

Data Sheet no. 6.22/2

## PD Fault Location in Cables

Type ICMcompact / F

### Application

The measured partial discharge (PD) level of a cable is a criterion for acceptance tests in factories, after-laying tests on site and also for diagnostic tests of older cable systems. If the PD level exceeds a limit value, the related weak point in the cable must be considered as an unacceptable PD fault. Then, the cable should be cut in such a way that the defect causing the PD fault will be removed. This requires the location of the PD fault. It is performed on the basis of the propagation of the electrical PD signals along the cable.

In **acceptance tests**, cables of production lengths on drums are PD tested. Usually, such cables are without or with only one PD fault which must be located. The PD equipment described in this Data Sheet is well adapted for acceptance tests. It should be mentioned that also multiple PD failures can be located and that PD failures due to bad preparation of the cable ends can be well identified with PD location.

In **after-laying tests** of cable systems, PD failures can mainly be expected in the joints or terminations, because the cables themselves are successfully PD tested in factory. PD location is a helpful tool to detect poor workmanship during assembly of these accessories. When measured at one end, PD location is limited to cable lengths of

few kilometres because of the damping when the PD signal travels along the cable. The measurable length can be doubled when PD measurement and PD location are performed from both ends.

In **diagnostic off-line tests**, PD failures must be expected in the whole cable system. For this application, PD location is extended to **PD mapping**. This means the measured apparent charges are displayed over the PD fault locality (Fig.1). The PD map identifies most critical PD faults for repair.

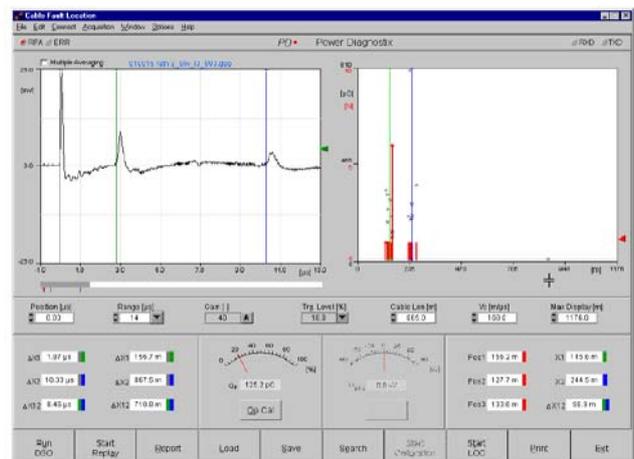


Fig. 1: Monitor for PD fault location and PD mapping

## Measuring Principle

PD location is an application of time domain reflectometry (TDR). Long high-voltage cables behave as a wave conductor. Therefore, a PD pulse travels to both cable ends. If these do not have the characteristic impedance of the cable (open ends), the PD pulse will be reflected back to the opposite end. Fig. 2 shows a cable with a PD fault. The travelling way of the two pulses and their reflections is shown on top of Fig. 2. PD pulses are registered by the PD measuring system at the times  $T_1$ ,  $T_2$ ,  $T_3$ , etc. The distance from the PD fault (pulse source) to the end of the cable is calculated from the time difference ( $\Delta t_m$ ) of two pulses measured at the near end (coupling unit).

Fig. 3 shows the time diagram of the three pulses entering the coupling unit. The 1<sup>st</sup> pulse travels the

direct way to the coupling unit. The 2<sup>nd</sup> pulse travels the opposite direction and is reflected at the open end of the cable. Thus resulting in the time delay  $\Delta t_1$  which indicates twice the distance  $\Delta x_2$  of the pulse source to the far end.

The 3<sup>rd</sup> pulse results from a reflection of the 1<sup>st</sup> pulse at the near end and thereafter at the far end. The time difference between the 2<sup>nd</sup> and 3<sup>rd</sup> pulse ( $\Delta t_2$ ) indicates twice the distance  $\Delta x_1$  of the pulse source to the near end.

With the calibrated pulse velocity on the cable, the locality of the PD fault is determined and displayed (for calibration see next paragraph).

