APPLICATION NOTE

Partial discharge monitoring of high voltage assets

EN
ENGLISH

ICM*observer*
Introduction

Partial discharge monitoring has become increasingly important in the past few years. Besides other parameters, such as dissolved gas analysis, temperatures, vibrations, load conditions, etc., the PD trending information completes a full set of monitoring data for important high voltage (HV) assets in the field. These data can be used to assess the quality of HV assets in substations and power plants. PD monitoring helps detecting insulation, bushing, and winding problems, before a failure may ultimately lead to a complete breakdown.

This document is meant to give examples of ICM*observer* applications and to present the general set-up and necessary accessories – if needed. It is not meant to be a conclusive explanation of all instrument functions. For this, refer to the ICM*observer* user guide.

Standard use

Different modes of installation of the couplers apply, depending on mainly the type, design, and size of the device under test. The following example describes the permanent monitoring of a large motor as one standard use of the ICM*observer*.

A coupling capacitor of the CCxxB series is connected to each phase bus in the connection box. The couplers have a high-voltage connection, a ground lead, and a BNC signal connector. Each BNC connector is linked to the coupler termination box (CTB1) by a coaxial cable. This CTB1 provides the protective ground for the BNC signal cable. The CTB1 is thus also tied to the protective ground potential.

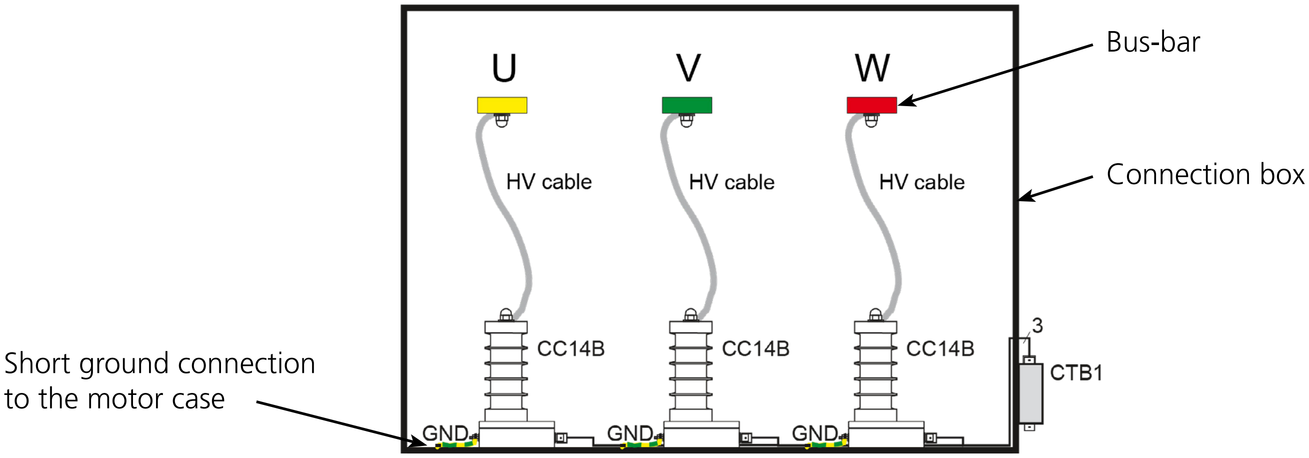

Figure 1: Coupler connection on a motor

Usually, large motors are fed using medium voltage cables. Those cables have a very low high frequency impedance, which reduces the high-frequency amplitude of the PD signal. Thus, the coupler needs to be mounted in general as close as possible to the machine terminal. The high voltage as well as the ground connection of the coupler needs to be connected close to the machine and away from the supply line.

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The noise signal for analogue gating is picked up from a coupling capacitor by a current transformer CT1. The output of CT1 is connected to CH4.

