

# Digital HVDC Partial Discharge Testing

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**Abstract:** The measuring circuit for measuring Partial Discharges (PDs) does not differ when using AC or DC voltage. What differs is the analysis of the measured data. First, because there is no phase resolved information. Secondly, because of the much lower repetition rates. In addition, AC and DC high voltage applications tend to be quite different. With a new digital PD detector, the HVDC PD testing can be done with one apparatus instead of a number of pulse counters (existing standards set limits to the number of PDs in a PD band) as well as a deeper understanding of the PD behavior. We present our experience with this new detector.

## INTRODUCTION

For AC voltages the harm which PDs cause is well known. Up to now PD measurements for high voltage direct current (HVDC) applications are more a quality check. This is mainly because the harmfulness of the different PD (levels) is not as well known as for AC. Usually the PD pulse is fed into several pulse counters with different upper and lower limits to the size of the PD. This way PD bands are generated. The information coming from this kind of measurement is good for a 'go' / 'no go' check. With this information it is practically impossible to tell what is wrong if the answer is 'no go'.

Because the measuring circuit for the detection of PDs is the same for AC as for DC, we made an extension to the Tettex digital PD detector TE571, the TE571-2. With this extension all PDs are recorded with a time stamp, and the performed measurements are in accordance with IEC 60270 [1]. After a measurement is finished, analysis of the measured PDs will be performed. Not only a precise calculation of the number of PDs per minute but also distributions can be made. These distributions will help in finding the origin of the PDs. As Fromm [3] stated in chapter 7, it may be possible to add diagnostics in the future.

## PARTIAL DISCHARGES AT DC VOLTAGES

As stated before, the measuring circuit for AC and DC is the same. For AC the discharge magnitude  $q$  and its phase position ( $\mathbf{j}$ ) are recorded. Since there is no phase position at DC voltages, the time of occurrence since the start of the measurement ( $t$ ) is saved instead of the phase position.

The resolution of the time stamp is 5  $\mu$ s. This is enough in regard to the low repetition rates of the PDs which occur at DC voltage.

Each PD that is recorded will be stored in the detectors' memory (its magnitude  $q$  and time  $t$ ). This means that the number of PDs that can be recorded with the detector does not depend on the measuring time but on the number of recorded PDs. Currently the upper limit is at about 1.5 million PDs. This will be enough, example, for the limits set by IEC 61954 "Testing of thyristor valves for static VAR compensators" [2], which states that in each of the four PD bands up to 1-10 PDs per minute are allowed. The memory size would provide a measuring time of more than 600 hours for this type of test.

## Partial Discharge Interpretation

From the two measured quantities ( $q$  and  $t$ ), derived quantities and distributions can be calculated. The most important derived quantity is the time between two consecutive discharges  $\mathbf{D}$  (see Fig. 1).

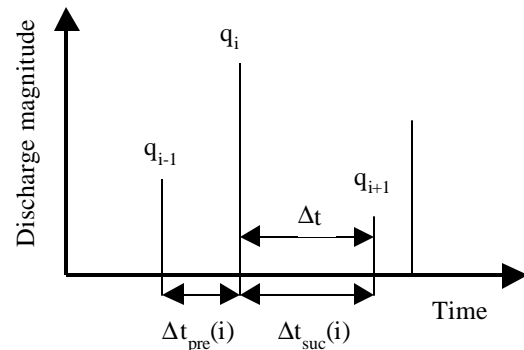


Fig. 1 Discharge occurrence at DC voltage

It is the most important derived quantity because it is related to the discharge physics. After a PD has occurred, it takes a certain time until the voltage drop caused by the discharge has vanished and before another discharge can occur. A more detailed description of partial discharge behavior and some possible discharge distributions are described by Fromm [3]. Apart from the recorded discharge information ( $q$  and  $t$ ), the voltage across the test object can also be recorded using a separate voltage divider (sample rate 3Hz; 12bit displayed and 8bit stored resolution). This voltage profile can be regarded as extra information about the test. When changing the voltage

during a test, the voltage dependency of the PDs can be observed.

During a measurement one of the following three PD units is displayed.

1. The highest PD measured between two screen updates (3 times a second) (in pC)
2. The discharge current ( $I(t)$  in A)
3. The repetition rate ( $n(t)$  in PDs/s)

This information together with the voltage gives a tester the possibility to check if the test is OK, or if it has to be stopped.

## Distributions

The new detector can display many different distributions. A very simple q-time diagram, which shows the two recorded quantities of a PD. But also  $\Delta t$ -time (time between two discharges over the measuring time),  $H(q)$  (distribution of the discharge magnitude) and  $H(\Delta t)$  (distribution of the time between two discharges) diagrams as well as the three dimensional  $H(q, \Delta t_{suc})$  distribution (distribution of the discharge magnitude depending on the time to the succeeding discharge). We are still extending the number of diagrams which will give extra information about the PD source.

