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National foreword

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Reaffirmed and reprinted in July 2013.
This document will be reviewed every five years
and be reaffirmed, amended, revised or withdrawn.

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NORME INTERNATIONALE INTERNATIONAL STANDARD

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IEC**

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Troisième édition
Third edition
2000-12

Techniques des essais à haute tension – Mesures des décharges partielles

High-voltage test techniques – Partial discharge measurements

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Commission Electrotechnique Internationale
International Electrotechnical Commission
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For price, see current catalogue*

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE TEST TECHNIQUES – PARTIAL DISCHARGE MEASUREMENTS

FOREWORD

- 1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
- 3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
- 4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
- 5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.
- 6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60270 has been prepared by IEC technical committee 42: High-voltage test techniques.

This third edition cancels and replaces the second edition published in 1981 of which it constitutes a technical revision.

The text of this standard is based on the following documents:

FDIS	Report on voting
42/162/FDIS	42/165/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annex A forms an integral part of this standard.

Annexes B, C, D, E, F and G are for information only.

Terms used throughout this standard which have been defined in clause 3: **bold roman type**.

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The committee has decided that the contents of this publication will remain unchanged until 2008. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

The contents of the corrigendum of October 2001 have been included in this copy.

HIGH-VOLTAGE TEST TECHNIQUES – PARTIAL DISCHARGE MEASUREMENTS

1 Scope

This International Standard is applicable to the measurement of **partial discharges** which occur in electrical apparatus, components or systems when tested with alternating voltages up to 400 Hz or with direct voltage.

This standard

- defines the terms used;
- defines 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;
- gives some assistance concerning the discrimination of **partial discharges** from external interference.

The provisions of this standard should be used in the drafting of specifications relating to **partial discharge** measurements for specific power apparatus. It deals with electrical measurements of impulsive (short-duration) **partial discharges**, but reference is also made to non-electrical methods primarily used for **partial discharge** location (see annex F).

Diagnosis of the behaviour of specific power apparatus can be aided by digital processing of **partial discharge** data (see annex E) and also by non-electrical methods that are primarily used for **partial discharge** location (see annex F).

This standard is primarily concerned with electrical measurements of **partial discharges** made during tests with alternating voltage, but specific problems which arise when tests are made with direct voltage are considered in clause 11.

The terminology, definitions, basic test circuits and procedures often also apply to tests with other frequencies, but special test procedures and measuring system characteristics, which are not considered in this standard, may be required.

Annex A provides normative requirements for performance tests on calibrators.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*.

IEC 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

CISPR 16-1:1993, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

3 Definitions

For the purpose of this International Standard, the following definitions apply.

3.1

partial discharge (PD)

localized electrical discharge that only partially bridges the insulation between conductors and which can or can not occur adjacent to a conductor

NOTE 1 **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 μ s. More continuous forms can, however, occur, such as the so-called pulse-less discharges in gaseous dielectrics. This kind of discharge will normally not be detected by the measurement methods described in this standard.

NOTE 2 "Corona" is a form of **partial discharge** that occurs in gaseous media around conductors which are remote from solid or liquid insulation. "Corona" should not be used as a general term for all forms of PD.

NOTE 3 **Partial discharges** are often accompanied by emission of sound, light, heat, and chemical reactions. For further information, see annex F.

3.2

partial discharge pulse (PD pulse)

current or voltage pulse that results from a **partial discharge** occurring within the object under test. The pulse is measured using suitable detector circuits, which have been introduced into the test circuit for the purpose of the test

NOTE A **partial discharge** which occurs in the test object produces a current pulse. A detector in accordance with the provisions of this standard produces a current or a voltage signal at its output, proportional to the charge of the current pulse at its input.

3.3 quantities related to partial discharge pulses

3.3.1 apparent charge q

of a **PD pulse** is 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 **apparent charge** is usually expressed in picocoulombs (pC)

NOTE The **apparent charge** is not equal to the amount of charge locally involved at the site of the discharge, which cannot be measured directly.

3.3.2 pulse repetition rate n

ratio between the total number of **PD pulses** recorded in a selected time interval and the duration of this time interval

NOTE In practice, only pulses above a specified magnitude or within a specified range of magnitudes are considered.

3.3.3 pulse repetition frequency N

number of **partial discharge** pulses per second, in the case of equidistant pulses

NOTE **Pulse repetition frequency N** is associated with the situation in calibration.

3.3.4 phase angle ϕ_i and time t_i of occurrence of a PD pulse is

$$\phi_i = 360 (t_i/T)$$

where t_i is the time measured between the preceding positive going transition of the test voltage through zero and the **partial discharge pulse** and T is the period of the test voltage

The phase angle is expressed in degrees (°).

3.3.5 average discharge current I

derived quantity and the sum of the absolute values of individual **apparent charge** magnitudes q_i during a chosen reference time interval T_{ref} divided by this time interval:

$$I = \frac{1}{T_{\text{ref}}} (|q_1| + |q_2| + \dots + |q_i|)$$

The **average discharge current** is generally expressed in coulombs per second (C/s) or in amperes (A).

3.3.6

discharge power P

derived quantity that is the average pulse power fed into the terminals of the test object due to **apparent charge** magnitudes q_i during a chosen reference time interval T_{ref} :

$$P = \frac{1}{T_{\text{ref}}} (q_1 u_1 + q_2 u_2 + \dots + q_i u_i)$$

where $u_1, u_2 \dots u_i$ are instantaneous values of the test voltage at the instants of occurrence t_i of the individual **apparent charge** magnitudes q_i . The sign of the individual values must be observed

The **discharge power** is generally expressed in watts (W).

3.3.7

quadratic rate D

derived quantity that is the sum of the squares of the individual **apparent charge** magnitudes q_i during a chosen reference time interval T_{ref} divided by this time interval:

$$D = \frac{1}{T_{\text{ref}}} (q_1^2 + q_2^2 + \dots + q_m^2)$$

The **quadratic rate** is generally expressed in (coulombs)² per second (C²/s).

3.3.8

radio disturbance meter

quasi-peak measuring receiver for frequency band B in accordance with the provisions of CISPR 16-1:1993

NOTE This type of instrument was earlier called a radio interference (or influence) meter.

3.3.9

radio disturbance voltage U_{RDV}

derived quantity that is the reading of a **radio disturbance meter** when used for indicating the **apparent charge** q of partial discharges. For further information, see 4.5.6 and annex D

The **radio disturbance voltage** U_{RDV} is generally expressed in μV .

3.4

largest repeatedly occurring PD magnitude

largest magnitude recorded by a measuring system which has the pulse train response as specified in 4.3.3

The concept of the **largest repeatedly occurring PD magnitude** is not applicable to tests with direct voltage.

3.5

specified partial discharge magnitude

largest magnitude of any quantity related to **PD pulses** permitted in a test object at a specified voltage following a specified conditioning and test procedure. For alternating voltage tests, the specified magnitude of the **apparent charge** q is the **largest repeatedly occurring PD magnitude**

NOTE The magnitude of any **PD pulse** quantity can vary stochastically in successive cycles and also show a general increase or decrease with time of voltage application. The **specified PD magnitude**, the test procedure and also the test circuit and instrumentation should therefore be appropriately defined by the relevant technical committees.

3.6

background noise

signals detected during PD tests, which do not originate in the test object

NOTE **Background noise** can be composed of either white noise in the measurement system, broadcast radio or other continuous or impulsive signals. For further information, see annex G.

3.7

applied test voltages related to partial discharge pulse quantities

as defined in IEC 60060-1. The following voltage levels are of particular interest

3.7.1

partial discharge inception voltage U_i

applied voltage at which repetitive **partial discharges** are first observed in the test object, when the voltage applied to the object is gradually increased from a lower value at which no **partial discharges** are observed

In practice, the inception voltage U_i is the lowest applied voltage at which the magnitude of a **PD pulse** quantity becomes equal to or exceeds a specified low value.

