Study Committee B1

Insulated Cables

10867 2022

Best practices for Partial Discharge Monitoring of HVDC Cable Systems and Qualification Tests

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(1) FFII-LCOE, (2) UPM, (3) DIAEL-AMPACIMON

Motivation

- The cables used for HVDC transmission lines have a low signal attenuation and therefore the sensitivity in the acquisitions is higher than in HVAC cables. However, on the other hand, it is known that the PD rate of an internal insulation defect (cavity type) in HVDC cables is very low and depends on the applied voltage and on the temperature variations.
- The technical requirements to be faced by the PD monitoring systems implemented in HVDC cables monitoring are described from the point of view of hardware, signal processing and intelligent diagnostic tools.

Method for PD Monitoring of HVDC Cable Systems

- If you want to monitor a complete cable system along its entire length, the use of HFCT sensors placed, depending on the cable attenuation every few kilometers, is the most suitable solution to reduce the number of sensors to be used.
- A recommended measurement procedure for PD monitoring of cable systems using HFCT sensors is shown in the flowchart (Figure 1).
- A standardized qualification procedure for HVDC and HVAC cable system PD monitoring systems is needed to define the requirements and the tests that must be met. Different research institutes collaborate in the EURAMET project "FutureEnergy" trying to contribute to this international standardization.

Measuring system using HFCT sensors

According to IEC 60270 the transfer impedance Z(f) of any PD measuring system is the ratio of the output voltage amplitude, V_{out}, to a constant input current amplitude, I_{in}, as a function of frequency f, when the input is sinusoidal.

The transfer impedance Z(f) has a direct relationship with the sensitivity of the entire measuring system, since the higher the output signal V_{out} for 1 mA of the input PD current pulse, the higher the sensitivity of a PD measurement. When the coupling device is HFCT sensor, the transfer impedance is given by the rms output voltage divided by the rms input current, (mV/mA), which should be determined from 0.5 kHz to 50 MHz.

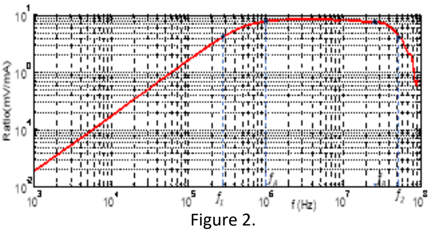

Figure 2.

Transfer impedance Z(f) of a HFCT sensor used as coupling device of a measuring system (Figure 2): Bandwidth defined by f_1 and f_2; operation frequency range defined by f_A and f_B (± 5%).

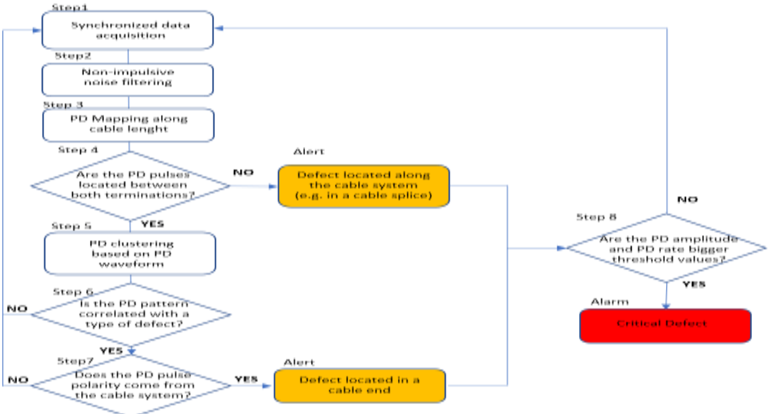

Figure 1.

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Synthetic PD Generator

- For qualification tests a current pulse generator is used (Figure 3). This pulse generator emulates PD current pulses trains, whose individual PD current pulse waveforms are synthetically generated at instants where PD pulses were recorded in PD event train. The synthetic PD generator of PD current pulse trains can operate in "PD calibration mode" generating known PD pulses, q, with a known pulse repetition frequency, N or in "PD pattern generation mode" generating PD current pulses according to a selected PD event train linked to a type of defect.

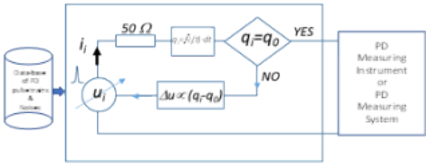


Figure 3.

- T_{PD}: The equivalent width of a rectangular PD pulse with the same charge value as the PD current pulse.

$$T_{PD} = \frac{1}{i_{peak}} \cdot \int_0^{\infty} i(t) \cdot dt$$

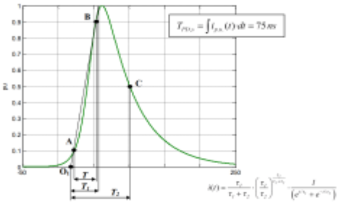


Figure 4.

