Partial discharge measurements on 110kV current transformers. Setting the control value. Case study

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Abstract. The case study presents a series of partial discharge measurements, reflecting the state of insulation of 110kV CURRENT TRANSFORMERS located in Sibiu county substations. Measurements were performed based on electrical method, using MPD600: an acquisition and analysis toolkit for detecting, recording, and analyzing partial discharges. MPD600 consists of one acquisition unit, an optical interface and a computer with dedicated software. The system allows measurements of partial discharge on site, even in presence of strong electromagnetic interferences because it provides synchronous acquisition from all measurement points. Therefore, measurements, with the ability to be calibrated, do render:

- a value subject to interpretation according to IEC 61869-1:2007 + IEC 61869-2:2012 + IEC 61869-3:2011 + IEC 61869-5:2011 and IEC 60270: 2000;
- the possibility to determine the quantitative limit of PD (a certain control value) to which the equipment can be operated safely and repaired with minimal costs (relative to the high costs implied by eliminating the consequences of a failure) identified empirically (process in which the instrument transformer subjected to the tests was completely destroyed).

1. Introduction

Electrical utility industry all over the world faces a tough challenge with ageing of the power grid components population as failure of these assets may cause interruption of power supply and also revenue losses. The insulation condition represents an essential cast for reliability in operating high voltage equipment. Considering this, it is very important to identify the healthy units in the ageing equipment' population as not extending service to these units will result in substantial cost savings for the power company [1].

Modern technologies and developments in signal acquisition and analysis techniques do provide new tools for diagnostic of electrical power equipment.
2. Instrument transformers

Per se, instrument transformers are non-rotating electromagnetic machines, powering electrical equipment falling into a broad category of metering and protection devices. Judging by their manufacturing technology, they have some common features with other non-rotating electromagnetic machines (power transformers), still their functional properties resembling more to those of electrical apparatus.

The order of magnitude of voltage and current in a power system is very diverse. Adapting both voltage or current metering systems and protective devices to this wide range of values is neither technically nor economically justified. Therefore, these devices are connected to the electrical circuitry indirectly, via current and voltage transformers – instrument transformers whose construction and operation is tailored specifically for this purpose. The instrument transformers possessing a primary winding and a certain number of secondary windings, performing an isolating function (isolating the utilization current or voltage from the supply current/voltage to ensure safety for both, operator and in use end device), change currents and voltages from one magnitude to another, suitable for power metering and protection devices.

Instrument transformers, in general acceptation [2]:

- transform current and voltage to standardized magnitude appropriate for supplying current and voltage windings of the metering and protection equipment;
- isolate high voltage circuit (the grid) from the low voltage circuit (metering and / or protection), thus removing meters and protection devices from the area influenced by the strong electric and magnetic fields of power grid circuitry, eliminating disruptive action that these fields may have on measurement accuracy and correct operation of the equipment;
- allow rational concentration of metering and protection devices in the control room right outside the substation, enabling thereby direct both command and monitoring of the entire grid.

For each instrument transformer, insulation issues are fundamental and do determine a priori the possible limits of their functional properties [3].

In a CIGRE survey also the used maintenance techniques prior to instrument transformers' failure are listed [4] in table 1.

| Maintenance strategy                                | How often used |
|----------------------------------------------------|----------------|
| Regular visual inspection                          | 95%            |
| Check of oil level and/or pressure gauge            | 61%            |
| Secondary voltage monitoring for CVTs               | 15%            |
| Insulation resistance checks                        | 11%            |
| DGA and/or moisture of oil                          | 7%             |
| Thermovision inspection                            | 4%             |
| DF measurement at mains frequency                   | 2%             |
| **PD measurement**                                 | **1%**         |

3. Partial discharge measurement

Partial Discharge (PD) measurement is a worldwide accepted tool for quality control of high voltage equipment [5]. PD indicates partial loss of the insulating capacity and is, thereby, considered a measure of electrical ageing of any insulation system [6].
The classical measuring circuit, according to IEC60270: High voltage test techniques – Partial discharge measurements, requires a coupling capacitor for the connection of the PD measurement instrument and works at a measuring frequency from several hundred kHz up to one MHz [7], detecting therefore, the line based pulse propagation. Beside these methods, there are also non-electrical PD measurements (e.g. acoustic), used above all for localizing partial discharges. Nevertheless, electrical PD measurement is being by far the most used technique standardized. As a general rule, successful diagnosis requires distinguishing internal partial discharges from any external interference, particularly for onsite applications. Excellent measurement and interference suppression algorithms have therefore been developed for conventional electrical measurement [7].