NOTE For tests with direct voltage, the determination of U_i needs special considerations. See clause 11.

3.7.2

partial discharge extinction voltage U_e

applied voltage at which repetitive **partial discharges** cease to occur in the test object, when the voltage applied to the object is gradually decreased from a higher value at which **PD pulse** quantities are observed

In practice, the extinction voltage U_e is the lowest applied voltage at which the magnitude of a chosen **PD pulse** quantity becomes equal to, or less than, a specified low value.

NOTE For tests with direct voltage, the determination of U_e needs special considerations. See clause 11.

3.7.3

partial discharge test voltage

specified voltage, applied in a specified **partial discharge** test procedure, during which the test object should not exhibit PD exceeding a **specified partial discharge magnitude**

3.8

partial discharge measuring system

system consisting of a coupling device, a transmission system and a measuring instrument

3.9

measuring system characteristics

The following definitions refer to measuring systems as specified in 4.3

3.9.1

transfer impedance $Z(f)$

ratio of the output voltage amplitude to a constant input current amplitude, as a function of frequency f , when the input is sinusoidal

3.9.2

lower and upper limit frequencies f_1 and f_2

frequencies at which the **transfer impedance $Z(f)$** has fallen by 6 dB from the peak pass-band value

3.9.3

midband frequency f_m and bandwidth Δf

for all kinds of measuring systems, the **midband frequency** is defined by:

$$f_m = \frac{f_1 + f_2}{2}$$

and the **bandwidth** is defined by:

$$\Delta f = f_2 - f_1$$

3.9.4

superposition error

caused by the overlapping of transient output pulse responses when the time interval between input current pulses is less than the duration of a single output response pulse. **Superposition errors** can be additive or subtractive depending on the **pulse repetition rate** of the input pulses. In practical circuits, both types will occur due to the random nature of the **pulse repetition rate**. However, since measurements are based on the **largest repeatedly occurring PD magnitude**, usually only the additive **superposition errors** will be measured

NOTE **Superposition errors** can attain levels of 100 % or more depending on the **pulse repetition rate** and the characteristics of the measuring system.

3.9.5

pulse resolution time T_r

shortest time interval between two consecutive input pulses of very short duration, of same shape, polarity and charge magnitude for which the peak value of the resulting response will change by not more than 10 % of that for a single pulse

The **pulse resolution time** is in general inversely proportional to the **bandwidth Δf** of the measuring system. It is an indication of the measuring system's ability to resolve successive PD events.

NOTE It is recommended that the **pulse resolution time** be measured for the whole test circuit, as well as for the measuring system, as **superposition errors** can be caused by the test object, for example reflections from cable ends. The relevant technical committees should specify the procedure for handling **superposition errors** and particularly, the allowable tolerances including their signs.

3.9.6

integration error

error in **apparent charge** measurement which occurs when the upper frequency limit of the PD current pulse amplitude-spectrum is lower than

- the upper cut-off frequency of a wideband measuring system; or
- the mid-band frequency of a narrow-band measuring system.

See figure 5.

NOTE If required for a special type of apparatus, the relevant technical committees are urged to specify more restrictive values for f_1 and f_2 to minimize the **integration error**.

3.10

digital partial discharge instruments

considered in this standard are in general based on analogue measuring systems or instruments for the measurement of **apparent charge** q , followed by a digital acquisition and processing system. The digital part of a **digital PD-instrument** is used to process analogue signals for further evaluation, to store relevant quantities and to display test results. See also annex E.

NOTE A **digital PD-instrument** can also be based on a coupling device and a digital acquisition system without the analogue signal processing front end. This standard does not provide specific information applicable to this type of instrument.

3.11

scale factor k

factor by which the value of the instrument reading is to be multiplied to obtain the value of the input quantity (IEC 60060-2:1994, 3.5.1)

4 Test circuits and measuring systems

4.1 General requirements

In this clause, basic test circuits and measuring systems for **partial discharge** quantities are described, and information on the operating principle of these circuits and systems is provided. The test circuit and measuring system shall be calibrated as specified in clause 5 and shall meet the requirements specified in clause 7. The technical committee may also recommend a particular test circuit to be used for particular test objects. It is recommended that the technical committees use **apparent charge** as the quantity to be measured wherever possible, but other quantities may be used in particular specific situations.

If not otherwise specified by the relevant technical committee, any of the test circuits mentioned in 4.2 and any of the measuring systems as specified in 4.3 are acceptable. In each case, the most significant characteristics of the measuring system (f_1 , f_2 , T_r , see 3.9.2 and 3.9.5) as applied, shall be recorded.

For tests with direct voltage, see clause 11.

4.2 Test circuits for alternating voltages

Most circuits in use for **partial discharge** measurements can be derived from one or other of the basic circuits, which are shown in figures 1a to 1d. Some variations of these circuits are shown in figures 2 and 3. Each of these circuits consists mainly of

- a test object, which can usually be regarded as a capacitor C_a (see, however, annex C);
- a coupling capacitor C_k , which shall be of low inductance design, or a second test object C_{a1} , which shall be similar to the test object C_a . C_k or C_{a1} should exhibit a sufficiently low level of **partial discharges** at the specified test voltage to allow the measurement of the **specified partial discharge magnitude**. A higher level of **partial discharges** can be tolerated if the measuring system is capable of distinguishing the discharges from the test object and the coupling capacitor and measuring them separately;
- a measuring system with its input impedance (and sometimes, for balanced circuit arrangements, a second input impedance);

- a high-voltage supply, with sufficiently low level of **background noise** (see also clauses 9 and 10) to allow the **specified partial discharge magnitude** to be measured at the specified test voltage;
- high-voltage connections, with sufficiently low level of **background noise** (see also clauses 9 and 10) to allow the **specified partial discharge magnitude** to be measured at the specified test voltage;
- an impedance or a filter can be introduced at high voltage to reduce **background noise** from the power supply.

NOTE For each of the basic PD test circuits shown in figures 1 and 3, the coupling device of the measuring system can also be placed at the high-voltage terminal side, so that the positions of the coupling device with C_a or C_k are exchanged; then, optical links are used for the interconnection of the coupling device with the instrument, as indicated in figure 1a.

Additional information and particular characteristics of the different test circuits are considered in annexes B and G.

4.3 Measuring systems for apparent charge

4.3.1 General

Partial discharge measuring systems can be divided into the subsystems: coupling device, transmission system (for example, connecting cable or optical link) and measuring instrument. In general, the transmission system does not contribute to the circuit characteristics and will thus not be taken into consideration.

4.3.2 Coupling device

The coupling device is an integral part of the measuring system and test circuit, with components specifically designed to achieve the optimum sensitivity with a specific test circuit. Different coupling devices may thus be used in conjunction with a single measuring instrument.

The coupling device is usually an active or passive four-terminal network (quadripole) and converts the input currents to output voltage signals. These signals are transmitted to the measuring instrument by a transmission system. The frequency response of the coupling device, defined by output voltage to input current, is normally chosen at least so as to effectively prevent the test voltage frequency and its harmonics from reaching the instrument.

NOTE 1 Though the frequency response of an individual coupling device is not of general interest, the magnitude and frequency characteristics of the input impedance are of importance as this impedance interacts with C_k and C_a and is thus an essential part of the test circuit.

NOTE 2 Interconnection leads between the coupling device and the test object should be kept as short as practical so as to minimize effects on the detection bandwidth.

