# Guide for Electrical Partial Discharge Measurements in compliance to IEC 60270

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## Introduction

Partial discharges (PD) have been recognized as a harmful ageing process for electrical insulation at the beginning of the last century when the HV technology was introduced for the generation and transmission of electrical power. Since that time numerous papers and books appeared, dealing with the physics and recognition of partial discharges. First industrial PD tests of HV apparatus were introduced at the beginning of 1940. The method applied was based on NEMA 107, which specifies the measurement of radio influence voltages (RIV) expressed in terms of µV. One disadvantage of this method is, however, that the RIV level is weighted according to the acoustical noise impression of the human ear, which is not correlated to the PD activity. Therefore, the IEC Technical Committee No. 42 decided the issue of a separate standard on electrical PD measurement associated with the PD quantity apparent charge, which is expressed in terms of pC.

The first and second editions of the IEC Publication 270 appeared in 1968 and 1981, respectively. IEC 60270 [High-voltage test techniques – Partial discharge measurements, third edition], published in December 2000, covers besides classical analogue instruments also requirements for digital measuring systems. Moreover, the maintaining of specific characteristics of PD measuring systems by the user in a record of performance is recommended.

For better understanding the background of the current standard IEC 60270, WG D1.33 "High-Voltage Testing and Measuring Techniques" decided the edition of a Technical Brochure, which is intended as a guideline for engineers dealing with conventional electrical PD measurements. In this context it should be noted that currently the new standard IEC 62478 is under preparation, which covers non-conventional electromagnetic and acoustical PD detection methods. These topics, however, are outside of the scope of this brochure.

## PD occurrence

Partial discharges are defined in IEC 60270 as:

*"localized electrical discharges that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. Generally, such discharges appear as pulses having a duration of much less than 1 µs."*

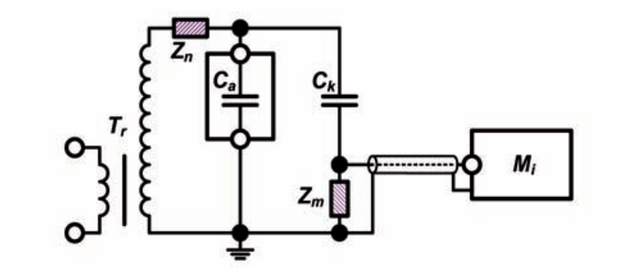
From a physical point of view self-sustaining electron avalanches may happen only in gaseous dielectrics. Consequently, typical discharge types occurring in ambient air, such as glow, streamer and leader discharges, may also happen in gaseous inclusions due to imperfections in solid and liquid dielectrics. The pulse charge of glow discharges is in the order of few pC. Streamer discharges may create pulse charges ranging from about ●●●

10 pC up to some 100 pC. A transition from streamer to leader discharges may occur if the pulse charge exceeds few 1000 pC.

Original PD current pulses are characterized by a duration as short as few ns, as exemplarily shown in Fig. 1. Consequently, the frequency spectrum covers the VHF and UHF range. The shape of such pulses, however, is strongly distorted if traveling from the PD site to the terminals of the test object. Different to this behavior the current-time integral is more or less invariant. As a consequence, not the peak value of the PD current pulses but the current-time integral, i.e. charge of the captured PD pulses, is most suitable quantity for assessment the PD intensity.

## PD measuring circuit

To ensure reproducible and comparable PD measurements in IEC 60270 three basic measuring circuits are recommended, which differ by the arrangement of the measuring impedance $Z_m$. The most common circuit employed in practice is shown in Fig. 2, where $Z_m$ is connected in series with the coupling capacitor $C_k$. An option of the PD coupling unit is the so-called bushing tap coupling mode which is generally utilized for induced voltage tests of liquid-immersed power transformers. Here the high voltage bushing capacitance $C_1$ represents in principle the coupling capacitor $C_k$. The measuring impedance $Z_m$ is connected to the tap of a capacitive graded bushing, usually intended for loss factor measurements.