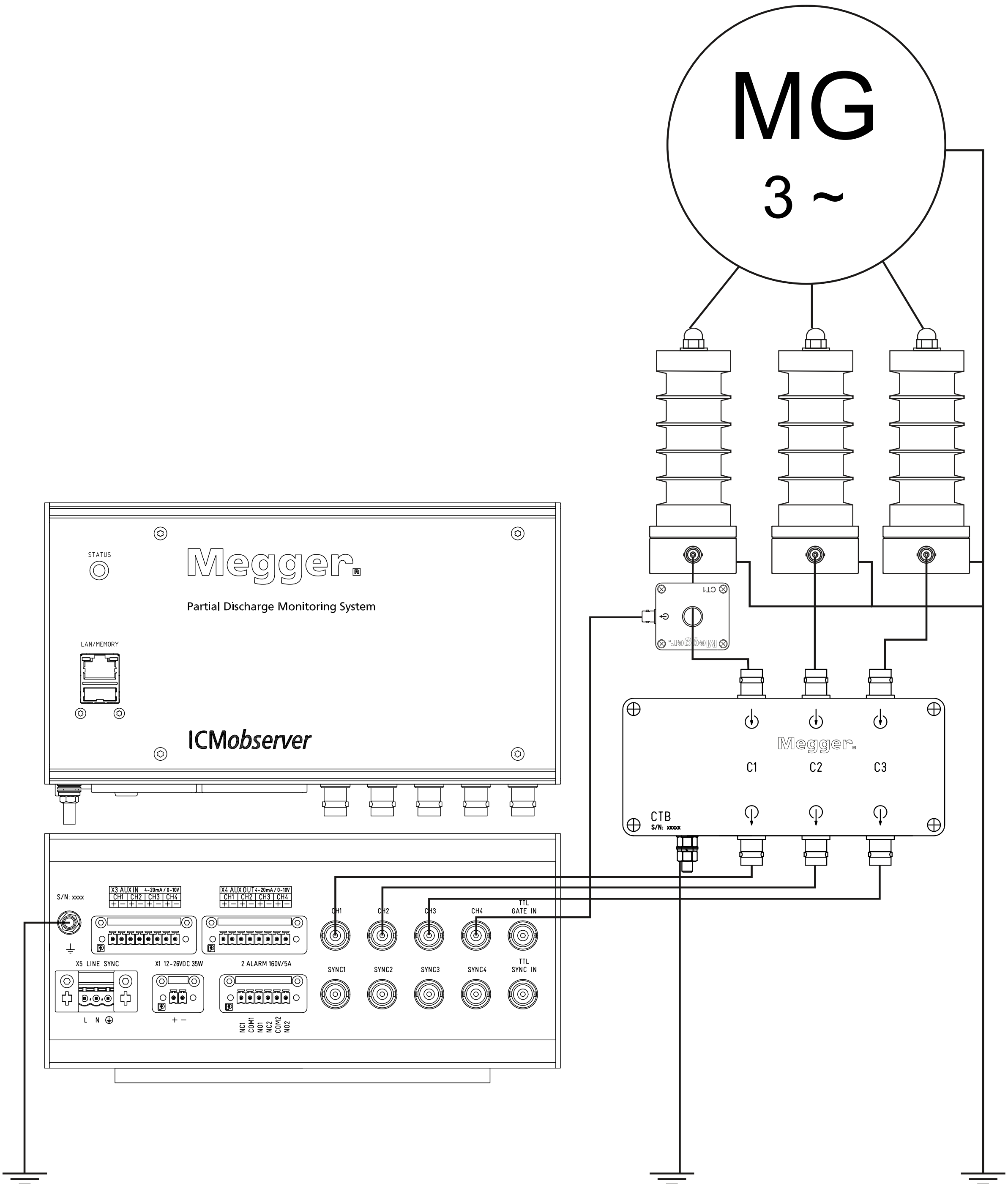

Figure 10: Example connections of a standard ICMobserver to a rotating machine

Typical setup

The following sketch provides an overview of a typical transformer PD monitoring configuration. Installations such as on three single-phase transformers, transformers with oil–SF6, or oil–oil bushings may vary.

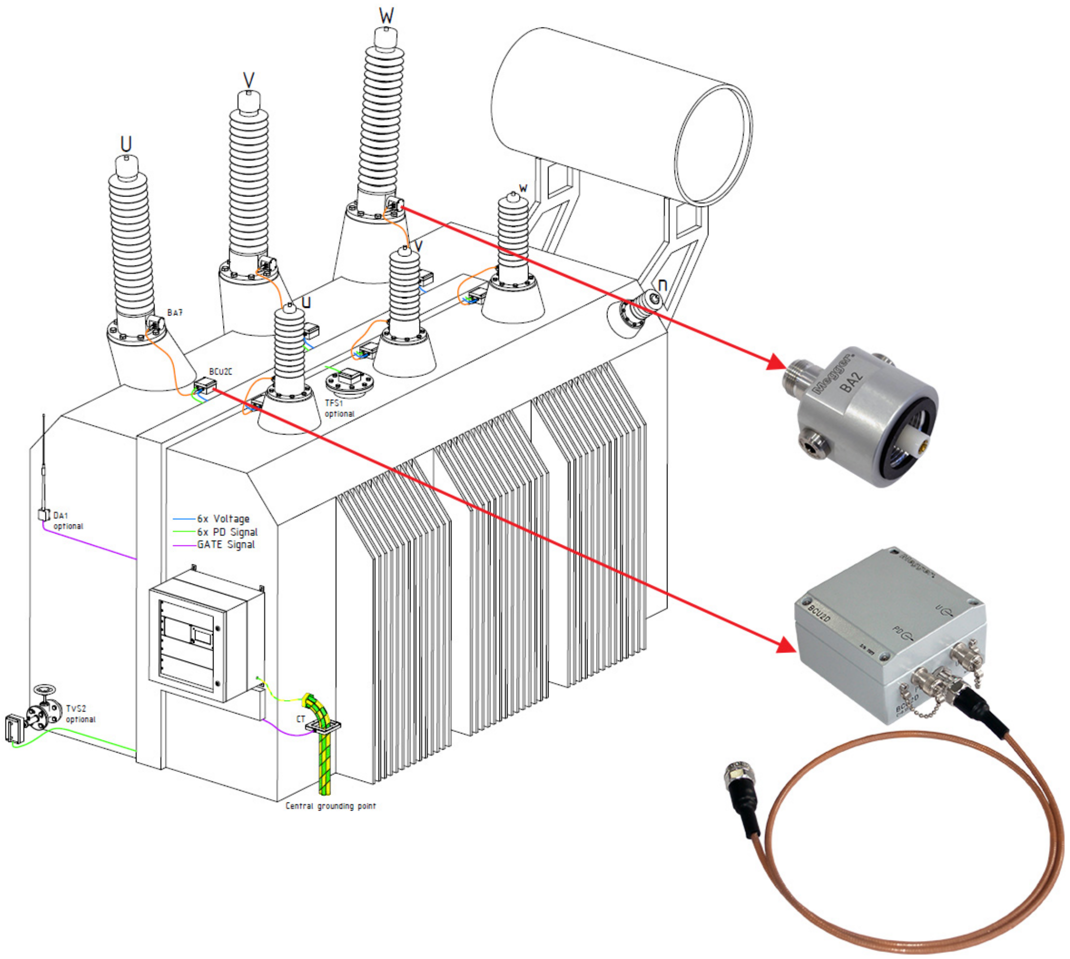

Figure 2: Power transformer with an ICMobserver permanently installed for monitoring purposes