4.3.3 Pulse train response of instruments for the measurement of apparent charge

Provided the amplitude frequency spectrum of the input pulses is constant at least within the **bandwidth** Δf of the measuring system (see figure 5), the response of the instrument is a voltage pulse with a peak value proportional to the (unipolar) charge of the input pulse. The shape, duration and the peak value of this output pulse are determined by the **transfer impedance** $Z(f)$ of the measuring system. Thus, the shape and duration of the output pulse can be completely different from that of the input signal.

Display of the individual output voltage pulses on the screen of an oscilloscope can assist in recognizing the origin of **partial discharges** and in distinguishing them from disturbances (see clause 10). The voltage pulses should be displayed either on a linear time-base which is triggered by the test voltage, or on a sinusoidal time base synchronized with the test voltage frequency or an elliptical time-base which rotates synchronously with the test voltage frequency.

In addition, it is particularly recommended that an indicating instrument or recorder should be used to quantify the **largest repeatedly occurring PD magnitude**. The reading of such instruments, when used in testing with alternating voltage, should be based on an analogue peak detection circuit, or digital peak detection by software, with a very short electrical charge time constant and an electrical discharge time constant not larger than 0,44 s. Independent of the type of display used in such instruments, the following requirements apply:

The response of the system to a pulse train consisting of equally large equidistant pulses q_0 with a known **pulse repetition frequency N** , shall be such that the reading R of the instrument indicates magnitudes as given in the following table. The range and gain of the instrument is assumed to be adjusted to read full scale or 100 % for $N = 100$. The calibrator used to produce the pulses shall conform to the requirements of clause 5.

Table 1 – Pulse train response of PD instruments

N (1/s):	1	2	5	10	50	≥ 100
R_{\min} (%):	35	55	76	85	94	95
R_{\max} (%):	45	65	86	95	104	105

NOTE 1 This characteristic is necessary to establish compatibility of readings obtained with different types of instruments. The requirement is to be fulfilled on all ranges. Instruments already in use at the date of issue of this standard are not required to comply with these requirements; however, the actual values for $R(N)$ should be given.

NOTE 2 The measured quantity can be indicated, for example, on pointer instruments, digital displays or oscilloscopes.

NOTE 3 The specified response may be obtained either by analogue or by digital signal processing.

NOTE 4 The pulse train response defined in this subclause is not appropriate for direct voltage tests.

NOTE 5 The relevant technical committee may specify a different response tailored to a particular apparatus.

4.3.4 Wide-band PD instruments

In combination with the coupling device, this type of instrument constitutes a wide-band PD measuring system which is characterized by a **transfer impedance $Z(f)$** having fixed values of the **lower and upper limit frequencies f_1 and f_2** , and adequate attenuation below f_1 and above f_2 . Recommended values for f_1 , f_2 and Δf are

$$30 \text{ kHz} \leq f_1 \leq 100 \text{ kHz};$$

$$f_2 \leq 500 \text{ kHz};$$

$$100 \text{ kHz} \leq \Delta f \leq 400 \text{ kHz}.$$

NOTE Combinations of different coupling devices with the measuring instrument can alter the **transfer impedance**. The overall response should, however, always fulfil the recommended values.

The response of these instruments to a (non-oscillating) **partial discharge** current pulse is in general a well-damped oscillation. Both the **apparent charge** q and polarity of the PD current pulse can be determined from this response. The **pulse resolution time** T_r is small and is typically 5 μ s to 20 μ s.

4.3.5 Wide-band PD instruments with active integrator

This type of instrument consists of a very wide-band amplifier followed by an electronic integrator which is characterized by the time constant of its integrating capacitor and resistor network. The response of the integrator to a **PD pulse** is a voltage signal increasing with the instantaneous sum of charge. The final amplitude of the signal is thus proportional to the total charge, assuming that the time constant of the integrator is much larger than the duration of the **PD pulse**. In practice, time constants in the range of 1 μ s are typical. The **pulse resolution time** for consecutive **PD** pulses is less than 10 μ s.

NOTE A corresponding **upper limit frequency** of some hundred kilohertz can be attributed to such instruments, calculated from the time constant of the combination of the amplifier and active integrator.

4.3.6 Narrow-band PD instruments

These instruments are characterized by a small **bandwidth** Δf and a **midband frequency** f_m , which can be varied over a wide frequency range, where the amplitude frequency spectrum of the PD current pulse is approximately constant. Recommended values for Δf and f_m are

$$9 \text{ kHz} \leq \Delta f \leq 30 \text{ kHz}$$

$$50 \text{ kHz} \leq f_m \leq 1 \text{ MHz}.$$

It is further recommended that the **transfer impedance** $Z(f)$ at frequencies of $f_m \pm \Delta f$ should be 20 dB below the peak pass-band value.

NOTE 1 During actual **apparent charge** measurements, midband frequencies $f_m > 1 \text{ MHz}$ should only be applied if the readings for such higher values do not differ from those as monitored for the recommended values of f_m .

NOTE 2 In general, such instruments are used together with coupling devices providing high-pass characteristics within the frequency range of the instrument. If resonance coupling devices are used, f_m has to be tuned and fixed to the resonance frequency of the coupling device and the test circuit to provide a constant **scale factor** of the circuit.

NOTE 3 **Radio disturbance meters** with quasi-peak response are not qualified under this standard for the measurement of the **apparent charge** q , but they can be used for detection of PD.

The response of these instruments to a **partial discharge** current pulse is a transient oscillation with the positive and negative peak values of its envelope proportional to the **apparent charge**, independent of the polarity of this charge. The **pulse resolution time** T_r will be large, typically above 80 μ s.

4.4 Requirements for measurements with digital PD-instruments

The minimum requirement for a **digital PD-instrument** is to:

- display the value of the **largest repeatedly occurring PD magnitude**. The instrument shall conform to the requirements of 4.3.3.

Additionally, one or more of the following quantities may be evaluated and recorded:

- the **apparent charge** q_i occurring at time instant t_i ;
- the instantaneous value of the test voltage u_i as measured at the time instant t_i of occurrence of the individual **apparent charge** q_i ;
- the **phase angle** ϕ_i of occurrence of the **PD pulse** occurring at time t_i .

4.4.1 Requirements for measurement of apparent charge q

The time between successive updates of the digital display shall not exceed 1 s.

The instrument response will normally include some level of continuous or base line noise. This noise can be caused by **background noise** or by a large number of **partial discharge pulses** whose magnitude is small compared with the highest level to be measured. Thus, a bipolar sensitivity threshold may be introduced to prevent such signals from being recorded. If a threshold level is used, this level shall be recorded.

Guidelines regarding the digital acquisition of the analogue response signals are provided in annex E.

4.4.2 Requirements for measurement of test voltage magnitude and phase

If the digital instrument is stated to be able to record the voltage level of the power frequency test voltage, it shall comply with the requirements of IEC 60060-2, 1994.

If the instrument is stated to be able to measure the phase angle of the test voltage, it shall be suitably demonstrated that the phase displacement of the reading is within 5 degrees of the true value.

4.5 Measuring systems for derived quantities

4.5.1 Coupling device

The provisions of 4.3.2 are also valid for measuring systems for derived quantities.

4.5.2 Instruments for the measurement of pulse repetition rate n

An instrument for the determination of the **pulse repetition rate** shall have a sufficiently short **pulse resolution time** T_r to resolve the highest **pulse repetition rate** of interest. Magnitude discriminators which suppress pulses below an adjustable, predetermined magnitude, may be required to avoid counting of non-significant signals. Several discriminator levels can be suitable to characterize PD, for example, in tests with direct voltage.

It is recommended that the counter input is connected to the output of a PD measuring system as described in 4.3. If a pulse counter is used with a PD measuring system with oscillatory or bi-directional response, suitable pulse shaping must be done to avoid obtaining more than one count per pulse.