## Ambivalent Definitions Of Number Of Discharges Per Minute In The Standards

Standards set limits to the allowed number of discharges per minute. But there are two definitions in use in the standards.

The first one is an average over the measuring time. This is done by counting all the PDs inside the PD band and dividing this by the measured time, e.g. IEC 61954 [2].

The second one is a one minute window which shifts along the measurement. The maximum number of PDs counted in this window may not exceed the limit set by the standards, e.g. Cigré WG14.01 [4]. This definition has to be used because it is not explicitly stated that averaging has to be used.

The detector is capable of handling both calculations.

## Differences In The Measuring Procedures

The detector has to be calibrated before a measurement starts. With the pulse counter solution, both the upper and the lower limits of every pulse counter have to be set separately.

When a measurement has started with the pulse counters, it depends on the applicable standard, if they have to be reset several times during a measurement. Since this has to be done for several pulse counters, the measurement is not very accurate. With the detector, the measurement is started and nothing needs to be done until the measurement is stopped.

## EXPERIMENTAL

Two types of test object will be discussed in this paper.

First, type test measurements of image intensifier tubes used in medical apparatus (e.g. radiotherapy). The type test consisted of heat cycles of  $-20^{\circ}\text{C}$  up to  $50^{\circ}\text{C}$  and had to withstand voltages up to 35kV.

Second, measurements on (damaged) 75kV, 8nF capacitors designed for DC voltage. These capacitors are oil impregnated and consist of a mixed paper-polypropylene dielectric with aluminum foil electrodes.

Since the measuring circuit is the same for AC as for DC both the straight as well as the balanced method could be used. The tests discussed in this paper are all performed using the straight method.

In fig. 2 the display during a measurement is shown. The ellipse shows the position of the PDs phase synchronized to the AC-mains. By using this, phase synchronous PD behavior can be recognized.

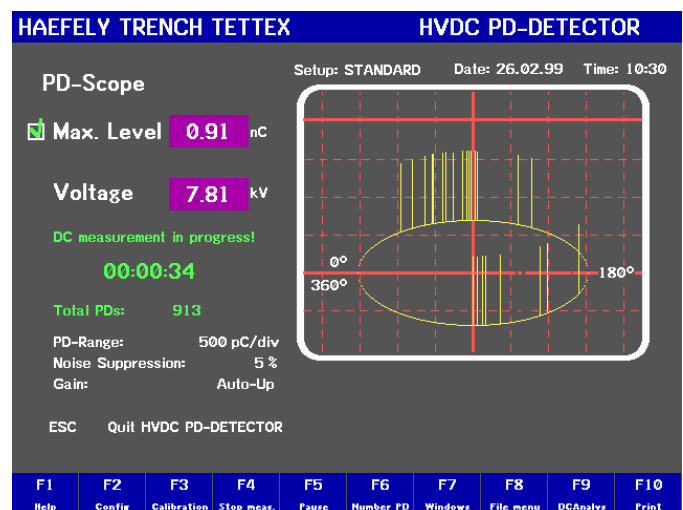


Fig. 2 Display during a test, the ellipse is shown in order to recognize phase synchronous disturbances.

The detector also has the possibility to use windowing. It can be used to suppress phase-synchronized disturbances and thereby eliminate them from the measurement. Because there is no test voltage cycle, the AC-mains of the detector is used for phase synchronizing of the window. In this way, diode or thyristor switching pulses in the DC power supply can be rejected. We did not have to use this noise suppression during our measurements.

The diagrams of the measurements shown in this paper (figures 3 till 8) are simple q-t diagrams. These diagrams are screen shots of the post-processing part of the detector. The measuring time ( $t$ ) in minutes is shown on the horizontal axis and the discharge magnitude ( $q$ ) is shown on the vertical axis.

## ANALYSING THE RESULTS

### Image Intensifier Tubes

In this paper three measurements on image intensifier tubes are discussed, see fig. 3-5. All measurements are carried out at a voltage of 25kVdc, with negative polarity.

The measurement that is shown in fig. 3 is a measurement on a good tube. The repetition rate is low as is the discharge magnitude. With the same time and PD magnitude settings, fig. 4 shows a measurement on a bad tube. The repetition rate is higher as are the PD magnitudes. An experienced test engineer would recognize this as a cavity in the insulation or as a bad interface of the insulation. This type of problem can be found most easily by performing a PD measurement. The third measurement, as is shown in fig. 5, is a measurement on a bad tube, but also with disturbances from outside (flashover testing in the same laboratory). The three flashovers can be easily recognized. For the pulse counting solution this measurement could be thrown away. But with this q-t diagram we can still use this measurement to get some information. The large amount of too big discharges is a good indication that it could be a kind of corona discharges, but it would take another measurement to confirm this.

