceptance test.

Insufficient effectiveness of the voltage tests carried out for many years caused that currently the scope of acceptance tests has been significantly extended - in addition to the voltage test, are actually performed: dielectric loss angle tangent (tanδ) measurements, which is a comprehensive measure of the state of insulation of the tested cable, and diagnostic tests of partial discharges, allowing detection and accurate location of discharges that do not cause insulation breakdown. The main purpose of the diagnostic test is to detect potential damage to the cable line long before it is generated - in most cases (80-90%), the insulation breakdown is preceded by an increased partial discharges. The use of advanced acceptance tests allows detection of most damages caused by material defects, assembly errors or transport damage. In order to detect damages caused during cable operation (connected with aging processes, degradation of insulation or increased operating temperature) at regular intervals, diagnostic tests should be repeated. Each time when diagnostic tests of partial discharges are performed, unfortunately, it requires switching off the line, causing in many cases power supply deprivation. For this reason, periodic tests are very often not performed, which results in the lack of information about the technical condition of cable lines already in operation. The necessity of excluding the line from voltage during the tests and relatively long periods between tests (5-10 years, if they are performed at all) cause that this solution is not ideal for ensuring trouble-free work of the cable line.

In order to eliminate these inconveniences, in recent years detection standards for partial discharges have been developed using unconventional methods, as described in IEC TS 62478:2016 *High voltage test techniques - Measurement of partial discharges by electromagnetic and acoustic methods* [6]. The developed methods do not allow direct measurement of the apparent charge of discharges, however, by indirect measurement of other quantities, they give the opportunity to determine the level of discharges in the tested object, without switching off the line (detection of partial discharges takes place with the operating voltage attached) [7, 8]. The advantages of unconventional methods of detecting partial discharges caused that steps were taken towards their implementation in the power grid in the form of on-line partial discharges (PD) diagnostic systems [9, 10, 11]. This article describes the first stage of the implementation of an innovative PD on-line diagnostic system, including installation of sensors and analysis of acquired measurement data, which will be followed by the implementation of a complete diagnostic system.

The pilot installation of UHF partial discharge sensors

The first stage of research work, preceding the implementation of a complete on-line PD monitoring system, was equipping the operating 110 kV high voltage power line with partial discharge detectors using the UHF method for detection of partial discharges (based on the measurement of electromagnetic radiation in the ultra-high frequency range) [12]. The sensor installation was preceded by a conventional PD diagnostic test (electric method) made using a VLF measuring system (including a voltage test, tanδ measurement and PD diagnostic measurement). The cable line covered by the implementation was made with a 3xXRUHKXS 1x630RMC/50 64/110 (123) kV cable. On its route, two cross-bonding joints were used, and the cables were terminated with dry cable terminations. The total length of the cable line is about 3 km. On both sides of the line exists transitions to the overhead line, where on the high voltage transmission towers, cable terminations with surge arresters are located. The conventional diagnostic test did not show internal partial discharges in the tested cable line (with the disconnected surge arresters), the only detected discharges were the corona discharges on the cable terminations. Confirmation of good technical condition of the cable line (lack of internal partial discharges) was necessary for correct verification of the measurement results obtained subsequently from UHF sensors. Attachments of one of the surveyed towers are shown in Fig. 1 (the photo was taken just before the conventional diagnostic tests, to which the surge arresters have been disconnected from the cable line).

Fig. 1. High voltage 110 kV transmission tower covered by the installation of UHF sensors

As UHF PD sensors were used Doble LDWS-T sensors (Fig. 2), which are actually capacitive dividers working in the UHF band (100 MHz - 1 GHz). The sensors were mounted in parallel to the cable termination post insulators, on both sides of the cable line (total number of 6). The measuring waveguides (connected to the sensors via TNC sockets) were brought to the measuring box attached to the transmission tower construction. The assembly of the UHF sensor to the cable termination is shown in Fig.3.

Fig. 2. Partial discharge UHF sensor (Doble LDWS-T)

Fig. 3. The method of assembly the UHF sensor to the cable termination

The UHF sensors enable PD unconventional measurement in a continuous mode (when the line is supplied with 110 kV 50 Hz operating voltage), without switching off the line from the voltage (in accordance with IEC TS 62478:2016). Applied sensors enable direct detection of partial discharges in cable terminations. By propagating the electromagnetic wave both in the air and in the cable metallic screen, the sensors can simultaneously detect partial discharges in the surrounding equipment (surge arresters and cable section near the termination). Because of the presence of electromagnetic waves of various origins in the air (such as radio, television or cellphones), these signals are also captured by UHF sensors, which results in measuring background and external interference during measurement.

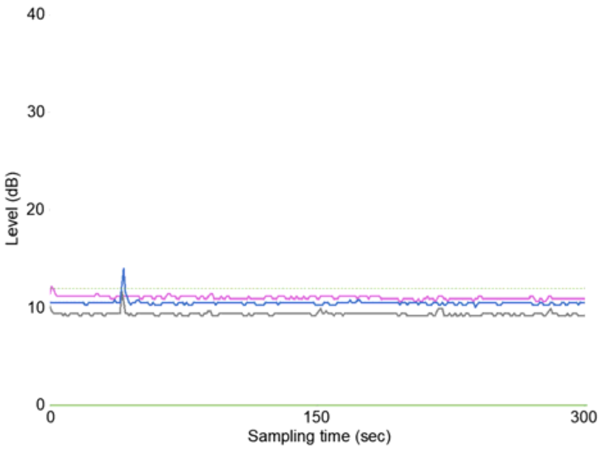

Fig. 4. Time chart of partial discharges activity – transmission tower no. 1, without rain

