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INVESTIGATION ON THE TECHNOLOGIES FOR DEFECT LOCALIZATION AND CHARACTERIZATION ON MEDIUM VOLTAGE UNDERGROUND LINES

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ABSTRACT

This study is based on the CORPRES project led by the utility Iberdrola and focused on improving the reliability of underground power lines of polymeric insulated Medium Voltage (MV) cables using the latest cable diagnosis technologies, mainly the analysis of partial discharges. The main concern is to detect and locate specific defects produced during the installation of the cable and of its accessories. The ageing of the cable is not considered in this research.

A real-scale test bench was built expressly to analyze the validity and the precision of each of the technologies available for the detection of defects and their location in underground cables, fundamentally through the analysis of partial discharges.

The voltage sources applied, the acquisition systems and the data analysis procedure were the basic differences between the different technologies used, which were: very low frequency (VLF), 50Hz resonant, resonant at variable frequency and damped alternating voltage (DAC). All the measurements were carried out by experts in each technology.

The results show important differences between technologies when we compare the results for the same specific defect and when we compare all the defects on the cables and their accessories.

This article describes the configuration of the test bench circuit and the criteria followed on designing the defects. A review of the technologies used was carried out with the aim of describing the main differences. The results obtained were analyzed from the point of view of the detection and of the location of defects. Finally, some processes were proposed for the standardization of the measuring equipment and procedures based on the results obtained.

KEYWORDS

Partial discharges, underground cable, underground cable accessories, time domain reflectometry.

INTRODUCTION

As the network expands and ages it is important to maintain its reliability. For this the utilities and the regulations of each country are developing test criteria for the commission and maintenance of cable systems.

Partial discharge tests are becoming the most appropriate tests for the commission of new cable systems, replacing the previous DC tests.

The partial discharge tests of cables systems on the field can be carried out using different types of energization sources, mainly very low frequency (VLF), 50Hz resonant, 20-400Hz variable frequency resonant and damped alternating voltage (DAC). The commercial units available on the market fixed the relationship between the measuring units and the high voltage sources used.

During the CORPRES project all these partial discharge analysis technologies were tested and compared on a test bench specially designed for this purpose. The objective was to verify the behaviour of the different field technologies used to detect defects in the cable installations.

The main objectives were: to establish the typology of defects caused during the installation of the cable and of its accessories, build a work bench reproducing this typology, and compare the technologies and the detection levels achieved by the latter.

WORK BENCH AND DESCRIPTION OF THE DEFECTS

As explained above, the first step was to establish the most common typology of defects caused during the installation of the cable and of its accessories. Using the historical data file of Iberdrola Distribution and the experience of the workforce, a catalogue of commonly found defects was obtained (see table 1).

Defects on joints	Example photos
Irregular cut of external semiconductor	
Longitudinal cut on the insulation	
Incorrect shape of the cable ends	

Incorrect distance between the cable insulation and the body of the sleeve	
Incorrect pressing of the body of the sleeve	
Inclusion of foreign elements in the body of the joint (water, earth, low voltage insulating tape)	
Defects on indoor and outdoor terminations	
Irregular cut of external semiconductor	
Longitudinal cut on the insulation	
Incorrect distance between the insulation and the terminal	
Defects on cable	
Partial elimination of the sheath affecting the external semiconductor	
Crushing of the cable	
Partial perforation by sharp object	
Excessive folding of the cable and return to its original position	
Permanent folding of the cable	

Table 1 Typology of defects.

Four cables of 12/20kV nominal voltage with HEPRZ1 insulation and cross-sections of $150mm^2$ and $240mm^2$ were laid in an underground gallery. The length of each cable was approximately 460 metres, approximately 60% installed on trays and 40% buried in dry ground. Prior to the tests the ground was watered to dampen it.

Following the typology of defects shown in table 1, a set of accessories with artificial defects was installed on each cable, simulating defective installations like those found in real installations, but with a much greater density of defects.