4.5.3 Instruments for the measurement of average discharge current I

In principle, instruments which measure the average value of the discharge current pulses after linear amplification and rectification will indicate, when suitably calibrated, the **average discharge current I** . Errors can be introduced into this measurement due to

- amplifier saturation at low **pulse repetition rate n** ;
- pulses occurring with separation times less than the **pulse resolution time T_r** of the system;
- low-level partial discharges being below the detection threshold of the digital acquisition equipment.

Such sources of error should be taken into account when evaluating such measurements.

The **average discharge current** may also be calculated by digital processing.

NOTE Saturation can occur when the **repetition rate n** is so low that **average discharge current I** is difficult to detect. In such cases, the temptation can be to increase substantially the gain of the PD instrument amplifier (thereby increasing the **scale factor**) until this current is detectable. This can result in the situation where the amplifier's dynamic range is such that it is unable to respond linearly to the infrequent PD pulses. To prevent this situation, the PD instrument can be equipped with alarm circuits to detect non-linear operation, or the output of the PD instrument can be visually monitored (for example, on an oscilloscope) during the measurement of **average discharge current**.

4.5.4 Instruments for the measurement of discharge power P

Different types of test circuits and analogue instruments may be used for the measurement of **discharge power**. They are usually based on the evaluation of $\sum q_i u_i$, a quantity which can be measured by the area of an oscilloscope display if the x-y-axes are used to quantify $\int q_i$ and $u(t)$ respectively, or by more sophisticated techniques. The calibration of such test circuits and instruments relies on the determination of the **scale factors** for applied voltage and **apparent charge**.

The **discharge power** may also be calculated by digital processing.

4.5.5 Instruments for the measurement of quadratic rate D

Instruments which measure the mean of the squares of the individual **apparent charge** magnitudes q_i will indicate the **quadratic rate D** . The design of such instruments should be based on characteristics as applicable for **apparent charge** measurements.

The **quadratic rate** may also be calculated by digital processing.

4.5.6 Instruments for the measurement of the radio disturbance voltage

Radio disturbance meters are frequency selective voltmeters. The instruments are primarily intended for measuring interference or disturbances to broadcast radio signals. Though **radio disturbance meters** do not indicate directly any of the quantities defined in this standard, they can give a reasonable indication of **apparent charge magnitude q** , when used with a coupling device having an adequate high-pass characteristic and when calibrated according to clause 5.

Due to the quasi-peak measuring circuit within this instrument, the reading is, however, sensitive to the **pulse repetition rate n** of the discharge pulses. For further information, see annex D.

4.6 Ultra-wide-band instruments for PD detection

Partial discharges can also be detected by oscilloscopes providing very high **bandwidth** or by frequency selective instruments (for example, spectrum analyzers) together with appropriate coupling devices. The aim of application is to measure and to quantify the shape or the frequency spectrum of **partial discharge** current or voltage pulses in equipment with distributed parameters, for example cables, rotating machines or gas insulated switchgear, or to provide information about the physics or origin of the discharge phenomena.

No recommendations are given in this standard for either measuring methods or bandwidth/frequencies of instruments to be used in such investigations, as these methods or instruments, in general, do not directly quantify the **apparent charge** of PD current pulses.

5 Calibration of a measuring system in the complete test circuit

5.1 General

The object of calibration is to verify that the measuring system will be able to measure the **specified PD magnitude** correctly.

The calibration of a measuring system in the complete test circuit is made to determine the **scale factor** k for the measurement of the **apparent charge**. As the capacitance C_a of the test object affects the circuit characteristics, calibration shall be made with each new test object, unless tests are made on a series of similar objects with capacitance values within $\pm 10\%$ of the mean values.

The calibration of a measuring system in the complete test circuit, is carried out by injecting short-duration current pulses of known charge magnitude q_0 , into the terminals of the test object (see figure 4). The value of q_0 shall be taken as the result of the performance test on the calibrator (see 7.2.3).

5.2 Calibration procedure

Calibration of measuring systems intended for the measurement of **apparent charge** q , should be made by injecting current pulses by means of a calibrator, as defined in clause 6.2, across the terminals of the test object, as shown in figure 4. The calibration should be performed at one magnitude in the relevant range of the magnitudes expected, to assure good accuracy for the **specified PD magnitude**.

The relevant range of magnitude should, in lieu of other specifications, be understood to be from 50 % to 200 % of the **specified PD magnitude**.

As the capacitor C_0 of a calibrator is often a low-voltage capacitor, the calibration of the complete test arrangement is performed with the test object de-energized. For the calibration to remain valid, the calibration capacitor C_0 should not be larger than $0,1 C_a$. If the requirements for the calibrator are met, the calibration pulse is then equivalent to a single-event discharge magnitude $q_0 = U_0 C_0$.

Consequently, C_0 must be removed before energizing the test circuit. If, however, C_0 is of high-voltage type, and has a sufficiently low level of **background noise** (see also clauses 9 and 10) to allow the specified PD level to be measured at the specified test voltage, it can remain connected in the test circuit.

NOTE The requirement that the capacitor C_0 should be less than $0,1 C_a$ is not required if C_0 is of high-voltage type and if it is left in the test circuit.

In case of tall objects of several metres in height, the injection capacitor C_0 should be located close to the high-voltage terminal of the test object as the stray capacitance C_s (indicated in figures 4a and 4b) could cause unacceptable errors.

The connection cable between the step voltage generator and capacitor C_0 should be shielded and be equipped with appropriate termination to avoid distortion of the voltage step.

6 Calibrators

6.1 General

The current pulses are generally derived from a calibrator that comprises a generator producing step voltage pulses of amplitude U_0 in series with a capacitor C_0 , so that the calibration pulses are repetitive charges each of magnitude

$$q_0 = U_0 C_0$$

In practice, it is not possible to produce ideal step voltage pulses. Though other wave-forms having slower rise times t_r (10 % to 90 % of peak value) and finite decay times t_d (90 % to 10 % of peak value) can inject essentially the same amount of charge, the responses of different measuring systems or test circuits can differ due to the **integration error** caused by the increased duration of such calibration current pulses.

The voltage pulses of the generator shall have a rise time t_r of less than 60 ns.

NOTE 1 For wide-band instruments with an upper limit frequency higher than 500 kHz, the requirement $t_r < 0,03/f_2$ must be fulfilled to produce a nearly constant amplitude frequency spectrum as shown in figure 5.

Calibration pulses can be generated either as a series of voltage pulses (unipolar or bipolar) being characterized by a fast rise time (as defined above) and with a slow decay time, or as a rectangular pulse train which is effectively differentiated by the calibration capacitor C_0 . For the first case, the decay time t_d of the voltage pulses shall be large compared with $1/f_1$ of the measuring system. For the second case, the voltage U_0 should not change by more than 5 % for the time interval between pulses. For both cases, the time interval between pulses should be longer than the **pulse resolution time**. For bipolar systems, the magnitude of both polarity pulses should have the same magnitude to within 5 %.

For the injection of current pulses into test objects with distributed electrical elements, such as gas insulated switchgear, C_0 may consist of a known capacitance between the high-voltage conductor and the sensor electrode connected to the calibration voltage source (see figure 4c).

NOTE 2 Calibrators qualified under this clause can be applied to the calibration of systems for measuring the **apparent charge** as well as to systems for measuring derived quantities.

6.2 Calibrators for the calibration of a measuring system in the complete test circuit

Calibrators can provide either unipolar or bipolar current pulses. The **pulse repetition frequency N** may be either fixed (for example, twice the frequency of the test voltage), or variable (provided that the interval between pulses exceeds the **pulse resolution time**). Such calibrators are applicable for the calibration of a measuring system in the complete test circuit to determine the **scale factor** of the **PD measuring system**.

NOTE 1 The **scale factor** is generally determined at one magnitude in the range of 50 % to 200 % of the **specified PD magnitude**.

