

Determining insulation condition of 110kV instrument transformers. Linking PD measurement results from both gas chromatography and electrical method

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Abstract. Working methods for on site testing of insulations:

1. Gas chromatography (using the TFGA-P200 chromatographer);
2. Electrical measurements of partial discharge levels using the digital detection, recording, analysis and partial discharge acquisition system, MPD600.

First performed, between 2000–2015, were the chromatographic analyses concerning electrical insulating environments of:

- A. 102 current transformers, 110kV. Items in operation, functioning in 110/20kV substations.
- B. 38 voltage transformers, 110kV also in operation, functioning in 110/20kV substations.

Then, electrical measurements of partial discharge inside instrument transformers, on site (power substations) were made (starting in the year 2009, over a 7-year period, collecting data until the year 2015) according to the provisions of standard EN 61869-1:2007 „Instrument transformers. General requirements”, applying, assimilated to it, type A partial discharge test procedure, using as test voltage the very rated 110kV distribution grid voltage.

Given the results of two parallel measurements, containing:

- I. to this type of failure specific gas amount (H_2) and

- II. the quantitative partial discharge' level,

establishing a clear dependence between the quantity of partial discharges and the type and amount of in oil dissolved gases inside equipments affected by this type of defect: partial discharges, was expected.

Of the „population” of instrument transformers subject of the two parallel measurements, *the dependency* between Q_{IEC} (apparent charge) and (H_2) (hydrogen, gas amount dissolved within their insulating environment) *represents a finite assemblage* situated between the two limits developed on an empirical basis.

1. Partial discharges. General considerations. Damaging effects on insulation systems

Insulating materials used in manufacturing processes of high voltage electrical equipment, do come sometimes with small local defects consisting of gaseous inclusions or voids (for solid insulation), gas bubbles/cavities (in liquid dielectrics) and metallic / non-metallic particles (metal grit / dust or lint) in quite all insulation systems either solid, liquid or gaseous.



Inside electrical equipment during operation¹, at certain amplitude of the electric field, local and nondestructive discharges occur, limited to a small portion of the dielectric, especially within local faults as described above.

PARTIAL DISCHARGES – PD result in an impulse current occurring within the dielectric providing to its external circuit, impulses, which although engaging low energy levels, are leading to progressive degradation of insulating material properties.

Without going into specific technical details, we state that PDs do modify the insulating materials and depending on the repetition rate and intensity of the process, sooner or later, destruction of the dielectric will be imminent.

Partial discharges stand out by the following features:

- transferred charge of low value, expressed in picocoulombs (pC);
- very short pulse duration ($10^{-9} \dots 10^{-6} s$);
- discharge does not occur throughout the cavity volume, but PARTIALLY;
- for the homogeneous, but also for the non-homogeneous electrical field, PD geometry is not identical to that of electric field that produces them.

Each discharge dissipates a small amount of energy which shall be located inside the cavity. Under these conditions, PD (by its generated pulses) are source of noise within power circuits, of dielectric losses and are always accompanied by emission of sound, heat and decomposition of affected insulating material into gaseous compounds [1]. These events point out multiple methods of detection, measurement and analysis of the PD phenomena.

The effects described above are capable of causing insulation degradation next to the cavities and therefore, if not detected and stopped on time, mechanical erosion of the insulation commencing from void walls will evolve in the mass of the healthy material, fundamentally shortening the life of that insulation system exhibiting such defects.

2. Two methods for detection and measurement of partial discharges

For the ongoing research, taking into account the studied objects – *high voltage instrument transformers, 110kV* – we chose a combination of *two methods for detection, measurement* of partial discharges, namely:

1. non-electrical, chemical: gas chromatography;
2. electrical, using pulses amplification measured from a network element (test object).

2.1. Non-electrical method. Gas chromatography

Due to internal partial discharges (local penetrations of insulation, possessing a high density of ionization or appearance of low energy arcing), decomposition of the insulating materials and formation of various combustible and noncombustible gases will occur; these gas amounts can be detected and measured through gas chromatography. By brief overview of characteristics and performance of gas chromatography, the applicability and effectiveness of this exceptional analytical technique stand out plainly. Very reproductive results recommend the use of gas chromatography. Gas analysis is not only a science but an art subject to variability arising from the vastness of electrical equipment operation and maintenance experience. It is now one of the most used methods for determining and then assessing electrical equipment internal faults [2].

Two are the main components of the complex insulation systems of electrical equipment in service that are affected by PD, namely:

- ① oil – the insulating liquid environment;
- ② paper – solid insulation.