	Defective terminations	Defective joints	Folding	Crushing	Perforations	Sheath damage
Cable1	2	6	1	0	0	2
Cable2	2	5	2	1	1	3
Cable3	1	4	1	0	0	1
Cable4	1	5	1	1	2	0

Table 2 Initial number and type of defects on each cable.

Six companies tested the cables using different cable diagnosis technologies. The technologies used were very low frequency VLF (1 company), 50 Hz resonant (1 company), 20-400 Hz resonant (1 company) and damped alternating voltage DAC (3 companies). Up to thirty different test configurations were obtained per combination of the cables and tested by each company. The maximum voltage level applied was in all cases $2 \cdot U_o$, with $U_o = 12kV_{rms}$.

TDR TEST RESULTS

The first analysis was focused on the use of time domain reflectometry (TDR). This technique was used initially for the location of joints and, after the PD tests, for the location of partial discharges.

Table 3 presents the TDR analysis for the location of joints. Letters A to F represent the different companies performing the tests.

Company	A	B	C	D	E	F
Impedance changes detected	151	190	-	112	-	-
Impedance changes which coincide with joints	105	151	-	65	-	-
Detection [%]	69.54	79.47	-	58.04	-	-

Table 3 TDR statistical data.

As shown in table 3, companies A, B and D performed the TDR analysis for joints detection, while C, E and F did not carry out the joint location analysis. The detection levels show that, for example, for company A, 69.54% of times the impedance change locations reported coincided with real joint positions, while 30.46% of times a joint was positioned in a location where there was no joint. An uncertainty of ±1% was used all along the cable to locate the impedance changes.

It should be stressed that the detection levels would have been higher if the number of joints being tested had been lower.

PD TEST RESULTS

The analysis of partial discharges focused on two aspects. First, the study from the point of view of detection, and second, the validity of the data reported, that is how many times a defect existed in the location reported and how many times there was no defect in the position reported (see table 4). The location of the source of partial discharges was carried out in all cases by reflectometry. The uncertainty used for the calculations was ±1% all along the cable being tested. The number of defects generating PD was the number of defects detected at least by two companies.

Company	A	B	C	D	E	F
Number of cables tested	24	24	30	20	24	23
Number of defects existing	52	53	53	55	53	55
Number of defects generating PD	20	20	20	20	20	20
Number of defects found	15	16	15	8	15	9
PD detection [%]	75	80	75	40	75	45
PD pulses reported	357	3365	209	335	468	69
PD pulses coinciding with defects	350	3197	159	288	455	67
PD pulses not coinciding with defects	7	168	50	47	13	2
PD pulses correctly positioned [%]	98.04	95.01	76.08	85.97	97.22	97.10

Table 4 Overall partial discharge results for each company.

The PD detection ratios should be interpreted cautiously. For example, company C has a high number of defects reported which do not correspond to positions of real defects. These data indicate that there is an incorrect interpretation by the operator on carrying out the data analysis and locating the source of the partial discharges. In particular, in this case the importance of the human factor is shown to be clear within this kind of analysis, as there are another two companies using the same technology with better results.

CONCLUSIONS

There is a certain group of defects which does not produce partial discharges at the time of reception of the installation, and which therefore cannot be detected by means of partial discharge diagnosis techniques, although some of these types of defects can evolve, producing partial discharges and consequently an insulation breakdown in the cable.

The TDR analysis shows that this technique can achieve good joint detection levels in cables. Very useful and reliable information can thus be used to contrast the joints found with those declared by the cable installers.

The analysis of the results of the partial discharge detection success rate clearly shows the influence of the operator when field tests are carried out, and warns the utilities and the companies which analyze the cables to take into account the training of the personnel involved in this type of tests.

Under the conditions in which this project was carried out, the experimental results show that there is not one partial discharge testing technology for installed MV cable systems which provides significantly better results than another. Companies A, B, F and E use different technologies with different types of high voltage sources, different sensors and different data filtering and analysis tools, but have overall similar success rates.

Although the analysis of results on a large population of cables shows that similar results can be obtained using different technologies, and moreover it has been confirmed that the influence of the operator is critical, large differences can be found when the analysis of results is focused on one MV cable in particular.