If the PD signal is coupled at the test taps of the bushings, it typically is not additionally necessary to install UHF sensors. UHF sensors are, however, available for the oil drain valve (TVS2) and for spare flanges (TFS1). External disturbance signals can be detected by an antenna, such as the DA1 shown in the picture, or by a clamp-on HF current transformer (CT1, CT100, CT120R, or similar, provided for different cable thicknesses). The instrumentation cabinet can be placed on the transformer tank wall, on a concrete wall, or on a nearby metal support. The instrument needs or provides the following external interface connections:

- Power supply cable, 220 V AC
- Network cable (optional)
- 4–20 mA or 0–10 V input signals for measurement, e.g., temperatures
- 4–20 mA or 0–10 V output signals for NQS/ trend analysis
- Alarm output signals of potential-free relay contacts

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With some special bushings, the test tap connector is under oil and not accessible from outside. In such cases it is possible to mount an oil-tight, N–N feedthrough connector into the outer metal enclosure. The figure below illustrates such a special configuration. It is important to keep the interconnection cable between test tap connector and wall connector as short as possible.

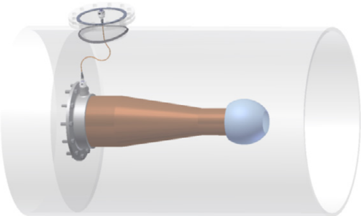

Figure 3: Test tap under oil with installed oil-tight, N–N feedthrough connector

The high-frequency PD signal is coupled from the capacitive tap of the transformer bushing. Special bushing adapters (type BA) are available for most of the commonly used bushings available in the market. This adapter is designed to ground the tap connector in case of failure, such as broken layers or overvoltage. A grounding of the test tap is guaranteed by integrated spark gaps that switch at a peak voltage of 350 V. From the N-type output connector of the bushing adapter, a short coaxial lead (typical RG142, 50 Ω) connects to the bushing coupling unit (BCU2 series). This box provides the HF PD signal on a TNC connector and additionally the synchronization voltage. The TNC protection caps should be left connected in the case no signal cable is attached to the TNC outputs.

The typical voltage at this "U" output can be calculated as:

$$U_{\mathrm{sync,out}} = \frac{U_{\mathrm{r}}}{\sqrt{3}} \frac{C_1}{C_{\mathrm{d}}}$$

where

$U_{\mathrm{sync,out}}$ is the AC RMS output voltage on the TNC output connector U of the BCU

U_{r} is the rated RMS voltage of the phase-to-phase transformer bushing

C_{d} is the divider capacitance as written on the BCU

C_1 is the capacitance of the bushing between the HV terminal and test tap connector

The value of C_{d} is usually calculated by the supplier of the PD monitoring system. A typical range for the maximum voltage U_{sync} lies in the range of 60–100 V AC RMS. This voltage signal can be used for instance for PD synchronisation, voltage monitoring, or tan delta calculations.

The PD output of the BCU provides high-frequency signal output in a range of either 2–20 MHz or 40 kHz to 10 MHz. For the BCU2 type, the specific range can be modified by setting a jumper under the cover of the BCU box.

Jumper settings:

On: 2–20 MHz range (default setting)

Off: 40 kHz to 10 MHz range

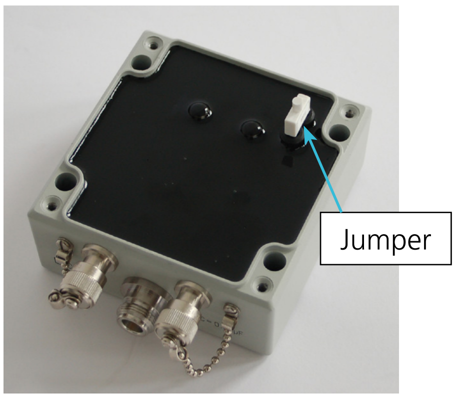

Figure 4: BCU2D, view from top with cover removed

Temperature-stable coaxial cables such as RG142 type can be used to connect all signal cables from the BCU to the instrumentation cabinet. The monitoring device within the cabinet acquires all data, generates trending strip charts and alarm events and provides all interfaces for remote control and remote monitoring.