*$T_r$ – HV test transformer*
*$C_a$ – Virtual test object capacitance*
*$Z_m$ – Measuring impedance as part of the coupling device*
*$Z_n$ – Noise blocking filter*
*$C_k$ – Coupling capacitor*
*$M_i$ – PD measuring instrument*

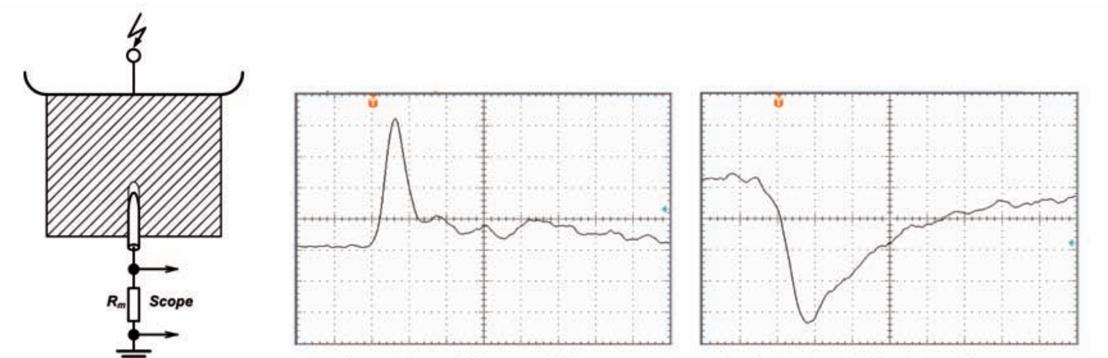
Fig. 2: Most common PD measuring circuit employed in practice

External electromagnetic noises disturbing sensitive PD measurements can be eliminated at certain extend if a balanced bridge is employed. Here both, the measuring and the reference branch, consist of a coupling unit comparable to Fig. 2. Balancing the bridge by adjusting both measuring impedances, external common mode noises can be rejected effectively by means of a differential amplifier.

## PD measuring instrument

The standard IEC 60270 recommends besides the measurement of the apparent charge an evaluation of numerous other PD quantities, such as the PD inception and extinction voltage, as well as the pulse repetition rate, the pulse repetition frequency, the phase angle, the average discharge current, the discharge power and the quadratic rate. All these quantities, however, are either derived from or related to the apparent charge, which can thus be considered as the most important PD quantity to be evaluated.

For measuring the apparent charge conventional analogue PD instruments are equipped with a band-pass filter amplifier followed by a peak level indicator. As long as the band-pass filter extracts the measuring frequency in a range where the spectral density of the PD ●●●



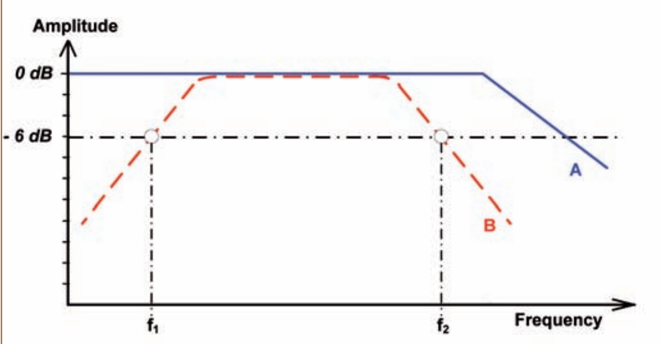

Scale: 0.8 mA/div, 2 ns/div
Scale 0.2 mA/div, 2 ns/div

Fig. 1: Positive and negative PD current pulses of a cavity discharge in XLPE recorded for an inverted point-to-plane electrode arrangement

pulses is nearly constant, see Fig. 3, the PD pulses captured from the terminals of the test object are quasi-integrated. That means the response at the output of the PD instrument and thus the reading of the peak level indicator is proportional to the apparent charge.

Another option for measuring the apparent charge is a very wide-band pre-amplification of the PD signal captured from the test object followed by an electronic integration. This principle offers several advantages not only for the reduction of electromagnetic interferences, but also for the location of PD faults in long power cables. The performance of such an electronic integrator is shown in Fig. 4.