3.1. Interference – free measurement setup
Often lacking screening, PD signals are every time superposed by various noise pulses, a fact that adds difficulty to PD data analysis for both human and software expert systems. Thus, handling disturbances is one of the main challenges when the goal is to accurately measure PD. The effects of external interference in the measuring circuit are minimized through electrical isolation between the measuring system and the control unit.

3.2. Frequency – selective, narrow band and wide – band measurement
The measuring systems used today extend the measuring range historically limited to ~ 1MHz, as far as 20MHz. Within this wide frequency range, the user can select a band that has only marginal superimposed interference or none at all.

3.3. Synchronous multi–location PD measurement
PD measurements are often performed under noisy conditions. By using synchronous multi-channel PD acquisition it will be possible to gain de-noised PD data from separated PD sources. The PD signal is superposed by stochastic noise pulses or even multiple PD sources, leading to a complex phase-resolved PD pattern that is not easy to analyze. Conventional frequency filters are not able to eliminate these pulse-shaped disturbances [6]. The superposition of multiple PD sources and noise will, nevertheless, raise laboriousness for PD experts and automated computer expert systems. Some well-known evaluation techniques as pulse-sequence analyses would even fail with non-correlated PD pulses to be compared [7]. Separating noise from PD and then separating multiple PD sources must be the starting point onto obtaining free-noise PD data.

3.4. 3PARD evaluation procedures
A new field of evaluation methods is opened by fully synchronous multi-channel PD acquisition in order to gain more reliable measuring results combined with effective noise suppression. Therefore the 3-Phase-Amplitude-Relation-Diagram (3PARD) was introduced as a new powerful analysis tool [3] to distinguish between PD sources and noise pulses when measuring 3-phase high voltage equipment [7]. Through suitable superimposition of the amplitudes, the traditional phase – resolved PD (PRPD) pattern can be broken down into individual components, allowing individual sources to be singled out.

3.5. Analysis of the frequency spectrums
With these processes, it is not the amplitudes measured at various locations that are superimposed, but rather the spectral components measured selectively but still synchronously at one single location. The frequently noisy PD patterns can also be broken down into individual sources using these methods.
4. PD Measuring System
The MPD600 as a fully digital PD measuring system is capable of performing synchronous multi-channel PD measurements [8]. It consists of one or more acquisition units (Figure 1), an optical interface (FO bus-controller) and a PC including the measuring software [9]. The PD signals are filtered, amplified and digitized. A frequency band can be chosen to avoid continuous-wave disturbances and to reach a high signal-to-noise-ratio (SNR) even under noisy conditions on site.

![Scene of a MPD system components](image)

**Figure 1.** Components of a MPD system:
- optic-USB converter (1), PD acquisition unit DP (2), battery pack (lithium-ion) (3),
- calibration unit CAL542 (4), measuring impedance (5), fiber optical cabling (6),
- Ethernet/BNC cables (7), battery cable (8), USB cable (9), notebook (10)

For multi-channel PD measurements several acquisition units can be connected to one distributed PD system [7] while a maximum number of 960 units can be operated in a fully synchronized mode.

5. Case Study
The case study of the current transformer, type CESU\(^1\) 110kV (925011/1979), operating in a 110/20kV transformer power substation, in a 110kV line bay, identified ever since 11 October 2000 (back then by gas chromatography) with potential failure: high-intensity partial discharges, active failure!

Temporal evolution of the technical condition both in terms of chromatographic analysis (for in the insulating oil dissolved gases) and PD measurement results is presented in full in attached Annex 1.

\(^1\) Encoding current transformers denomination:
- C – current transformer;
- E – exterior / outdoor mounting;
- S – support;
- U – insulating environment, ulei (oil);
- m – embodiment with metal compensator;
- o – construction type (monospiral, with bar crossing and median round flange fixing);
- 110(123) – rated insulation voltage [kV];

after these groups of letters and numbers, the rated ratio is printed as: rated primary current / rated secondary current.
Electrical measurements of partial discharge, for this particular current transformer, on site (power substation) were made (starting in July 2007) according to the provisions of standard EN 61869-1:2007 „Instrument transformers. General requirements”, applying, assimilated to it, partial discharge test procedure, using as test voltage the very rated 110kV distribution grid voltage [2].