With the pulse counter solution we could only say that those two tubes are not good. With this simple q-t diagram and experience with artificial defects, we could make a clear suggestion regarding the PD source.

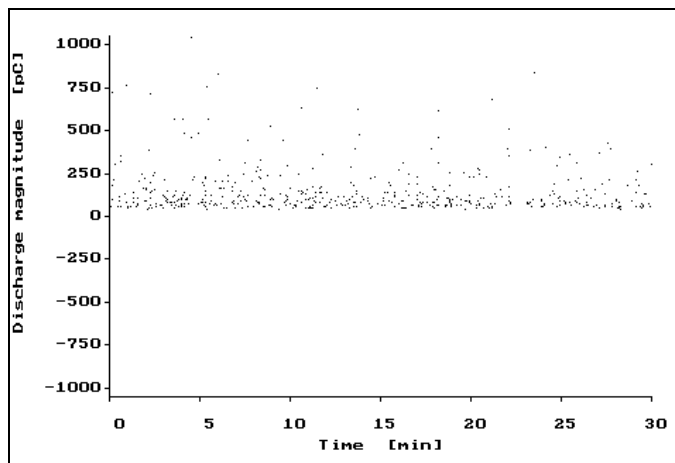


Fig. 3 The q-t diagram of a good image intensifier tube.

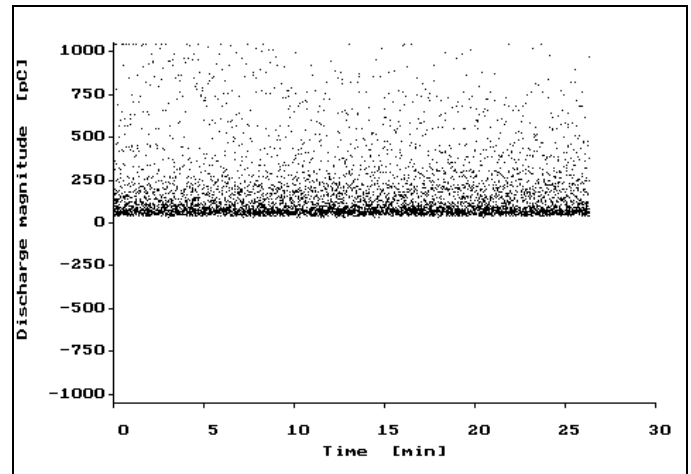


Fig. 4 The q-t diagram of an image intensifier tube with a cavity in or at the insulation.

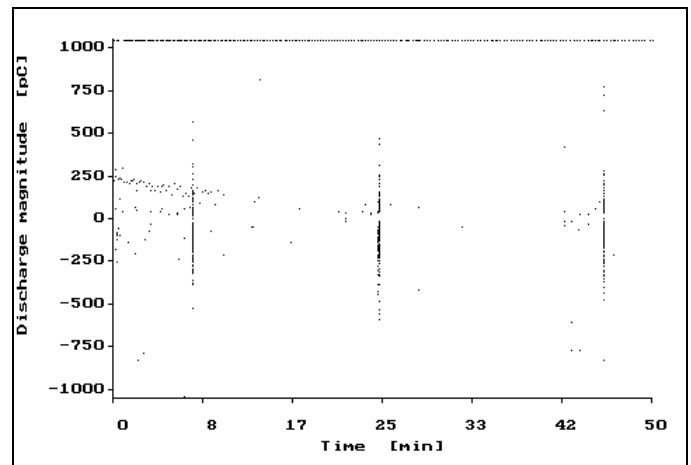


Fig. 5 The q-t diagram of a bad image intensifier tube. During the measurement flashover tests were performed.

### 75kV, 8nF, DC Capacitor

Another three measurements, as are shown in figures 6-8, were performed on DC capacitors. As a reference, a good capacitor is measured in fig. 6. As can be seen, the group of small discharges is slowly increasing in magnitude. To make the case more interesting, a couple of drops of water were added to the oil. This resulted in the measurement of fig. 7. Discharges became smaller and the overall repetition rate changed from ~30 to ~40 PDs/min. This can be explained in the following way. As the moisture in the oil decreases the resistivity of the oil increases exponentially. Especially at DC voltage charging of the oil will occur. Due to the motion of the oil (MHD effect) and its viscosity, charge separation will follow which leads to discharges confined to the oil. If the moisture content of the oil is raised, charging phenomena diminish and hence a lower PD level results.

In another capacitor a 'production' error had been introduced. The wire link to a foil was soldered badly, so the wire

protruded over the edge of the foil electrode. This resulted in a corona point inside the good oil. The measuring results are visible in fig. 8. After charging of the oil and attracting the impurities to this point it starts to discharge in a typical way. Some discharges are beyond the detectable level and the overall PDs/min value is ~50. If a pulse counter had been used a small difference in the PD count had to be used in order to distinguish between good and bad.