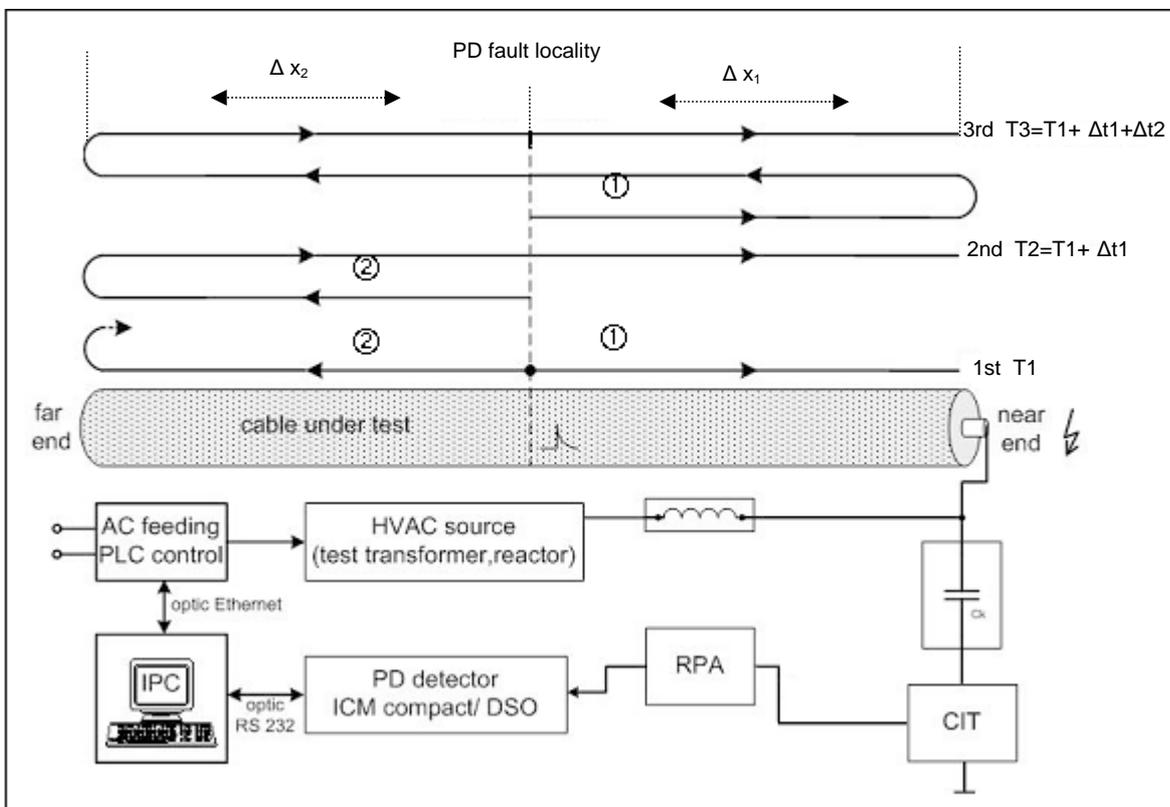


Fig. 2: Measuring circuit and propagation of a PD pulse (CK coupling capacitor; CIT-measuring impedance; RPA-preamplifier)

## Connections, Calibrations

For PD location the PD detector, type *ICMcompact / F* is equipped with an acquisition board for PD fault location, type DSO. The PD signals in the time domain (Fig. 3) are recorded with a resolution of 10 ns and a maximum total display of 80  $\mu\text{s}$ . Since the display of that PD detector is limited to 200 pixel, the data display is compressed. To take the full advantage of the high resolution, the PD detector can be connected via an optic RS 232 interface to a separate computer, preferably the control computer (IPC) of the HV test system (Fig. 2). Then, a much better display is reached by the help of the software *ICMcompro* (Fig. 1).

For PD fault location the cable under test is connected to the HV circuit (Fig. 2) as usual for PD measurement (see Catalog Sheet 6.21). The cable conductor is connected via the coupling capacitor (CK) to the measuring impedance, type *CIT* (see Data Sheet 6.31). From here, the signal is wide-band amplified by the preamplifier, type *RPA 1H*, for laboratory or factory testing, respectively type *RPA 1L* for testing on site (see Data Sheet 6.32). Via the measuring cable the signal is transferred to the PD detector, type *ICMcompact / F* and processed there in the described way.

**Calibration** without high voltage is necessary for the PD magnitude as well as for the reflectometry. The type of the calibrator CAL (see Data Sheet 6.33) shall be selected according to the expected PD magnitude (see also last clause of this paper!). The TDR calibration can be made in two directions: If the PD signal velocity is known from measurement at cables of identical type, the exact length of the cable can be determined. Fig. 4 shows the calibration pulse and its reflection. The measured time difference of 4.54  $\mu\text{s}$  is related to twice the length of the cable. Based on a signal speed of 192 m/ $\mu\text{s}$  in the cable the resulting cable length is  $\Delta x_2=435.7$  m. If the exact cable length is known, the TDR calibration results in the determination of the signal speed. For cable systems, TDR calibration can be used to locate also cable joints.

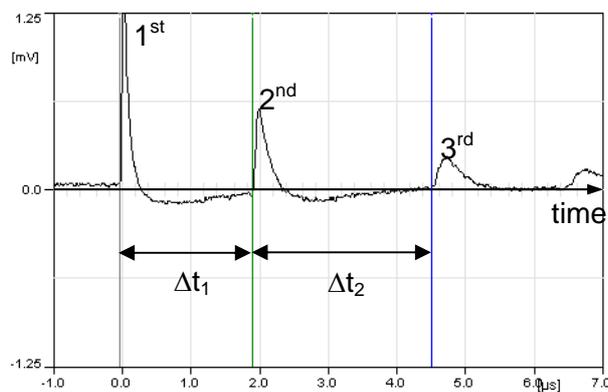


Fig. 3: Time domain measurement of the PD propagation in Fig. 2 ( $T_1 = 0$ )

## Measurement

Usually, PD location is only performed when the PD measurement indicated an unacceptably high PD level before. When the TDR behaviour is calibrated, the gain and the PD trigger level must be set at the PD detector *ICMcompact / F* by the related buttons. Also the calibrated (or known) values for cable length (Fig. 5: 460 m is only an estimation) or signal velocity (192.0 m/ $\mu\text{s}$  is a precise value) must be set.