Scale Factor of a PD Measuring System

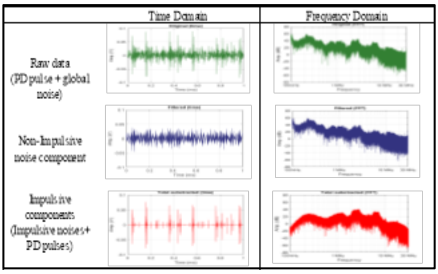
- The smaller the scale factor the greater the sensitivity of the measuring system is achieved; therefore, the rated transfer impedance should be as high possible. Small values of T_{PD} (very narrow pulses) correspond to a higher upper frequency limit in its amplitude-spectrum. T_{PD} values around 75 ns are the most representative of the PD measurements in HV cable systems

$$k\left(\frac{pC}{mV}\right) = \frac{q}{u_{peak}} = \frac{i_{peak} \cdot T_{PD}}{Z_t \cdot i_{peak}} = \frac{T_{PD}(ns)}{Z_t\left(\frac{mV}{mA}\right)}$$

Type of electrical noises

- Noise rejection tools should operate in two steps. The first step is focused to reject non-impulsive components of the background noise, for example by means of band-rejection filters or wavelet filters [5] and [6] and the second step to remove the impulsive components by means of pulse clustering tools [7] and [8]. An example of a raw data acquisition in a HVDC converter plant is shown in table 1.

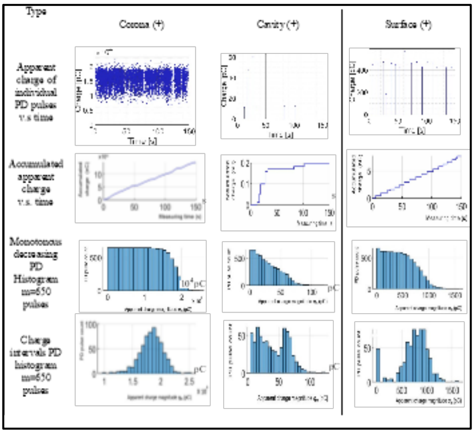
Table 1.



Representative PD Pulse Trains in HVDC Cable Systems

- For each defect type three representative PD curves can be displayed: a) accumulated charge curve, b) monotonous decreasing histogram and c) PD histogram distributed in levels, as they are shown in Table 2.

Table 2.



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Qualification Procedure of PD Analysers

- Any PD analyser is composed by a PD measuring system and additional hardware or software tools to get an automatic or semi-automatic evaluation of insulation condition. The qualification tests are summarized in Table 3. Tests 1 and 2 are related to the PD Measuring System and tests 3, 4 and 5 to specific abilities of their software tools.

Table 3.

		Qualification Tests
PD Analyser		1) Non-impulsive noise rejection (for AC and DC).
	PD Measuring System	2) PD sensitivity
		2.1 Largest repeatedly occurring PD magnitude (for AC)
		2.2 Linearity check of the measuring system (for AC and DC).
		2.3 Resolution time, T, of the measuring system (for AC and DC).
		2.4 Determination of the Scale factor, k vs PD time, T_{PD} (for AC and DC).
		3) PD clustering performance (for AC and DC).
		4) PD recognition performance (for AC and DC).
		5) PD location performance (for AC and DC).

- The calibration setup to check PD analyser performances is shown in Figure 5. It is composed of a Synthetic PD generator connected to a 50 Ω load resistor through a coaxial cable of 50 Ω characteristic impedance. The PD current pulse trains is injected in a current loop where the HFCT sensor of the PD analyser under characterization is installed. A reference PD measuring instrument connected at the 50 Ω load resistor through a transmission coaxial cable can be used to carry out comparative measurements.

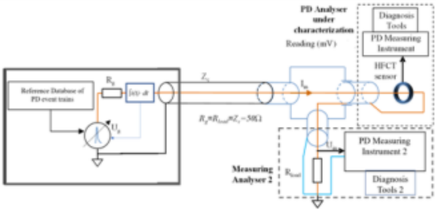

Figure 5.

No impulsive Noise-rejection Test

- A PD pattern related to a defect is all the more difficult to recognize the greater the number of erroneous pulses it contains. Filtering techniques are used to reject erroneous PD pulses but, at the same time, they remove pulses belonging to the original pulse train related to the defect. A filtering tool should remove noise by sacrificing the fewest number of PD pulses belonging to the original PD pulse train. To evaluate the efficiency of a noise-rejection filter, the PD repetition rate error is determined when a white noise superimposed to a PD pulse train. The curve of PD repetition error vs different amplitude levels of the white noise is determined. The measurement error refers to the reading of the measuring instrument without noise. The noise level is expressed in pC measured with a wideband PD measurement system operating between the upper and lower frequencies of 100 kHz and 500 kHz, respectively.

- Figure 6 shows PD repetition rate errors of two different Filters based on: a) Manual selection of the measuring frequency range; b) Automatic wavelet filtering. Smaller PD repetition ratio errors were obtained using the automatic wavelet filtering

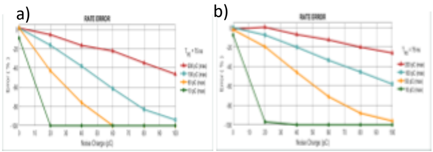

Figure 6.

Conclusion

For PD monitoring of HVDC cable systems a set of five qualification tests have been defined: noise rejection test, sensitivity test, clustering test, recognition test an PD location test. A reference database of PD current pulses linked to type defects has been generated by laboratory tests thanks to the EURAMET project "FutureEnergy". It is advisable that other research institutes develop more reference databases of "defect types" to make international comparisons that lead to international traceability of reference PD event trains linked to "defect types". Using synthetic PD calibrators and an appropriate testing setup a Round Robin Test is planned between six research institutes applying this qualification procedure.

Acknowledgments

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