Nowadays the conventional analogue PD pulse processing is more and more substituted by the advanced digital technique. A bloc diagram for a computerized PD measuring system is shown in Fig. 5. Here the digitalization of the PD pulses captured from the test object is done in the real-time mode, i.e. the band-pass filtering required for the quasi-integration, as well as the peak detection are performed after the A/D conversion using a FPGA.




*A – Frequency spectrum of PD pulses*
*B – Band-pass filter characteristics of the PD measuring instrument*

Fig. 3: Principle of the quasi-integration of PD pulses

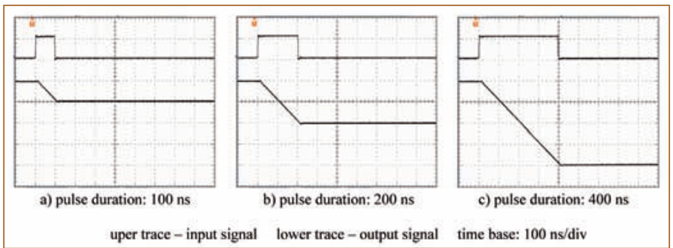



Fig. 4: Rectangular pulse response of an electronic integrator

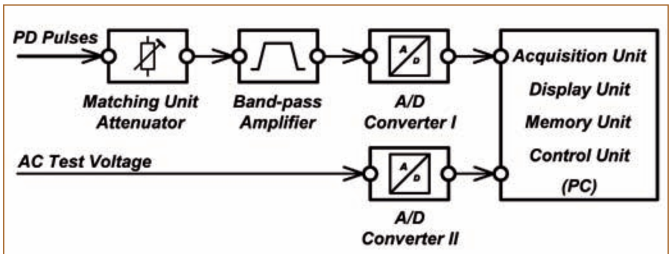



Fig. 5: Bloc diagram of an advanced digital PD measuring system

The main feature of a digital PD measuring system is the ability to store the following characteristic parameters of each PD event:

$t_i$ – instant time of PD occurrence
$q_i$ – apparent charge at $t_i$
$u_i$ – test voltage magnitude at $t_i$
$\psi_i$ – phase angle at $t_i$

The vector $[q_i - u_i - t_i - \Psi_i]$ stored in the computer memory is utilized for further processing as well as for a visualization of phase-resolved PD patterns. This ensures the evaluation of all PD quantities recommended in IEC 60270 as well as an in-depth statistical analysis of the very complex PD occurrence. Moreover, a PD pulse waveform analysis can be performed capable for the location of the PD site in power cables as well as for the recognition of different PD sources and also for the denoising of PD signals.

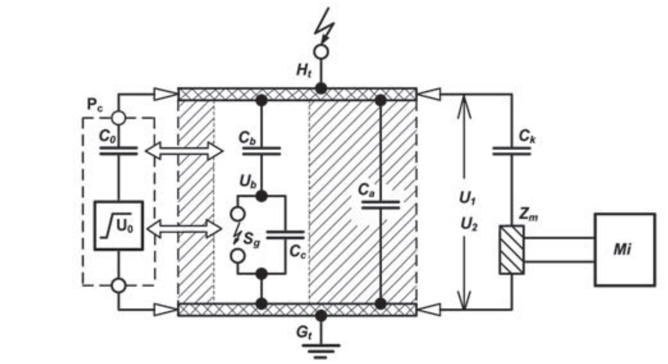
## Calibration of PD measuring circuits

The quantitative assessment of the apparent charge transferred from the PD source to the terminals of the test object is based on the approach of Gemant and Philippoff, often referred to as a – b – c model due to the characteristic capacitances $C_a - C_b - C_c$, as illustrated in Fig. 6

Due to the series connection of $C_b$ and $C_c$, where the condition $C_b / C_c << 1$ is always satisfied, the apparent charge $q_a$ detectable at the test object terminals can be written as:

$$q_a = q_c * C_b / C_c \qquad (1)$$

That means the measurable apparent charge $q_a$ is only a small fraction of the true pulse charge $q_c$ created in the PD source. Consequently, the PD severity of HV apparatus cannot be estimated on the basis of the apparent charge alone, because the • • •