¹ This is the framework within the analysis of partial discharge effects on the state of insulation of high voltage instrument transformers has been developed.

Gas chromatography² is an analytical technique used for separation of sample components between two **phases: a mobile phase (the carrier gas, in this case, helium (He)) and a stationary phase (the column packing or coating).**

Separation begins when a gaseous sample (which diffuses through molecular agitation in a free volume well proportioned compared to the volume of the oil in which they were dissolved) fills the sample loop of the **injector**. The sample is then injected from the loop onto the column. Actual separation occurs inside the column. As each component emerges from the column, separately, (seven (7) gases, key gases: hydrogen(H_2), methane(CH_4), carbon monoxide(CO), ethylene(C_2H_4), ethane(C_2H_6), acetylene(C_2H_2), which are combustible gases and carbon dioxide(CO_2), non – combustible gas) they pass through the **detector**, one at a time. The detector response versus time plot will be a *peak*. This chain of peaks is **the end result – the chromatogram** – with accurate data of the gas chromatography [3].

Computer systems can serial communicate with gas analyzers (Figure 1). This feature of the device allows the computer to control the entire chromatographic process.

It requires a small amount of oil, namely $100ml$ (without air inclusions or other impurities), which will be extracted directly from the electrical equipment in a special container – syringe – (Figure 2) and then immediately airtight sealed.



Figure 1. Portable gas chromatograph
TFGA – P200



Figure 2. Special container, syringe.
for insulating oil sampling

The dissolved in oil gas analysis itself follows (120 sec.). Gases that due to the strong agitation will elute from oil into a free space ($10ml$ of oil will be evacuated to allow this method of gases diffusion – molecular agitation – be applied), from where they will be sampled in by the gas analyzer.

2.2. Electrical method. Pulses amplification measured from a network element

It should be specified that the pulse shape that reaches the measuring instrument depends on the pulse involved at the site of the discharge inside the dielectric, on the geometry of the insulation system and on the characteristics of the external measuring circuit. This pulse will always be different from the one that emerges at the very site of the discharge.

² It dwells on the use of the portable chromatographer TFGA – P200 produced by Morgan Schaffer (Figure 1).

The *SR EN 60270:2003*, standard: *High voltage test techniques – Partial discharge measurements* [4], the Romanian version of the English text for the European standard EN60270:2001/IEC60270:2000):

- defines the used terms and the quantities to be measured;
- describes test and measuring circuits which may be used;
- defines analogue and digital measuring methods required for common applications;
- specifies methods for calibration and requirements of instruments used for calibration;
- gives guidance on test procedures and assistance concerning the discrimination of partial discharges from external interference.

The difficulty in measuring partial discharges is that the pulses can not be measured directly at the site where they occur but only after passing through the test object detection circuit (direct, electromagnetic, etc.).

To measure PD inside the insulation of high voltage instrument transformers, we'll use the method of partial discharges measurement by using broadband amplifiers, trying to determine the quantitative limit $PD(pC)$, to which the electric element can operate under maximum operating safety.

The measurements of partial discharges to determine the insulation state of 110kV high voltage instrument transformers starting in the year 2009 were achieved using the digital system, MPD600 (Measuring Partial Discharge System) for detecting, recording and analyzing partial discharge events.

Measurements by the ability to be calibrated have resulted in: a quantity subject to interpretation according to the standard *SR EN 60270:2003*: **apparent charge**, $Q_{IEC}(pC)$.

Displaying individual output voltage pulses on an oscilloscope screen enables both recognition of partial discharges origin and their separation from any interference / background noises.

Thus, the PD apparent charge can be visualized either on a time base (depending on test voltage) or on a sinusoidal time base synchronized with the test voltage' frequency or on an elliptical time base crossed synchronous with the frequency of the test voltage [5].

According to recommendations of standard: *SR EN 60270:2003* for measuring partial discharges, the procedure:

Determining partial discharges amplitude at a specified test voltage - is the subject addressed in this paper' measurements and for which:

the partial discharges' amplitude (expressed in terms specified) is measured at the nominal voltage of the power grid, voltage value much higher than the alleged partial discharges inception voltage.

The test object will be brought to the specified voltage, voltage to be maintained throughout the range of measurement performing. DP associated characteristics will be recorded throughout the whole period of measurement (DP activity (Q_{IEC}) was measured over a preset, 2 minutes, period of

time and the PD pulses recorded $\left(\frac{k_{PDs}}{s}\right)$ were those just above the threshold / offset of: $1pC$).