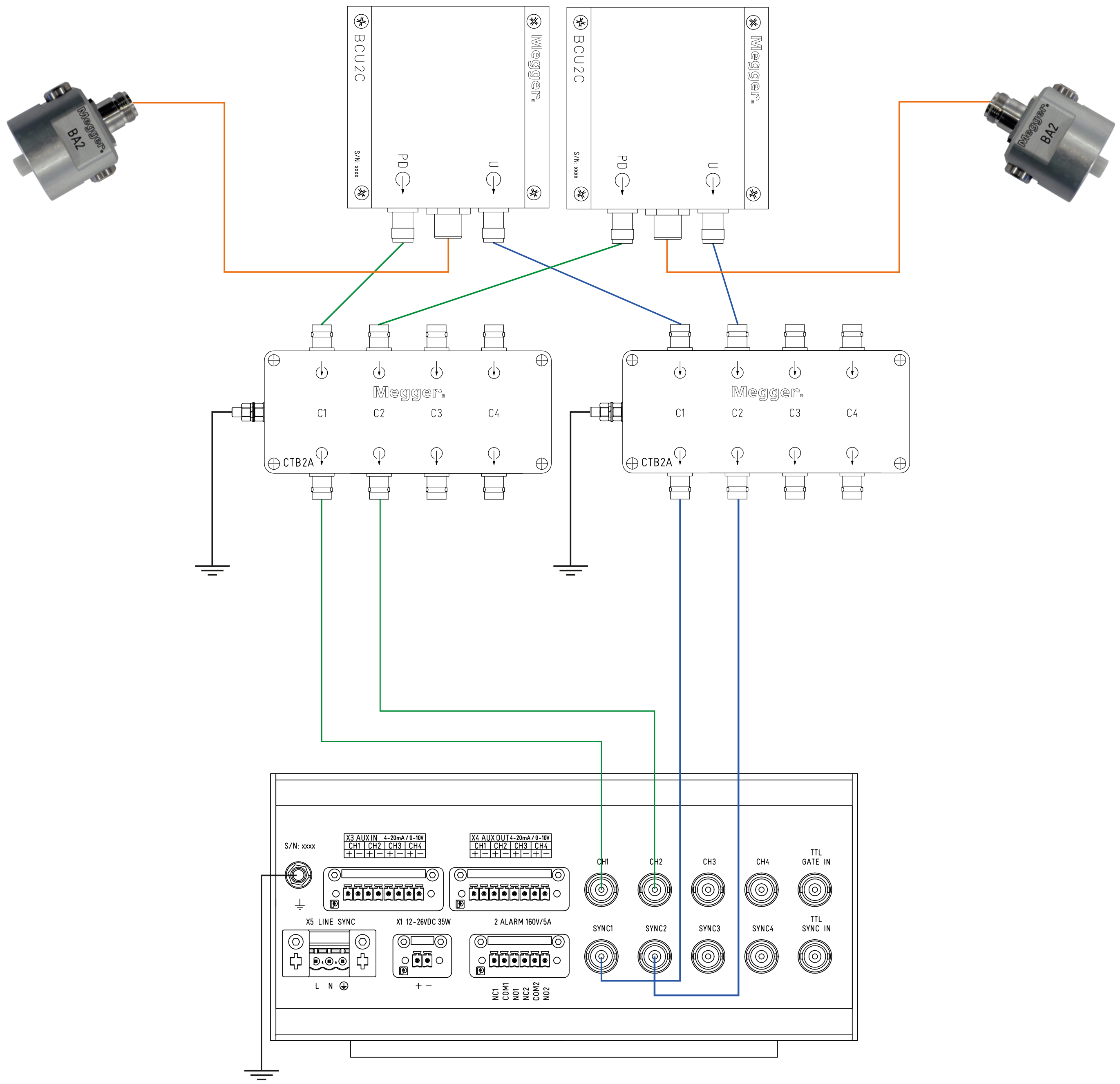

Figure 5: Example connections of an ICMobserver to a transformer via bushing adapter (BA) and bushing coupling unit (BCU2C)

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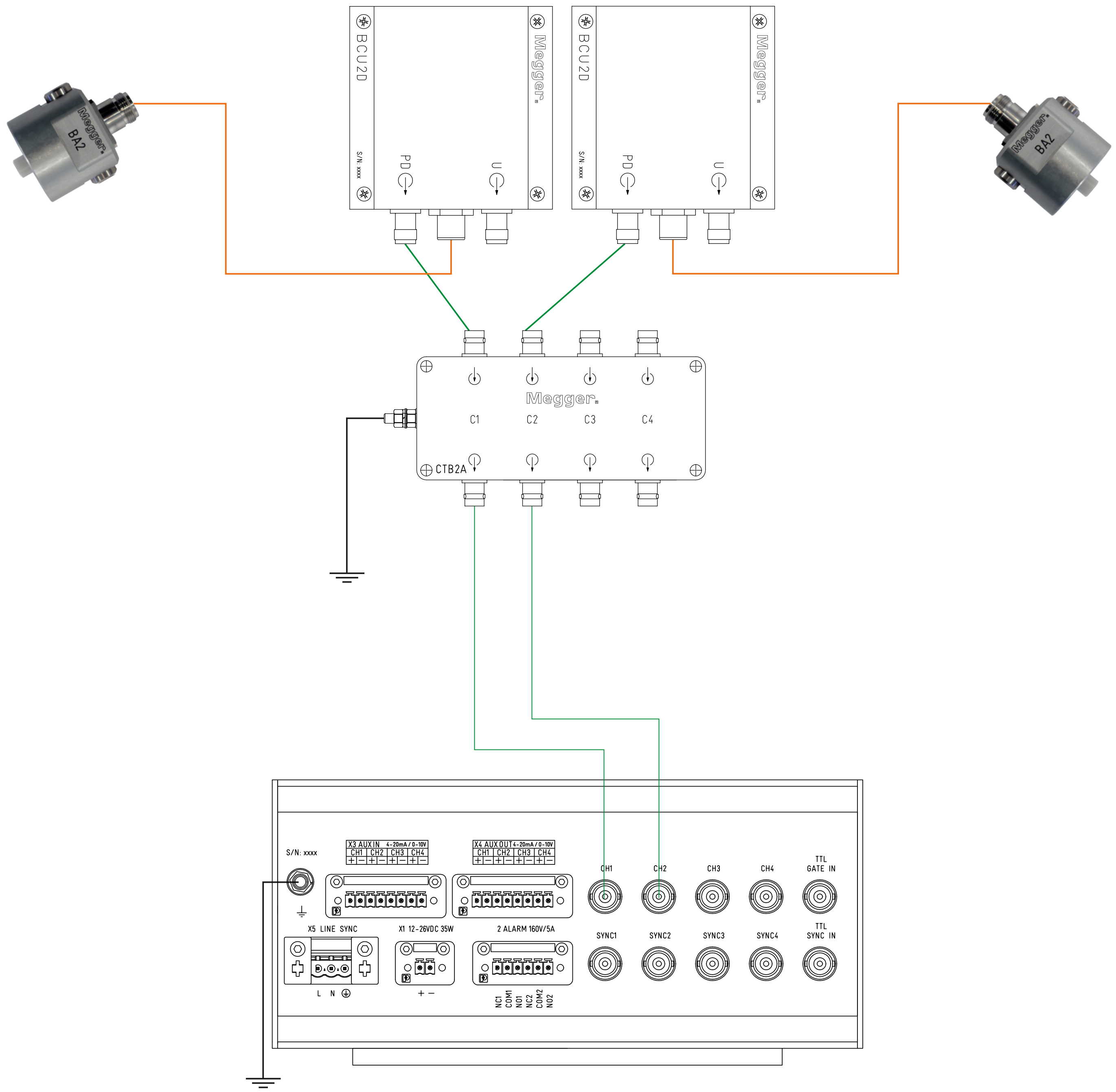