NOTE 2 The calibration of a measuring system can be checked indirectly by injecting calibration pulses into the high-voltage test circuit (often at the input of the coupling device), but not at the terminals of the test object. This method does not constitute a calibration alone, but if used in conjunction with a calibration of the measuring system in the complete test circuit (see clause 5), this technique can be used as a transfer reference to simplify calibration procedures. The calibrator used should comply with the provisions of this standard.

6.3 Calibrators for performance tests on measuring systems

For checking additional features of the test circuit and measuring system characteristics, a more sophisticated calibrator device or even calibration procedure is recommended. The following characteristics are recommended for a calibrator used for performance tests:

- variable charge magnitude q_0 , in steps or continuously, for determination of the linearity of the **scale factor** k . The variation should be achieved by varying the step voltage. The linearity of the calibrator should be better than $\pm 5\%$ or ± 1 pC, whichever is the greater;
- variable time delay between two consecutive pulses of the same polarity to check the **pulse resolution time** T_r of the measuring system alone or the **pulse resolution time** of the whole test circuit;
- both output terminals of the calibrator floating, i.e. potential-free output;
- for battery-operated calibrators a battery status indicator should be provided;
- bipolar pulses to detect a change in **apparent charge** magnitude measurement with respect to PD current pulse polarity;
- a series of calibration pulses with known number of equal charge magnitudes and **repetition frequency** N to check **digital partial discharge instruments**.

7 Maintaining the characteristics of calibrators and measuring systems

Performance tests and performance checks are carried out to assess and maintain the characteristics of measuring systems.

Performance tests and performance checks are also carried out to assess and maintain the characteristics of calibrators.

In general, manufacturers of calibrators intended to calibrate **partial discharge** quantities will provide specifications and guidelines to perform periodic maintenance for the verification of the calibrator.

Independent of such manufacturer's specifications, the following procedures shall be followed. The results of the tests and checks shall be recorded in the record of performance.

7.1 Schedule of tests

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

Acceptance tests can comprise both type tests and routine tests. This schedule is in accordance with the general provisions of IEC 60060-2.

7.2 Maintaining the characteristics of calibrators

7.2.1 Type tests on calibrators

Type tests on calibrators shall be performed for one calibrator of a series. These type tests are to be carried out by the manufacturer of the calibrator. If type test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

The type test shall include all the tests required in a performance test.

7.2.2 Routine tests on calibrators

Routine tests on calibrators shall be performed for each calibrator of a series. These routine tests are to be carried out by the manufacturer of the calibrator. If routine test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

The routine test shall include all the tests required in a performance test.

7.2.3 Performance tests on calibrators

The accuracy of PD measurements depends on the accuracy of the calibrators. It is, therefore, recommended that the first performance test on a calibrator for which approval is sought should be traceable to national standards.

The following performance tests shall be made:

- determination of the actual calibrator charge q_0 on all nominal settings of the calibrator. The uncertainty of this determination should be assessed to be within $\pm 5\%$ or 1 pC, whichever is greater. It is the actual value of the calibrator charge that shall be employed when utilizing the calibrator;
- determination of the rise time t_r of the voltage step U_0 , with an uncertainty of $\pm 10\%$;
- determination of the **pulse repetition frequency N** with an uncertainty of $\pm 1\%$ by means of a pulse counter; this requirement applies only to calibrators intended for calibration of reading of **pulse repetition rate n** .

Annex A describes an adequate procedure to perform such tests related to q_0 and t_r . Other procedures may be applied if their applicability is confirmed by tests.

The results of all tests shall be kept in a record of performance established and maintained by the user.

7.2.4 Performance checks on calibrators

The following performance checks shall be made:

- determination of the actual calibrator charge q_0 on all nominal settings of the calibrator. The uncertainty of this determination should be assessed to be within $\pm 5\%$ or 1 pC, whichever is greater;

The results of all checks shall be kept in a record of performance established and maintained by the user.

Table 2 – Tests required for calibrators

Type of test	Reference to test method	Test classification			
		Type test	Routine test	Performance test	Performance check
Measurement of q_0	7.2.3	X	X	X	X
Measurement of t_r	7.2.3	X	X	X	
Measurement of N	7.2.3	X	X	X	

7.2.5 Record of performance

The record of performance of a calibrator shall include the following information:

- a) Nominal characteristics
 - 1) Identification (serial number, type, etc.)
 - 2) Range of operation conditions
 - 3) Range of reference conditions
 - 4) Warm-up time
 - 5) Range of charge output
 - 6) Supply voltage
- b) Result of type test
- c) Result of routine test
- d) Results of performance tests
 - 1) Date and time of each performance test
- e) Results of performance checks
 - 1) Date and time of each performance check
 - 2) Result – pass/fail (if fail, record of action taken)

7.3 Maintaining the characteristics of measuring systems

In general, manufacturers of measuring systems intended to measure quantities as specified in 3.3 will provide specifications and guidelines to perform periodic maintenance for the verification of the measuring instrument or system characteristics.

Independent from such manufacturers' specifications, the following procedures shall be followed. The results of the tests and checks shall be recorded in the record of performance.

7.3.1 Type tests on PD measuring systems

Type tests on PD measuring systems shall be performed for one measuring system of a series. These type tests are to be done by the manufacturer of the measuring system. If type test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

Type tests on PD measuring systems shall at least include:

- determination of the **transfer impedance $Z(f)$** and **lower and upper limit frequencies f_1 and f_2** of the measuring system over a range of frequencies in which it has dropped to 20 dB from the peak pass-band value. The input quantity should be sinusoidal current signals with variable frequency;
- determination of the **scale factor k** of the measuring system to calibration pulses of at least three different charge magnitudes, ranging from 100 % to 10 % of full range, at low **pulse repetition rate n** (about 100/s) on each magnitude range. The variation of k shall be less than ± 5 % in order to prove the linearity of the measuring system;
- determination of the **pulse resolution time T_r** of the measuring system by applying calibration pulses of constant charge magnitude but decreasing time interval between consecutive pulses. The **pulse resolution time** shall be determined for all coupling devices intended to be used with the instrument and at the minimum and maximum capacitance for which each coupling device is intended;
- verification that the variation of the reading of the **apparent charge q** with **pulse repetition frequency N** of the calibration pulses is in accordance with the values as provided in 4.3.3 for tests with alternating voltage.

7.3.2 Routine tests on measuring systems

Routine tests on measuring systems shall be performed for each measuring system of a series. These routine tests are to be done by the manufacturer of the measuring systems. If test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

The routine test shall include all the tests required in a performance test.

7.3.3 Performance tests on measuring systems

Performance tests on measuring systems shall include:

- determination of the **transfer impedance $Z(f)$** and **lower and upper frequency limits f_1 and f_2** of the measuring system over a range of frequencies in which it has dropped to 20 dB from the peak pass-band value. The input quantity should be sinusoidal current signals with variable frequency;
- the linearity of the measuring system shall be determined by applying the signal from a variable PD calibrator to the input of the measuring system. The linearity of the **scale factor k** should be verified from 50 % of the lowest, to 200 % of the highest **specified PD magnitude** to be measured. The variation of k shall be less than ± 5 % in order to prove the linearity of the measuring system.

The results of all tests shall be kept in a record of performance established and maintained by the user.

7.3.4 Performance checks for measuring systems

- Determination of the **transfer impedance $Z(f)$** of the measuring system at one frequency in the pass-band is required. It should be verified that the value has not changed by more than 10 % from the value recorded in the preceding performance test. The input quantity should be a sinusoidal current signal with variable frequency.

The results of all checks shall be kept in a record of performance established and maintained by the user.