Considering paramount maintaining the same operation conditions for the instrument transformers and precisely to the purpose of an increased reproducibility of measurement results, following the guidelines of standard EN 61869-1:2007, we knowingly used the rated voltage of the 110kV power distribution grid to perform PD measurements.

One of the main benefits of the PD measuring system used is that the PD acquisition units can be placed very close to the transformer. This minimizes the required length of electrical connecting cables and allows PD signal acquisition with high bandwidth, while minimizing electromagnetic interference.

Using the built-in frequency sweep function, a measuring frequency of 1MHz (1.5MHz bandwidth) was selected. Results of the PD measurements on CT (110kV CESU (925011/1979)), are shown in the following Figures 2 and 3.

![Figure 2](image-url)  
**Figure 2.** Electrical PD measurement according to IEC 60270, center frequency: 1MHz, bandwidth: 1.5MHz, all PD data

As usual for conventional on-line PD measurements, the diagram shows a notable 3-phase corona cross-talk from the substation and the near overhead transmission lines.

The external noise was successfully gated with the information from one second PD acquisition unit. Figure 3 shows the corrected PD pattern recorded.

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2 Partial discharge test voltage is reached while decreasing rated power-frequency withstand voltage.
This significant increase in PD level was measured in August 27, 2011, about two weeks before the complete destruction of insulation: 09.07.2011 (Figure 4). This PD level value, exceeding from a far the permissible PD level [10], according to IEC 61869-2:2012 (10pC), was identified empirically (process in which the instrument transformer subjected to the tests was completely destroyed).

Judging by the temporal evolution of the PD level, measured for 5 years (2007-2011) and considering the maximum slope segment (specific time intervals of 1 year) represented graphically in figure 5, it is necessary to use a safety factor of 17.95% of the maximum measured value (586,285pC).

3 Which applies only to newly manufactured current transformers.
6. Conclusion
The quantitative limit of PD to which the equipment can be operated safely and still be repaired with minimal costs (relative to the high costs implied by eliminating the consequences of a failure) is 480 nC.

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| No | Equipment | Type | Location | Date       | Value        | Description                  | Value        | Description                  | Value        |
|----|-----------|------|----------|------------|--------------|-----------------------------|--------------|-----------------------------|--------------|
| 1  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 10-Nov-2000 | 14.335 CESU | Apparent charge (H2)        | 26.610 CESU | Linear (upper limit)         | 4.183 FREE   |
| 2  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 25-Feb-2001  | 11.085 CESU  | Linear (upper limit)         | 2.224 FREE   | Linear (lower limit)         | 1.879 FREE   |
| 3  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 1-Sep-2001   | 2.179 CESU   | Linear (upper limit)         | 2.749 CESU   | Linear (lower limit)         | 2.004 FREE   |
| 4  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 25-Aug-2001  | 2.418 CESU   | Linear (upper limit)         | 2.224 FREE   | Linear (lower limit)         | 2.004 FREE   |
| 5  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 15-May-2002  | 2.779 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |
| 6  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 1-Jun-2003   | 2.418 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |
| 7  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 1-Sep-2003   | 2.418 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |
| 8  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 15-May-2004  | 2.779 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |
| 9  | CT-A. Vlaicu-Agnita-S  | iTRN | 110/20kV Aurel Vlaicu substation | 1-Jun-2005   | 2.418 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |
| 10 | CT-A. Vlaicu-Agnita-S | iTRN | 110/20kV Aurel Vlaicu substation | 1-Sep-2005   | 2.418 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |
| 11 | CT-A. Vlaicu-Agnita-S | iTRN | 110/20kV Aurel Vlaicu substation | 15-May-2006  | 2.779 CESU   | Linear (upper limit)         | 2.004 FREE   | Linear (lower limit)         | 1.857 FREE   |

**Apparent charge - hydrogen (ppm)/insulating oil dissolved gas dependency for 110kV CT, Aurel Vlaicu substation, bay A12A, phase 5, 2007 - 2011**