Figure 6: Example connections of an ICMobserver to a transformer via bushing adapter (BA) and bushing coupling unit (BCU2D); the synchronisation voltage is supplied as a superimposed signal with the PD signal

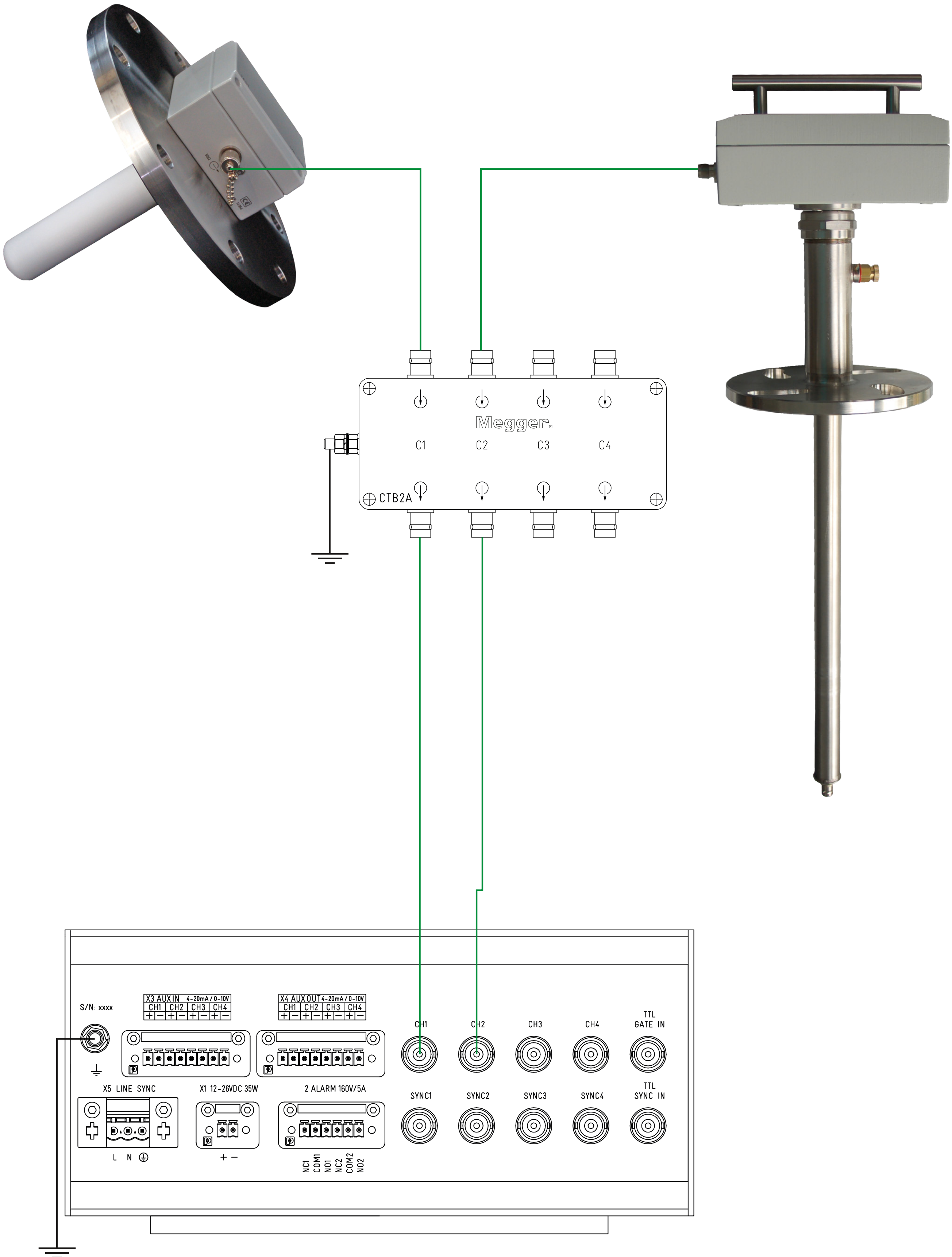

Figure 7: Example connection of an ICMobserver to a transformer via transformer valve sensor (TVS2) and transformer flange sensor (TFS1)

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Commissioning

Commissioning of a power transformer begins with its erection on site. The bushing adapters and coupling units can be connected after assembly of the bushings. All signal cables are then fed to a central point in close proximity to the transformer. The PD monitoring rack can be mounted there, for instance on a metal support . All cables are fed in from the bottom of the cabinet. Coupler termination boxes can be used to connect all coaxial cables. The internal cabling to the ICM*observer* should be prepared at the PD or OEM manufacturer site in advance.