Table 3 – Tests required for measuring systems

Type of test	Reference to test method	Test classification			
		Type test	Routine test	Performance test	Performance check
Determination of $Z(f)$	7.3.1	X	X	X	
Determination of $Z(f)$ at single frequency	7.3.4				X
Determination of k	7.3.1	X			
Determination of T_r	7.3.1	X			
Pulse train response	4.3.3	X			
Linearity	7.3.1	X			
Linearity	7.3.2		X	X	

7.3.5 Checks for additional capabilities of digital measuring systems

The provisions valid for analogue measuring systems shall be applicable to digital measuring systems, but as the digital systems provide additional capabilities to record many quantities related to **partial discharges**, their abilities should be quantitatively demonstrated by additional tests.

As a complete calibration procedure for digital PD instruments would depend on the specific abilities of the instruments which can be quite different, the following minimum additional calibration procedures are specified:

- To demonstrate the extent to which digital acquisition can correctly record input pulses irrespective of their frequency, the calibrator shall have the ability to produce, during a defined time interval, a known number of pulses (for example 10^4) with adjustable **pulse repetition frequencies**. The **pulse repetition frequency** of the calibrator shall be increased in adequate steps from low values (for example, 100 Hz) up to higher values that should not exceed the limits imposed by the **pulse resolution time** of the measuring system used. For every value of the **pulse repetition frequency**, the recorded number of pulses as observed during the defined time interval shall be within ± 2 % of the known number of calibration pulses applied.
- To demonstrate the extent to which the digital acquisition is successful in capturing every PD event, the calibrator shall be used with a constant but well-known **pulse repetition frequency** (for example 100 Hz) and the number of recorded events shall be compared with the number of calibration pulses generated by the calibrator during the maximum time of registration for which the digital instrument is designed. A deviation of ± 2 % is permitted when comparing the two numbers.

See also annex E for further information.

7.3.6 Record of performance

The record of performance of a measuring system shall include the following information:

- a) Nominal characteristics
 - 1) Identification (serial number, type, etc.)
 - 2) Range of operation conditions
 - 3) Range of reference conditions
 - 4) Warm-up time
 - 5) Range of measured charge quantity
 - 6) Supply voltage
- b) Result of type test
- c) Result of routine test
- d) Results of performance tests
 - 1) Date and time of each performance test
- e) Results of performance checks
 - 1) Date and time of each performance check
 - 2) Result – pass/fail (if fail, record of action taken)

8 Tests

This clause lists test object and test voltage requirements. Additional requirements, for special test conditions and methods of test, may be specified by the relevant technical committee. The committee should also specify the minimum measurable magnitude required. Information on practical limits of minimum measurable magnitude is given in annex G. For the case of tests with direct voltages, see clause 11. The technical committee may also recommend a partial discharge quantity other than the **apparent charge** to be measured.

NOTE Some guidance for the measurement of **partial discharges** on cables, gas insulated switchgear, power capacitors and in test objects with windings will be found in annex C.

8.1 General requirements

In order to obtain reproducible results in **partial discharge** tests, careful control of all relevant factors is necessary. The **partial discharge measuring system** shall be calibrated in accordance with the provisions of clause 5 prior to testing.

8.2 Conditioning of the test object

Before being tested, a test object should undergo a conditioning procedure specified by the relevant technical committee.

Unless otherwise specified:

- a) the surface of the external insulation of test objects shall be clean and dry because moisture or contamination on insulating surfaces can cause **partial discharges**; and
- b) the test object should be at ambient temperature during the test.

Mechanical, thermal and electrical stressing just before the test can affect the result of **partial discharge** tests. To ensure good reproducibility, a rest interval after previous stressing may be necessary before making **partial discharge** tests.

8.3 Choice of test procedure

The specification of procedures to be used for particular types of test and test objects is the responsibility of the relevant technical committee. They shall define any preliminary conditioning process, the test voltage levels and frequency, the rate of rise and fall of applied voltage, the sequence and duration of voltage application, and the relationship of **partial discharge** measurement tests to other dielectric tests.

To assist in preparing such test specifications, examples of test procedures for alternating voltages are given in 8.3.1 and 8.3.2.

8.3.1 Determination of the partial discharge inception and extinction voltages

A voltage well below the expected **inception voltage** shall be applied to the test object and gradually increased until discharges attain, or exceed, a specified low magnitude. The test voltage at this specified magnitude is the **partial discharge inception voltage** U_i . The voltage is then increased to a specified voltage level and thereafter gradually reduced to a value at which the discharges become less than the same specified magnitude. The test voltage at this discharge limit is the **partial discharge extinction voltage** U_e . Note that the value of U_i can be affected by the rate of rise of voltage, and U_e can be affected by the amplitude and time of voltage application and also by the rate of decrease of voltage.

NOTE 1 In some types of insulation, **partial discharges** occur only intermittently when the voltage is first raised to U_i , in others the discharge magnitude rises rapidly, whereas in others discharges extinguish when U_i is maintained for some time. Thus, the appropriate test procedure should be specified by the relevant technical committee.

Under no circumstances, however, shall the voltage applied exceed the rated short-duration power frequency withstand voltage applicable to the apparatus under test.

NOTE 2 In the case of high-voltage apparatus, there is some danger of damage from repeated voltage applications approaching the rated short-duration power frequency withstand voltage.

8.3.2 Determination of the partial discharge magnitude at a specified test voltage

8.3.2.1 Measurement without pre-stressing

The **partial discharge** magnitude in terms of the specified quantity is measured at a specified voltage, which can be well above the expected **partial discharge inception voltage**. The voltage is gradually increased from a low value to the specified value and maintained there for the specified time. As the magnitudes can change with time, the specified quantity shall be measured at the end of this time.

The magnitude of the **partial discharges** may also be measured and recorded while the voltage is being increased or reduced or throughout the entire test period.

8.3.2.2 Measurement with pre-stressing

The test is made by raising the test voltage from a value below the specified **partial discharge test voltage** up to a specified voltage exceeding this voltage. The voltage is then maintained for the specified time and, thereafter, gradually reduced to the specified **partial discharge test voltage**.

At this voltage level, the voltage is maintained for a specified time and, at the end of this time, the specified PD quantity is measured in a given time interval or throughout the specified time.

9 Measuring uncertainty and sensitivity

The magnitude, duration and **pulse repetition rate** of **PD pulses** can be greatly affected by the time of voltage application. Also, the measurement of different quantities related to **PD pulses** usually presents larger uncertainties than other measurements during high-voltage tests. Consequently, it can be difficult to confirm PD test data by repeating tests. This should be taken into consideration when specifying **partial discharge** acceptance tests.

The measurement of **apparent charge q** using a measuring system in accordance with the provisions of this standard and calibrated in accordance with the provisions of clauses 5 and 7, is considered to have a measuring uncertainty of $\pm 10\%$ or ± 1 pC, whichever is the greater.

The measurements are also affected by disturbances (clause 10) or **background noise**, which should be low enough to permit a sufficiently sensitive and accurate measurement of the **specified partial discharge magnitude**.

The minimum magnitude of PD quantities which can be measured in a particular test is in general limited by disturbances. Though these can effectively be eliminated by suitable techniques as described in annex G, additional limits are determined by the internal noise levels of the measuring instruments and systems, by the physical dimensions and layout of the test circuit and the values of the test circuit parameters.

Another limit for the measurement of a minimum PD quantity is set by the capacitance ratio C_a/C_k and optimal values for the input impedance of the coupling device and its matching to the measuring instruments used. Highest sensitivity would be realized if $C_k \gg C_a$, a condition which is generally inconvenient to satisfy due to the additional loading of the high-voltage supply. Thus, the nominal value of C_k is limited for actual tests, but acceptable sensitivity is usually achieved with C_k about 1 nF or higher.