*$C_a$ – virtual capacitance of the test object*
*$C_b$ – stray capacitance of the PD source*
*$C_c$ – internal capacitance of the PD source*
*$C_0$ – series capacitance of the calibrator*
*$S_g$ – spark gap*
*Pc – PD calibrator*
*$C_k$ – coupling capacitor*
*$Z_m$ – measuring impedance*
*$U_0$ – voltage step created by the calibrator*
*$U_b$ – voltage step created by the PD source*
*$U_1$ – voltage step across $C_a$ due to the calibration*
*$U_2$ – voltage step across $C_a$ due to a PD event*
*$H_t$ – high voltage termination of the test object*
*$G_t$ – grounded terminal of the test object*
*$M_i$ – PD measuring instrument*

Fig. 6: Equivalent circuit for calibrating the apparent charge

ratio $C_b / C_c$ is not known at all. Therefore, knowledge rules for PD diagnosis have been established in the past which are based on practical experiences gained from comprehensive PD studies in laboratory and on-site.

Each PD event causes a reading $R_i$ of the PD instrument which is proportional to $q_a$. To measure this quantity in terms of pico Coulomb (pC) the Standard IEC 60270 specifies a calibration method which is based on the simulation of the internal charge transfer between the PD source and the terminals of the HV apparatus by means of an external adapted calibrator, as evident from Fig. 6. Based on this calibration procedure the apparent charge of a PD pulse is defined in IEC 60270 as:

*"that charge which, if injected within a very short time between the terminals of the test object in a specified test circuit, would give the same reading on the measuring instrument as the PD current pulse itself."*

The PD calibrator is generally equipped with a pulse generator connected in series with a calibrating capacitor. In order to simulate the transient voltage across the PD defect the pulse generator creates equidistant voltage steps of known magnitudes $U_0$. If the value of the calibrating capacitor $C_0$ is substantially lower than the value of the virtual test object capacitance $C_a$, the calibrating charge injected in the test object terminals, see Fig. 6, can simply be expressed by:

$$q_0 = C_0 * U_0 = C_a * U_1 \quad (2)$$

If real PD events appear, the apparent charge is given by:

$$q_a = C_a * U_2 \quad (3)$$

Introducing equation (2) in equation (3) the unknown value of $C_a$ can be eliminated and we get:

$$q_a = q_0 * U_2 / U_1 \quad (4)$$

Because the transient voltages $U_1$ and $U_2$, which appear across the test object capacitance $C_a$, cause the readings $R_0$ and $R_i$, equation (4) can also be written as:

$$q_a = q_0 * R_i / R_0 \quad (5)$$

Where the ratio $R_i / R_0$ represents the scale factor $S_f$ of the PD measuring circuit applied.

## Maintaining the characteristics of PD measuring systems

For maintaining the characteristics of PD measuring systems the following procedures are recommended in IEC 60270:

- Routine calibration of the complete PD measuring system connected to the HV test circuit to provide the scale factor required for the calculation the apparent charge from the reading of the PD instrument. This should be performed prior each PD test.
- Determination of the specified characteristics of the complete PD measuring system. This should be performed at least once a year or after major repair.
- Calibration of the PD calibrator. This should be performed at least once a year or after major repair.

In general the manufacturers of PD measuring devices provide the necessary guidelines for verification the specified technical parameters. Independent from such guidelines IEC 60270 recommends additional test procedures, where the results shall be maintained by the user in a "Record of Performance". This shall include the nominal characteristics (identification; operation conditions, measuring range, supply voltage), the results of type tests, routine tests and performance tests as well as the results of performance checks, including date, time, passed/ failed, action taken.

Verifications of PD measuring systems and PD calibrators shall be performed once as acceptance tests. Performance tests shall be performed periodically or after any major repair, and at least every five years. Performance checks shall be performed periodically and at least once a year. ■