After powering the ICM*observer*, the system setup and calibration needs to be prepared. Refer to the ICM*observer* user guide to setup the instrument correctly. Measurement mode, frequency bandwidth, centre frequency, LLD, and Gain are the most relevant settings for the calibration procedure. A typical calibration charge for onsite calibration is 1 nC, 2 nC, or 5 nC. A background noise floor of less than 500 pC on power transformers and less than 200 pC on cast resin distribution transformer is considered to be sufficient for a sensitive PD monitoring installation. It is advisable to perform multiple calibrations on different centre frequencies and to store them individually on the computer. The best signal to noise ratio can be found after energizing of the transformer earliest.

The following figure shows a simplified circuit diagram of the calibration setup. The standard procedure can be compared with the shop floor testing methods. On site the situation will be different as the bushing connects to a GIS, a cable box, or to the HV overhead lines directly. The additional impedance of this attached equipment of the HV grid will influence the calibration depending on its properties.

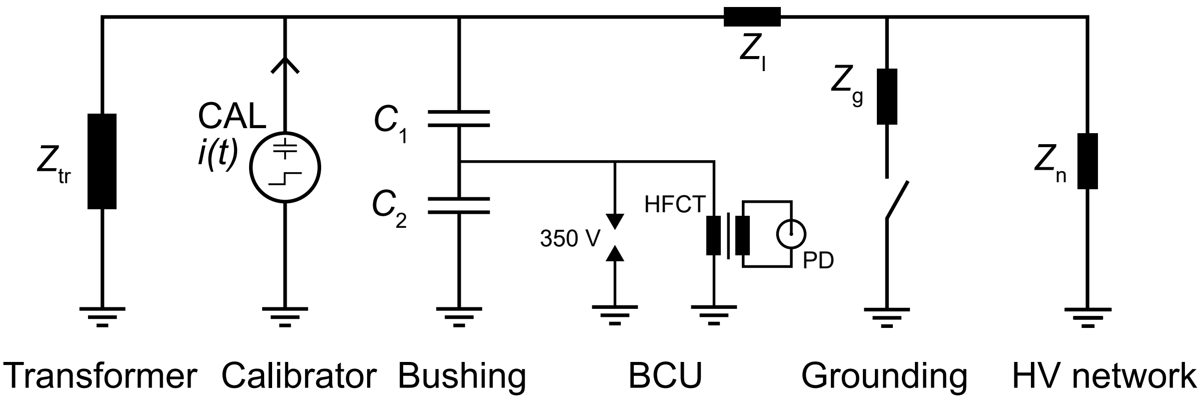


Figure 8: Calibration setup diagram

In the figure:

Z_{tr}	Impedance of the transformer
CAL	Impulse calibrator
C_1	Capacitance between HV line and bushing test tap
C_2	Capacitance between test tap and ground
350 V	Spark gap of the bushing adapter (twice)
HFCT	High frequency current transformer (alternatively CIL circuit, not shown)
PD	Partial discharge measurement output of BCU
Z_1	Impedance of the HV link connected to the bushing
Z_g	Impedance of the grounding cable during commissioning, if connected
Z_n	Impedance of the HV network (GIS, GIL, HV cable, overhead line, etc.)

Consider the following important points while calibrating:

- Keep all connections leads from the calibrator to the bushing terminal and to ground as short as possible to minimize stray capacitance.
- Remove the ground connection from the HV terminal, or
- keep a minimum distance of the ground connection to the HV terminal of several meters to increase the impedance (L_g) between the calibration point and the grounding point.
- Do not connect the calibrator clamps to painted parts. A proper connection of the clamps to metal is mandatory for every calibration.

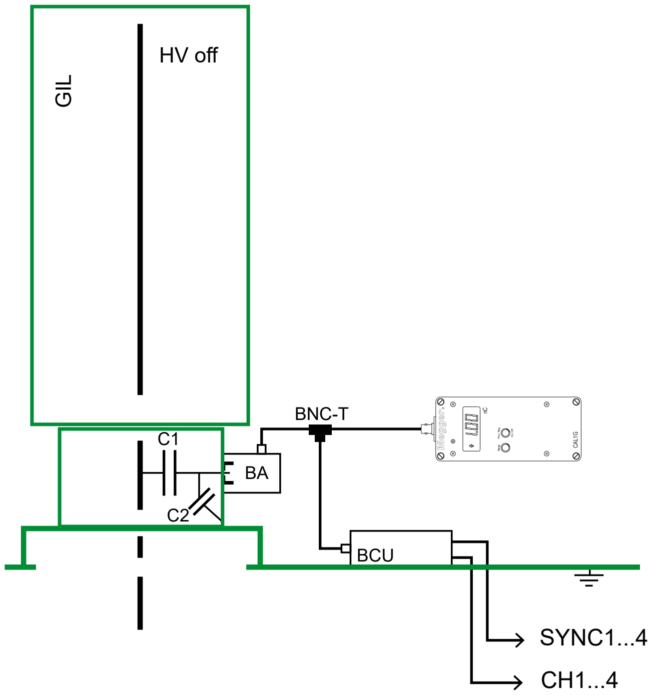
Alternative methods

In some special cases it may not be possible to calibrate according to the standard definition, because:

- The access to the HV terminals is prohibited due to safety issues
- The oil–oil bushing is already filled with oil and the access to the HV terminal is not given or prohibited
- A cable box is already installed

In these cases, it is necessary to estimate the sensitivity and the background noise level by injecting the calibrator pulse directly into the test tap. Note that this method **is not a valid calibration** according to IEC 60270.