10 Disturbances

The measurements are affected by disturbances which should be low enough to permit a sufficiently sensitive and accurate measurement of the PD quantity to be monitored. As disturbances may coincide with **PD pulses** and as they are often superimposed on the measured quantities, the **background noise** level should preferably be less than 50 % of a specified permissible **partial discharge** magnitude, if not otherwise specified by a relevant technical committee. For acceptance tests and type tests on high-voltage equipment, the **background noise** level shall be recorded.

High readings that are clearly known to be caused by external disturbances may be neglected.

Signal gating by time window, polarity discrimination, or similar methods can result in the loss of true **partial discharge** signals if those signals occur concurrently with the disturbance or the gated-out (inhibited) part of the cycle. For this reason, the signal should not be blocked by the gate for more than 2 % of each test voltage period in alternating voltage systems, nor by more than 2 % of the cumulative test time in direct voltage systems.

If, however, several mains-synchronized interference sources per period are present, the blocking interval limit may be increased to 10 % of the test voltage period. Hence, this gating shall be set before the full test voltage is applied and these settings shall not be altered during the test. The relevant technical committee may decide on different limits for signal gating.

NOTE Nearby operation of large rectifiers or inverters can produce a particular type of regularly repeated disturbance, which is related to the transition of current in the rectifier or inverter elements.

Further information regarding disturbances and mitigation thereof is given in annex G.

11 Partial discharge measurements during tests with direct voltage

11.1 General

Test objects with solid or liquid impregnated insulation show very different **partial discharge** characteristics when tested with direct voltage compared with those with alternating voltage. The differences may be minor in objects with gaseous insulation.

Some of these differences are summarized as follows:

- the **discharge pulse repetition rate** may be very low for direct voltage applied to solid insulation, because the time interval between discharges at each discharge site is determined by the relaxation time constants of the insulation;
- numerous discharges may occur when the applied voltage is changed. In particular, polarity reversal during test can cause numerous discharges at low voltage, but subsequently the **pulse repetition rate** will decrease to the steady-state condition;
- in liquid insulation, motion of the liquid tends to reduce the relaxation time constants so that discharges are more frequent;
- the PD characteristics of test objects may be affected by ripple on the test voltage.

NOTE 1 With direct voltage, the effect of voltage changes may be pronounced because the stress distribution is no longer primarily determined by the volume or surface resistivities, as it would be under conditions of constant voltage.

NOTE 2 Specific PD magnitudes, pulse count limits and the duration of voltage application should be determined by the relevant technical committee.

11.2 Quantities related to partial discharges

In general, all quantities related to **partial discharge pulses** as specified in 3.3 are also applicable to tests with direct voltage. The instrument used to measure the **apparent charge** shall have a pulse train response that is independent of the **repetition rate** of the **partial discharge pulses**.

11.3 Voltages related to partial discharges

11.3.1 Partial discharge inception and extinction voltages

The **partial discharge** inception and extinction voltages may be difficult to determine during tests with direct voltages as they are dependent on factors such as the voltage distributions under variable voltages, temperature and pressure. **Partial discharges** are more likely to occur during the initial application of voltage or during voltage changes and then become more intermittent as the voltage distribution becomes resistive.

Under certain conditions, the **partial discharges** can continue even after removal of the test voltage. This is valid particularly for combinations of solid, liquid and gaseous insulation.

NOTE In some cases, application of direct voltage to test objects with solid insulation will result in a conditioning process for the **partial discharges**. This is evidenced by PD count rates increasing and decreasing cyclically, with a constant applied voltage, until a conditioned state is reached after a long period.

11.3.2 Partial discharge test voltage

During application of the **partial discharge test voltage**, the test object should not exhibit **PD pulse** quantities exceeding a specified magnitude. Whereas for alternating voltages in general only **apparent charge magnitudes** are considered, for direct voltage tests also the number of **partial discharge pulses** exceeding a specified magnitude should not exceed a specified total during a specified time at the test voltage. It should be noted that single high-magnitude **PD pulses** can occur during the test.

11.4 Test circuits and measuring systems

In general, test circuits and measuring instruments used during tests with alternating voltages can also be used with direct voltages.

Since occurrence of **partial discharge** pulses is intermittent, pulse counting devices or **digital partial discharge instruments** should be used.

NOTE 1 When the **pulse repetition rate** n is low, pulse-counting devices which display the number of discharges in different, selectable magnitude ranges over each time interval are useful.

NOTE 2 The response of the instrument to different **pulse repetition frequencies** given in 4.3.3 is not applicable to testing with direct voltage.

11.5 Tests

11.5.1 Choice of test procedures

The procedures described for alternating voltage to determine the **PD inception and extinction voltages** are generally not applicable for tests with direct voltage as the stress on the dielectric during voltage rise and decrease is different from that during the period when the voltage is constant.

There is no accepted general method for the determination of **partial discharge** quantities during tests with direct voltage. Whatever method is used, it is important to note that magnitudes related to **partial discharges** at the beginning of the voltage application can be different from the magnitudes measured after a considerable time at the same test voltage.

11.5.2 Disturbances

The information given in clause 10 is also applicable for tests with direct voltages. However, in this case, a particular type of regularly repeated disturbance can occur, which is related to the commutation of current in the rectifier elements of the direct voltage source.

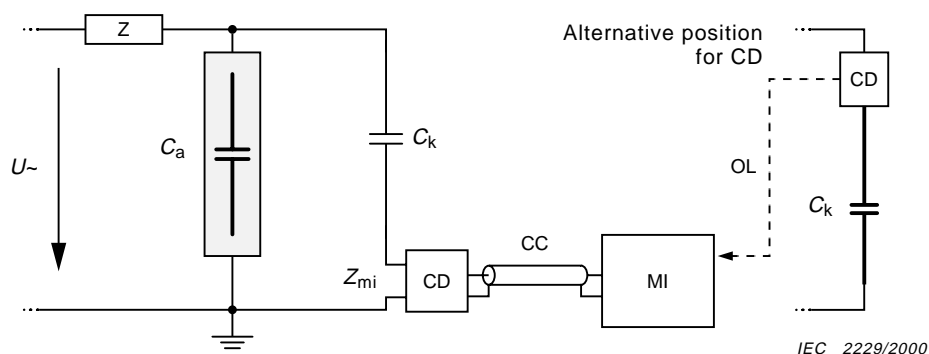


Figure 1a – Coupling device CD in series with the coupling capacitor

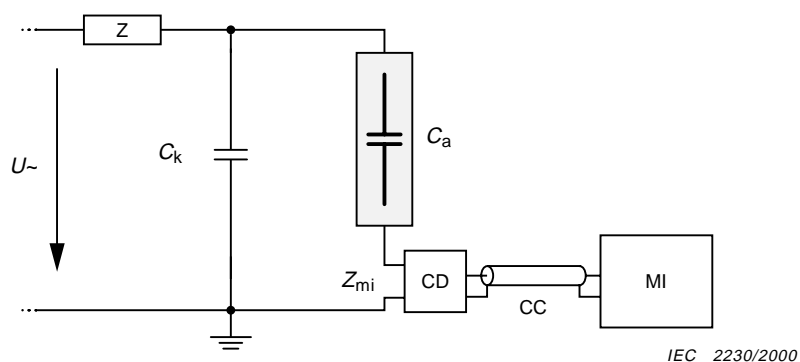


Figure 1b – Coupling device CD in series with the test object

Components

- U_{\sim} high-voltage supply
- Z_{mi} input impedance of measuring system
- CC connecting cable
- OL optical link
- C_a test object
- C_k coupling capacitor
- CD coupling device
- MI measuring instrument
- Z filter