An example of this is shown in figure 2, where the axis X represent an MV cable being tested, indicating on the thick line two lengths of cable with a cross-section of 240mm^2 and on the thin line a length of cable with a cross-section of 150mm^2. Each mark represents an artificial defect made on the cable or its accessories.

In this case, the defect D1 was detected by companies A and B, while the defect D2 was detected by companies A, C and E, and the defect D3 was detected by companies A, B, C, D and E.

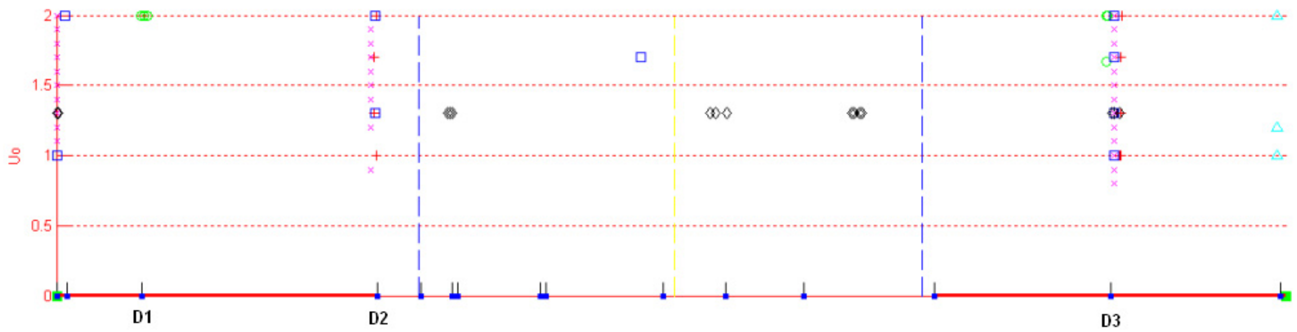

Fig. 2 PD activity on a cable measured by different companies.

The study of cables separately shows differences between technologies, possibly due to the different voltages levels of PD inception on each defect depending on the type of the voltage source. In conclusion, the partial discharge tests cannot be compared among themselves if different types of voltage sources are used for testing.

The possible relationship between the magnitude of the partial discharges and the type of high voltage source used was investigated, but no relationship was found between them due to the great dispersion of results.

The same conclusion was reached on researching the possible relationship between the PD inception voltage levels and the type of voltage source used. It was not possible to establish any correlation.

It was observed that there is no unanimity among the different equipment available on the market when it comes to determining the form in which the assessment of the PD level is carried out. Of the four technologies used in this project, three different methods were found to carry out the assessment of the PD level.

The simplest method obtains the calibration constant starting from the relationship between the injected calibration charge and the peak value of the pulse recorded. Another method obtains the calibration constant starting from the relationship between the calibration load and a partial integration of the pulse detected. The final method consists of obtaining the calibration constant with the regulatory method described in IEC 60270 which consists of obtaining the calibration constant from the relationship between the calibration pulse and the peak value of a quasi-integration of the pulse.

Independently of the method in which the PD level is assessed, all the methods obtain their reference constants from the calibration process, so the calibrators play a fundamental role in the process.

It was detected that there are calibrators with excessively small rise times, which causes high current peaks with equal charge, thus increasing the difference of results between technologies.

The differences in load obtained between different types of technologies could be reduced partially if the characteristics of the calibrators, the sensors and the way in which the load is assessed were more delimited for the field tests.

Figure 3 shows an example of three types of wave belonging to three calibrators from different manufacturers. The pulses shown were captured on an analog bandwidth oscilloscope of 500MHz with a sampling of 1.25GS/s. The load resistance of the oscilloscope of 50Ω was used. All the calibration pulses correspond to the 200pC range of each calibrator.