The following figure shows the principle of this method. The calibrator signal is connected to the test tap and in parallel to the BCU input connector. The diagram on the right shows the simplified equivalent circuit diagram, supposing that the inductance of the ground connection L_g and the inductance of the network L_n are comparably high and the influence of these connections and the network is therefore negligible.



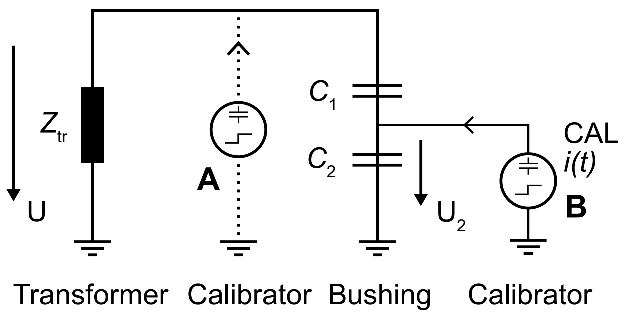


Figure 9: Alternative calibration method

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Position A shows the correct location of connecting the calibrator according to IEC 60270. Position B shows the connection location of the calibrator from the test tap connector. The injected charge value translates into a short pulse current.

$$Q_\mathrm{c} = \int i(t)\mathrm{d}t$$

where

$Q_c = Q_{ca}$ is the calibration value if injected at position A

Q_b is the calibration value shown on the calibrator if injected from position B

$i(t)$ is the impulse current provided by the calibrator

k is the correction factor

The correction factor k and thereby Q_c can be calculated as

$$U = kU_2$$

$$U = k\left(U\frac{\frac{1}{jwC_2}}{\frac{1}{jwC_1}+\frac{1}{jwC_2}}\right)$$

$$k = \frac{C_2 + C_1}{C_1}$$

$$Q_\mathrm{c} = kQ_\mathrm{b}$$

When using this alternative method, the operator needs to use the value of Q_c as the calibration value to be set on the instrument instead of using the value Q_b as shown on the calibrator.

After energising the transformer, it is important to check the AC voltage on the synchronisation connector using a standard multimeter with high input impedance. It is possible to T-connect a BNC connector on the sync inputs of the ICM*observer* directly. The input impedance of the sync channels of the ICM*observer* is 10 MΩ.

Problems that might occur include:

- No voltage on the SYNC input: SYNCx
    - Faulty cable connection (check the crimping of the connectors)
    - PD and HV signal cables mixed up
- Higher voltages on the SYNC input than expected[1)]
    - BCUs of LV and HV mixed up
    - Wrong C_d value for the type of bushing

1) When using a bushing coupling unit of type BCU2D, the synchronisation voltage is superimposed on the PD signal.

Alarm settings

After commissioning of the PD monitoring system, it can be helpful to consider some general rules for the operation of the instrument. The most prominent question is regarding the correct setting of alarm levels. The instrument provides two general alarms that are independent on the active channel, meaning if an alarm condition is met on one of the four channels, the instrument will either trigger the relays or generate a software alarm event.

Alarm condition 1 (Q_p alarm)

$$Q_{\mathrm{p}}[i, T_{\mathrm{cycle}}] \geq Q_{\mathrm{alarm}}$$

where

i is the channel number

T_{cycle} is the refresh cycle of the instrument, typically 50 ms–100 ms

Q_{alarm} is the preset alarm level in the instrument

Q_p is the highest PD value within one internal refresh cycle; value is shown in pC or nC

Alarm condition 2 (NQS alarm)

$$\mathrm{NQS}[i, t] \geq \mathrm{NQS}_{\mathrm{alarm}}$$

where

i is the channel number
t is the time stamp
NQS_{alarm} is the preset alarm level in the instrument
NQS is the number of PD quantities per second; value is shown in pA or nA

The NQS value is calculated continuously. After one scan period, the highest value during one scan on the selected channel is stored temporarily. The highest value of multiple scans is captured and stored permanently into the strip chart according to the MEM setting on the equipment (see ICM*observer* user guide). The internal calculation of the NQS value is:

$$\mathrm{NQS}(t) = \frac{\sum_{i,t=T_0}^{t} Q[i,t]}{t - T_0}$$

where

NQS is the NQS value on one channel at time

T_0 is the time stamp at the start of the calculation period

t is the current time stamp

i is the index of sampled Q value

Due to the integration over time, the NQS current value is a more stable value than the Q_p value, so it is recommended to use the NQS for alarm detection instead of the Q_p value. The Q_p alarm can easily be triggered by switching pulses, short disturbance pulses, or other intermediate interference. The NQS will cross the trigger level only if an ongoing PD activity is present. After commissioning, it is advisable to record the Q_p and NQS trending for a while. After finding a constant level for both values, it is common to set the alarm levels about 30–50 % higher than this standard value. The NQS trending should be cross-checked from time to time to find deviations from the standard level. If the NQS alarm triggers frequently, it can be caused due to deviation of the environmental noise floor.