Now PD location may start after the cable being energized. It is recommended to display in minimum the triggered pulse and two reflections. The example in Fig. 5 shows the TDR with the triggering pulse set at zero. When the second (at the far end reflected) pulse arrives after 1.93  $\mu\text{s}$ , it has additionally crossed twice the distance between the PD failure locality and the far end. This means that distance can be simply calculated by  $\Delta x_2 = \frac{1}{2}(192.0 \text{ m}/\mu\text{s} * 1.93 \mu\text{s}) = 185.3 \text{ m}$ . The precise length of the cable  $l = 435.7 \text{ m}$  results from the time difference between first and third impulse (4.54  $\mu\text{s}$ ) and the exact signal velocity (192.0 m/ $\mu\text{s}$ ). The distance to the near end is consequently  $\Delta x_1 = 435.7 \text{ m} - 185.3 \text{ m} = 250.4 \text{ m}$ . To get a sufficiently precise signal, the evaluated impulses should have a steep front. In case of a flat front (e.g. fourth pulse in Fig. 5), the cursor cannot be set as exactly as for a steep one.

In case of on-site PD testing of cable systems with joints, the TDR calibration shall be used to locate the joints without high voltage before PD location and PD mapping starts.

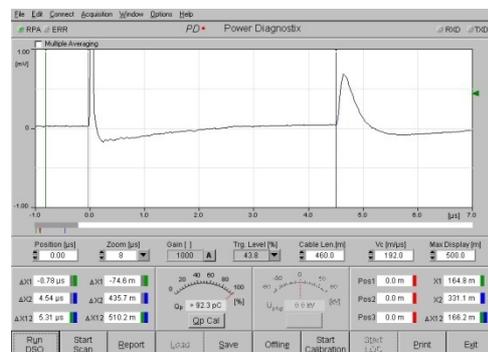


Fig. 4: TDR calibration and pulse measurement at the same cable end

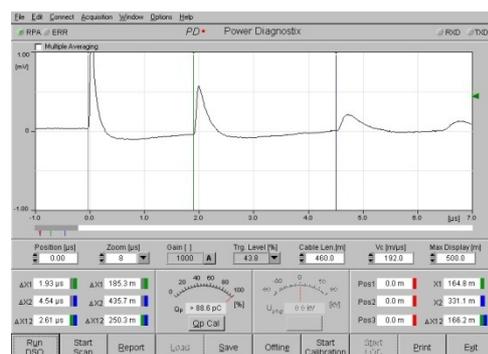


Fig. 5: TDR measurement

## Specification

The PD detector type *ICMcompact* (Catalog Sheet 6.21) for measurement of the apparent charge according to IEC 60270: 2000 is completed for PD fault location in cables by the digital storage oscilloscope (*DSO*) board. The version including this *DSO* board has the type designation *ICMcompact / F*. It is characterized by the following parameters:

**Parameters for PD measurement:**  
see Catalog Sheet 6.21

### Parameters for PD location:

Time resolution	10 ns
Sampling rate	100 MS/s
Max. display	80 $\mu$ s
Max. cable length	approx. 5 km
Location uncertainty	$< \pm (1\text{m} + 0.001 \times l_k)$

**Weight dimensions and power supply:**  
see Catalog Sheet 6.21

**Temperature range:** 10 ... 40 °C

## Accessories

### Basic accessories:

For PD measurement and PD fault location at high- and medium-voltage cables, the *ICMcompact / F* has to be completed by:

- one measuring impedance of the type *CIT* (see Data Sheet 6.31)
- one preamplifier (see Data Sheet 6.32), recommended type *RPA1H* for factory and laboratory testing, and type *RPA1L* for testing on site
- one PD calibrator (see Data Sheet 6.33), recommended for:
  - acceptance tests in factory:  
*CAL1A* (1...100 pC)
  - diagnostic tests on site:
    - extruded cables *CAL1D* 10...1000 pC
    - or *CAL1B* (0.1...10 nC)
    - oil-paper cables *CAL1B* (0.1...10 nC)
    - or *CAL1E* (1...50 nC)
- one coaxial signal cable, type *RG58*, standard length 10 m or 25 m

### Optional accessories:

- additional industrial PC or laptop computer for more precise display of the time-domain reflectometry (TDR) and hardware base for PD mapping (preferably this IPC will also be used as control IPC of the HV test system (see Catalog Sheet 1.52)
- software for improved PD fault location and PD mapping, type *ICMcompro*

### KEY ADVANTAGES

- PD measurement and PD fault location by one "easy-to-handle" PD detector
- Extendable by external computer and software package also for PD mapping (computer can also be used for control of the HV test system)
- Accessories enable the optimum adaptation to both, HV acceptance testing in factory as well as on-site tests after laying and for diagnostic purposes
- Very compact and robust design
- Optimum price-performance relation

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