3. Instrument transformers. General considerations. Measuring circuits

To safe operate a power system, appliances capable of measuring electrical quantities (current, voltage, power, energy, frequency, power factor ($\cos\phi$), etc.) are indispensable and also those that ensure correct functioning of the network and / or do limit proportions of possible damage to it. First are called *meters*, and other, *protective devices*.

Instrument transformers are non – rotating electromagnetic machines, powering electrical equipment falling into a broad category of metering and protection devices. In this regard, judging by their manufacturing technologies, they have some common features with other non-rotating electromagnetic machines (power transformers), but their functional properties do resemble more to those of electrical apparatus.

High voltage – 110kV – instrument transformers, part of the survey:

A. current transformers (102 elements);

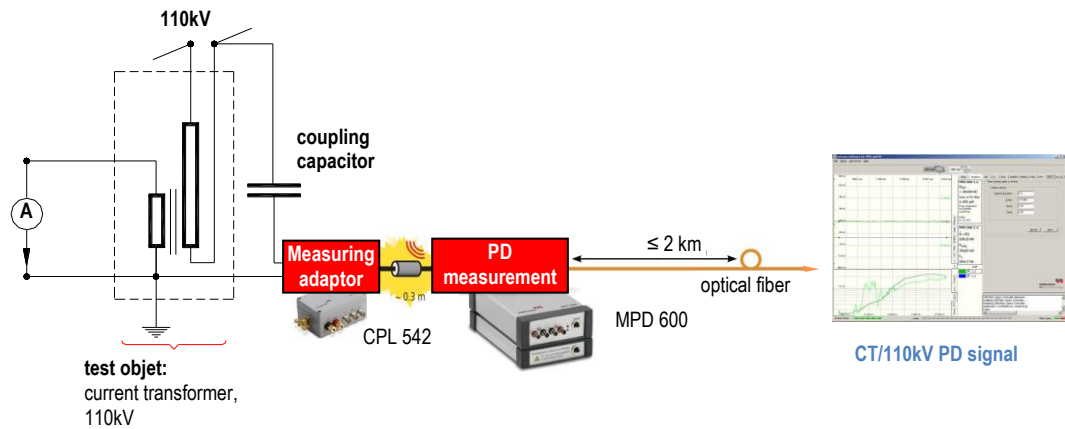


Figure 3. Test circuit for partial discharge measurement on current transformers

B. voltage transformers (38 elements);

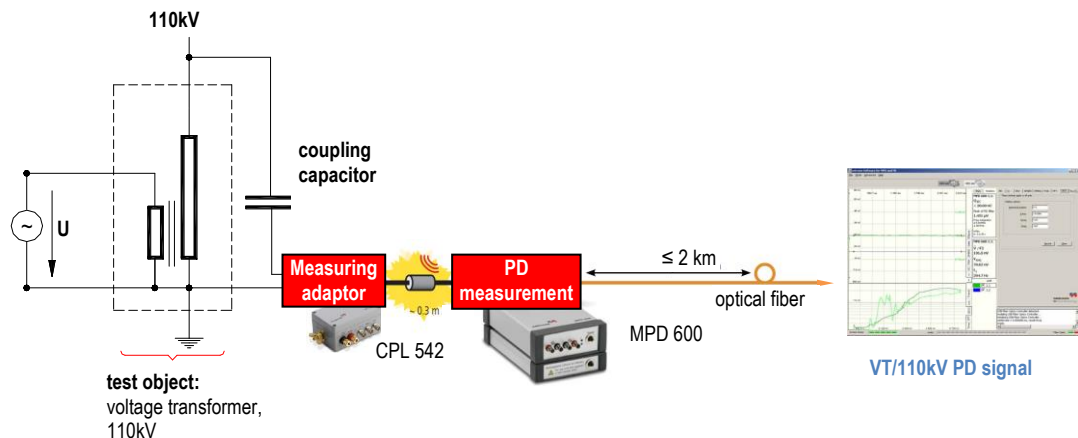


Figure 4. Test circuit³ for partial discharge measurement on voltage transformers

³ Using a high-voltage coupling capacitor: 112kV (1,2nF).

4. Linking high voltage instrument transformers insulation PD measurement results from both methods: non-electrical and electrical

Working methods for on site testing of liquid insulations (insulating oils) were:

1. Gas chromatography for the electrical insulating environment (using the TFGA-P200 chromatographer manufactured by Morgan Schaffer);
2. Electrical measurements of partial discharge levels using the digital detection, recording, analysis and partial discharge acquisition system, MPD600 (Measuring Partial Discharge System) produced by Mtronix Precision Measuring Instruments.