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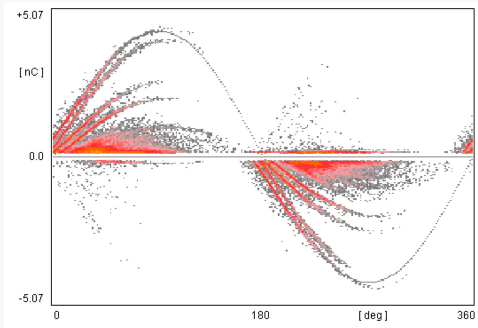
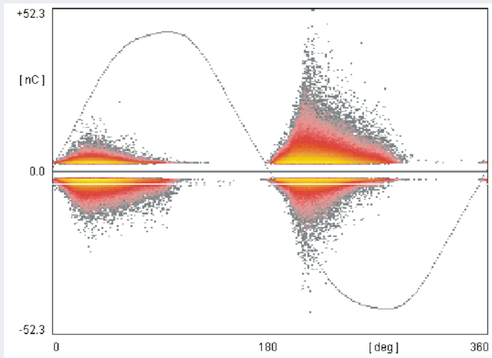
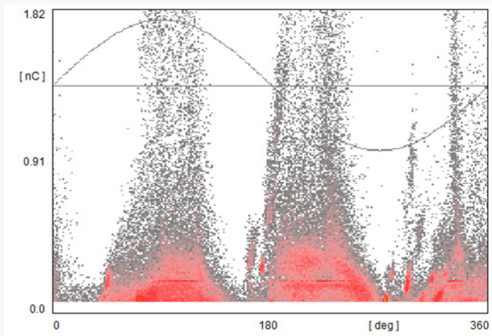
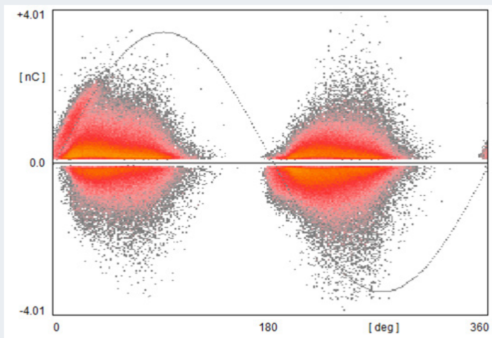
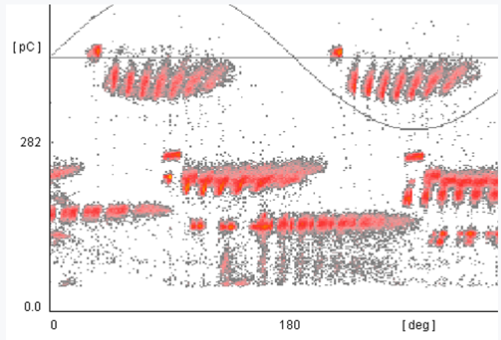
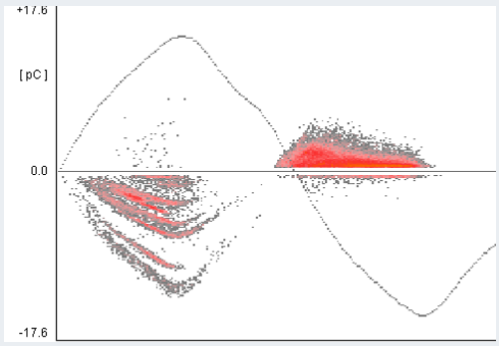
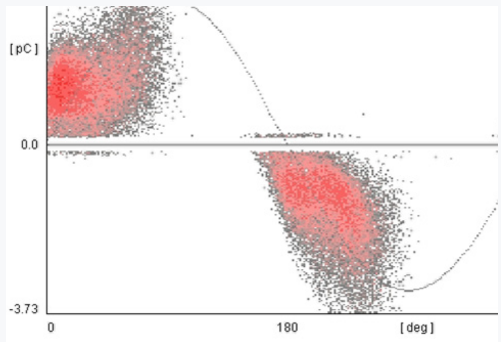
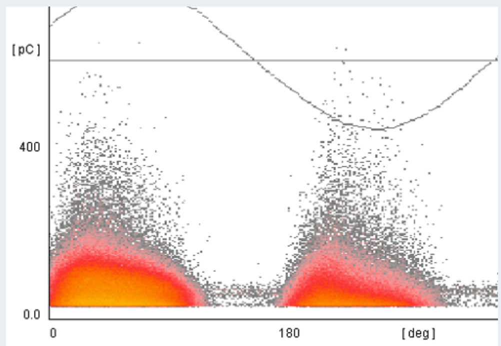
PD pattern examples

Distribution and power transformers are tested in the factory according to common IEC standards. The guarantee level for new transformers is typically less than 20 pC on cast-resin transformers and 200 pC on oil-filled power transformers. Therefore, all PD detected on transformers under applied voltage up to 1.2 times rated voltage should be considered as problematic. Further analysis should clarify the root cause of such internal PD activity.

PD phenomenon or external interference	Typical range	Further analysis recommended	PRPD example
Void discharge with low availability of starting electrons	< 100 pC	> 200 pC	
Surface discharge	< 2 pC	> 20 pC	
Corona discharge on a 400 kV air bushing; cross coupling from all phases	nC	-	
Surface discharge on a damaged insulator part of an oil bushing			

PD phenomenon or external interference	Typical range	Further analysis recommended	PRPD example
Floating potentials			
Void discharges on a semi-conduc-tive layer			
Treeing			
Sharp point on a poorly crimp con-nection			

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