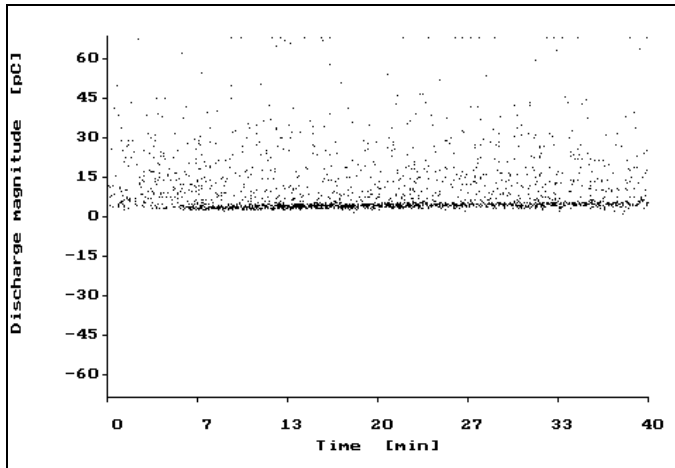


Fig. 6 The q-time diagram of a good DC capacitor.

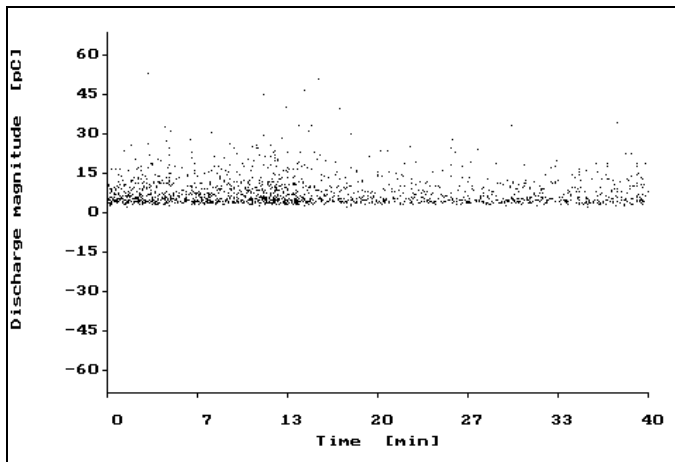


Fig. 7 The q-time diagram of a DC capacitor with some water added to the oil.

## CONCLUSIONS

Measuring PDs with the new detector has great advantages over the method which uses a number of pulse counters. First because the measuring is easier and can run without any intervention of the testing personnel. Secondly because all the PDs are stored and post processing of the measured data is possible. This allows not only a 'go' / 'no go' test as a quality check, as is the case with pulse

counters, but it also gives the possibility to check what is wrong.

Also this new detector opens new fields for future research.

## HINTS FOR FURTHER RESEARCH

**Evaluation of the measured PDs:** since this kind of testing will just start with the new detector, an exchange of results will be helpful for everyone. For example, the distributions of different types of defects, but also their voltage and temperature dependence.

**Diagnostics:** Fromm [3] has given a hint how diagnostics for DC PD measurements can be made, in a similar way as is already in use for AC PD measurements (the fingerprint method). He wants to make separate distributions for  $\Delta t_{pre}$  and  $\Delta t_{suc}$ , as is visualized in fig. 1. Hoogenraad [5] has made an attempt in this field, but much work still has to be done.

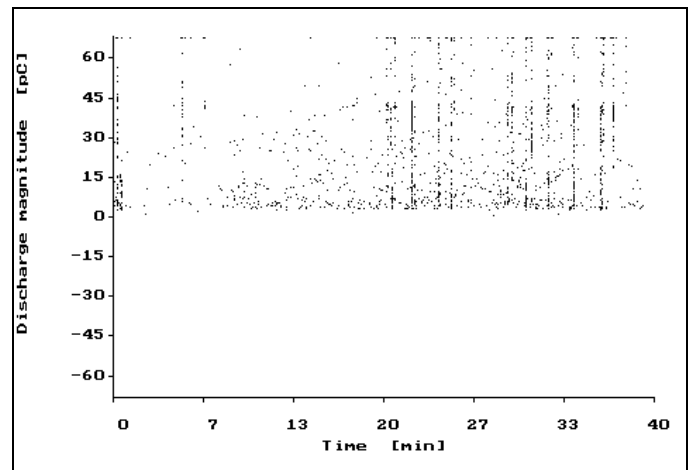


Fig. 8 The q-time diagram of a DC capacitor with a interconnecting wire outside the aluminum foil electrode.

## REFERENCES

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4. CIGRÉ Working Group 14.01, Task Force 2, "Valves of SVC", "Guidelines for testing of thyristor valves for static VAR compensators", March 1995.
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