First we performed, between 2000 – 2015, chromatographic analyses (2,545) concerning the electrical insulating environments of:

- A. **102 current transformers, 110kV.** Items (indigenous production of various types) in operation, functioning in 110/20kV substations.
- B. **38 voltage transformers, 110kV.** Devices (all indigenous production, three constructive types) in operation, functioning in 110/20kV substations, mounted in 110kV OHL bays or in 110kV metering/measure bays.

Then, electrical measurements of partial discharge (1,125 individual measurements), inside instrument transformers (figure 3 and 4), on site (power substations) were made (starting in 2009, over a 7-year period, collecting data until 2015) according to the provisions of standard EN 61869-1:2007 „Instrument transformers. General requirements”, applying, assimilated to it, ⁴ a partial discharge test procedure, using as test voltage the very rated 110kV distribution grid voltage [6].

Considering paramount maintaining the same operation conditions for the instrument transformers and precisely to the purpose of an increased reproducibility of measurement results (of gas chromatography and electric measurements), 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 [6].

Given the results of two parallel measurements, containing **(3,760 measurements)**:

- I. to this type of failure specific gas amount (H_2), as results of gas chromatographies performed on the insulating environment of high voltage instrument transformers (current and voltage) 110kV and
- II. the quantitative partial discharge' level inside the same high voltage (110kV) instrument transformers,

establishing a certain dependence between the quantity of PD and the type and amount of in oil dissolved gases inside equipments affected by this type of defect: partial discharges, was expected.

5. Conclusion

Of the „population” of instrument transformers subject to the two parallel measurements, *the dependency between Q_{IEC} (apparent charge) and H_2 (hydrogen, gas amount dissolved within their insulating environment) represents a finite assemblage situated between the two limits developed on an empirical basis* (figure 5):

$$\bullet \text{ upper limit: } \frac{Q_{IEC}(pC)}{H_2(ppm)}, \text{ assimilated, } y = 19\sqrt{2} \cdot x - 230; \quad (1)$$

$$\bullet \text{ lower limit: } \frac{Q_{IEC}(pC)}{H_2(ppm)}, \text{ assimilated, } y = \frac{52}{\sqrt{3}} \cdot x - 521, \quad (2)$$

⁴ Partial discharge test voltage is reached while decreasing rated power-frequency withstand voltage.

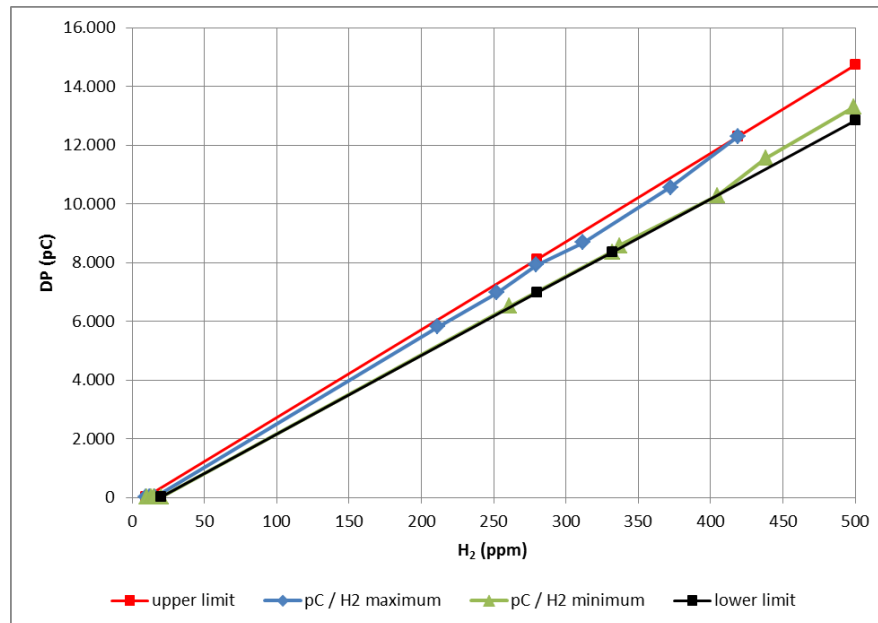


Figure 5. Dependency between Q_{IEC} (apparent charge) and H_2

The two lowest amounts of gas H_2 (hydrogen) dissolved within the insulating environment of those instrument transformers are the maximum quantitative values that can exist (threshold) in the insulating oil of an electrical equipment without it ever functioning [7].

References

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