The scope of research carried out using UHF sensors included the determination of the external background level with the supplied high voltage line and the determination of the measurement signal dependence on atmospheric conditions. As previously mentioned, the measurement stations were equipped only with the sensors themselves, without a continuous monitoring system, also the measurements were carried out periodically, under various atmospheric conditions, using the partial discharges analyzer NDB PD Annunciator, operating in accordance with IEC TS 62478:2016. A single analyzer enables connection of up to 3 partial discharges sensors operating in the UHF band (the measuring band for the analyzer is from 10 MHz to 500 MHz). The tests were aimed at testing the sensors and their cooperation with the analyzer before using the devices in the target on-line monitoring system. The works were carried out in various atmospheric conditions at the terminations on both sides of the high voltage cable. The time charts of partial discharges activity selected from the series of measurements are shown below in Fig. 4, 5 and 6. The pink color indicates the phase L1, the gray phase L2 and the blue phase L3.

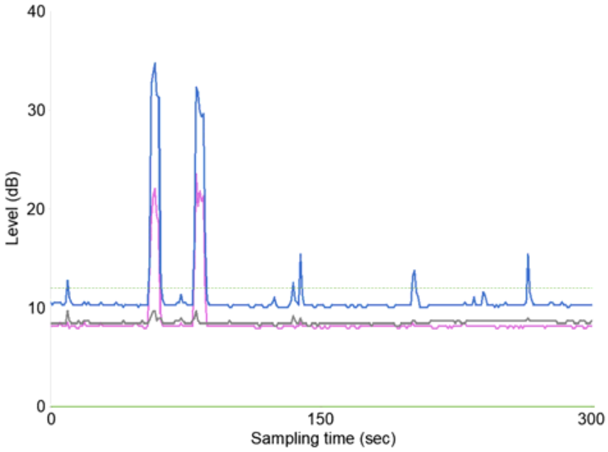

Fig. 5. Time chart of partial discharges activity – transmission tower no. 2, without rain

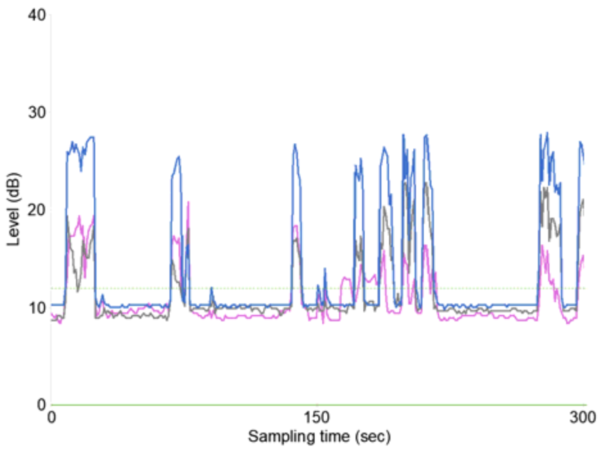

Fig. 6. Time chart of partial discharges activity – transmission tower no. 2, rainfall

On the basis of the PD measurements results, it can be noticed that the measurement signal is dependent on interference of external origin (constant component of the signal) and atmospheric conditions (such as rainfall, which causes surface and corona discharge). The difference between both ends of the cable line is also visible - the sensors located on the transmission tower no. 1 in normal operating conditions do not show significant changes in the measurement signal, and the measuring system on transmission tower no. 2 detects regular increases in the level of the signal with different amplitude, probably due to partial discharges in cable accessories (in particular L3 phase). It should be noted that the discharges present on one phase propagate in the air and grounding, and also they are detected by sensors installed on the other phases, from where the time overlap of the partial discharges activity for different phases results. The rain has a significant influence on the measurement signal - the discharges caused by them reach the value even 3 times higher than the determined level. These arrangements are possible only by measuring the activity of partial discharges while simultaneous monitoring the weather conditions. Otherwise, based on the measurement signal itself, an unambiguous evaluation of the source visible on the discharges would be impossible. Even with the known weather conditions, it is unfortunately not possible to determine the sources of internal discharges. The repeated discharges detected on L3 phase on tower no. 2 can occur in the termination or surge arrester - they can also come from a section of the cable in the immediate vicinity of the sensor. Without an additional analysis of the measurement signal, it is impossible to accurately indicate a potentially damaged element. The assessment of the technical condition of the cable accessories is also difficult by the fact that there are currently no standards for defining alarm levels in systems using unconventional partial discharges measurement methods. Based on the signaled problems in the interpretation of measurement data, it can be concluded that there is currently a need to develop criteria for the evaluation of measurement results in terms of unambiguous identification of PD sources and correct levels of alarm activation. This issue will be the subject of further research by authors in the near future.

Conclusions

1) The need to improve the power supply reliability requires urgent action to limit SAIDI and SAIFI indicators;
2) One of the main directions of grid modernization is the replacement of overhead lines for cable lines;
3) In cable lines, an important issue is partial discharges that precede the failure and which early detection makes it possible to take corrective actions before insulation breakdown;
4) In order to ensure reliable operation of cable lines, it is necessary to equip them with monitoring and diagnostic systems operating under operating voltage;
5) The measured level of partial discharges is strongly dependent on external factors, including disturbances and atmospheric conditions;
6) Based on the measurement signal itself, it is not possible to clearly assess the source of partial discharges;
7) The lack of standards for defining alarm levels of partial discharges activity causes uncertainty in the unambiguous assessment of measurement results;
8) There is a need to develop measurement criteria for measurement results to unambiguous identification of discharge sources and correct levels of alarm activation;
9) The solution to above problems will be the subject of further research, which will include simulation tests using laboratory high and medium voltage test cable lines, and whose results will be implemented into real partial discharges diagnostic systems.

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