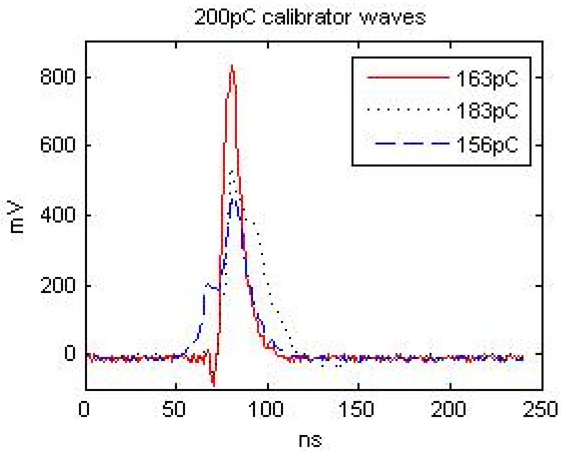

Fig. 3 Pulses of 200pC of three different calibrators.

As can be seen in figure 3, the load injected values from the calibrators expressed in picocoulombs (pC), do not correspond to the 200pC range chosen, presenting differences of up to 22%. In addition, the rise and fall times and duration of the pulses present substantially different durations. Therefore, even the 163pC pulse presents a peak value above the pulse of 183pC. These variations obviously influence the assessment of the magnitude of the PD and the processes to estimate the sensitivity of the measurement and the noise.

An example of difference in the PD level obtained for different technologies is shown in figure 4, where the magnitudes obtained by each company are shown for the same defective accessory, in this case a joint.

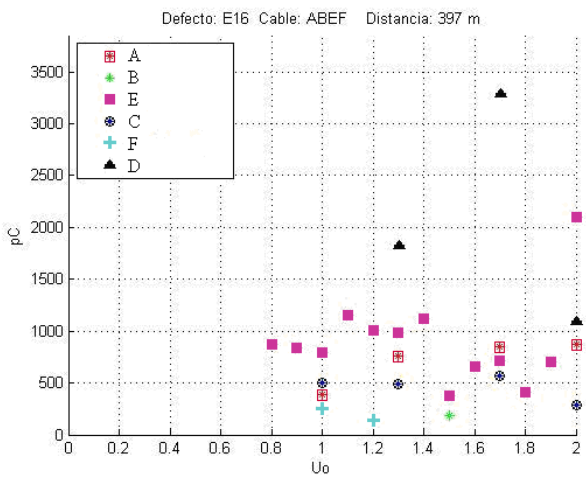

Fig. 4 PD activity on a joint.

It is also important to stress that during the partial

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discharge tests it was demonstrated that the use of simple clips as an element of connection between the cable being tested and the high voltage source may generate PD. To avoid generating corona type partial discharges at the connection point, connection clips should only be used when the connection is made between discs, plates or toroids at the same potential as the clip, and only when there is no termination installed at the connection point. For cell type connectors the appropriate connector must be used (see figure 5).

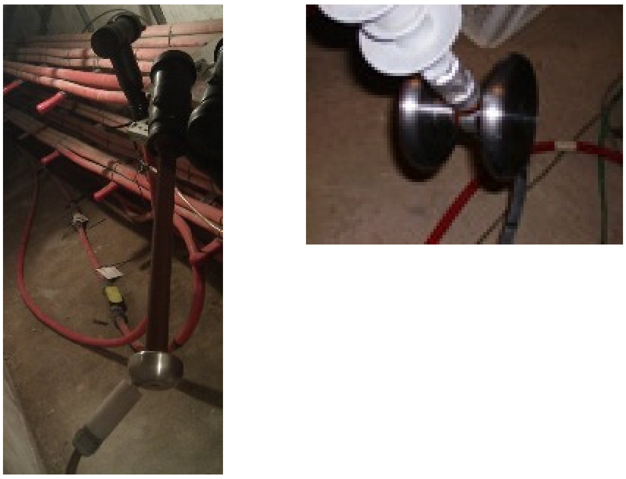

Fig. 5 Connections free from PD appropriate for use in field tests.

Acknowledgments

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GLOSSARY

PD: Partial discharge
TDR: Time domain reflectometry