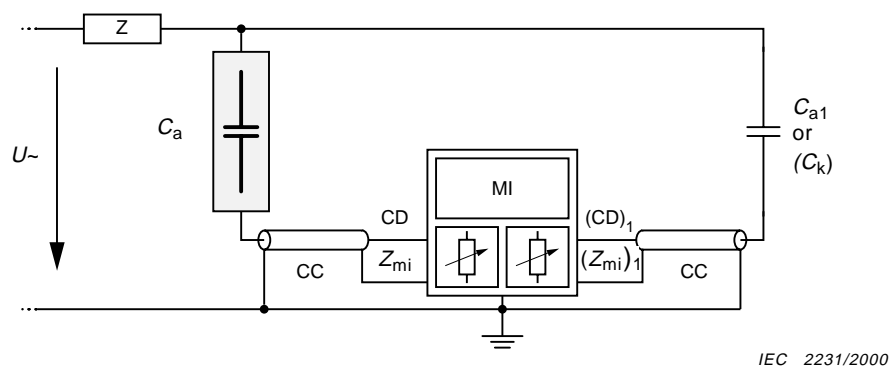


Figure 1c – Balanced circuit arrangement

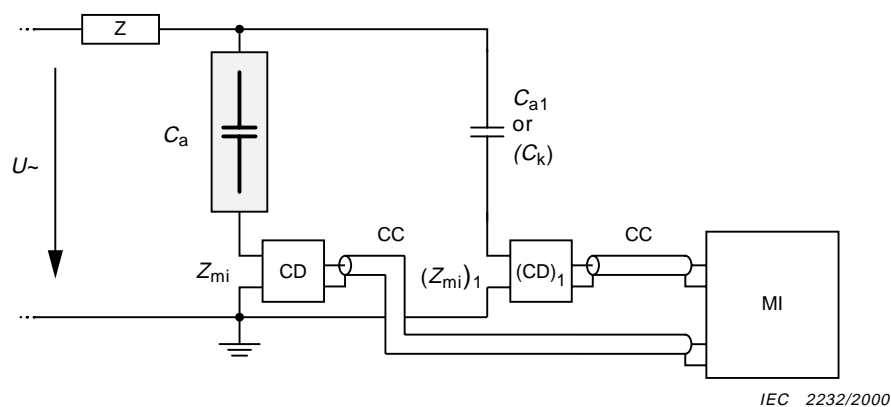
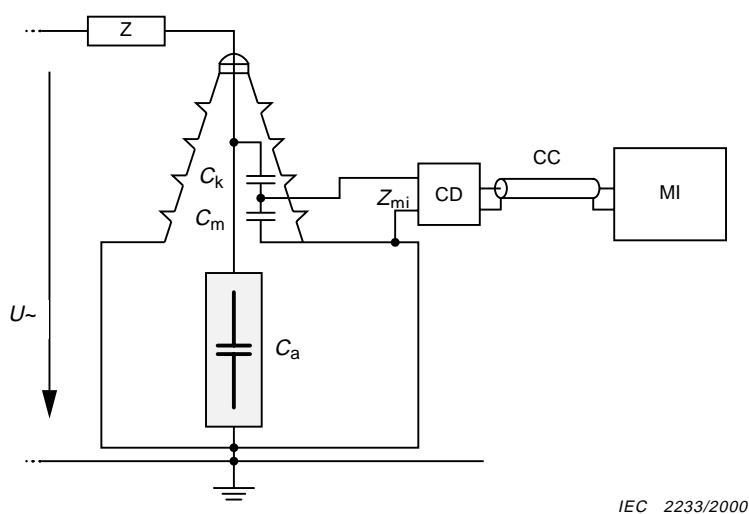


Figure 1d – Polarity discrimination circuit arrangement

Components

- U_{\sim} high-voltage supply
- Z_{mi} input impedance of measuring system
- CC connecting cable
- OL optical link
- C_a test object
- C_k coupling capacitor
- CD coupling device
- MI measuring instrument
- Z filter

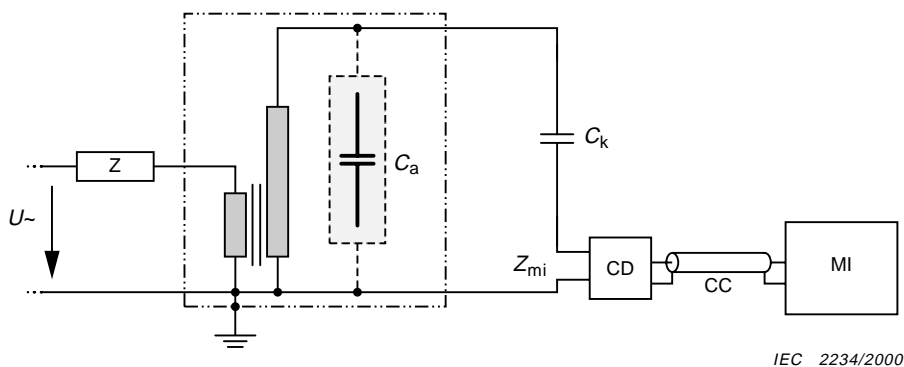
Figure 1 – Basic partial discharge test circuits



Components

- U_{\sim} low- or high-voltage supply
- Z_{mi} input impedance of measuring system
- CC connecting cable
- C_k coupling capacitor
- C_m capacitance in parallel to Z_{mi}
- CD coupling device
- C_a test object
- MI measuring instrument
- Z filter

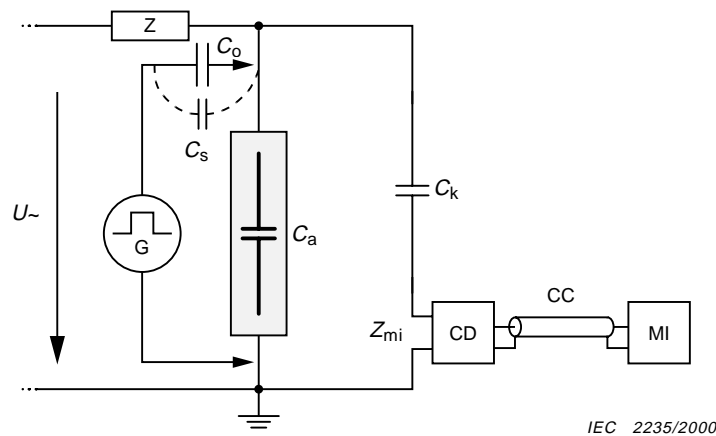
Figure 2 – Test circuit for measurement at a tapping of a bushing



Components

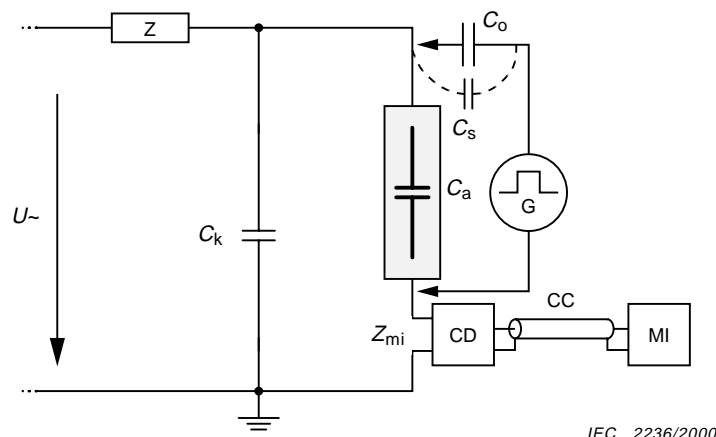
- U_{\sim} low- or high-voltage supply
- Z_{mi} input impedance of measuring system
- CC connecting cable
- C_k coupling capacitor
- CD coupling device
- C_a test object
- MI measuring instrument
- Z filter

Figure 3 – Test circuit for measuring self-excited test objects



IEC 2235/2000

Figure 4a – Coupling device CD in series with the coupling capacitor

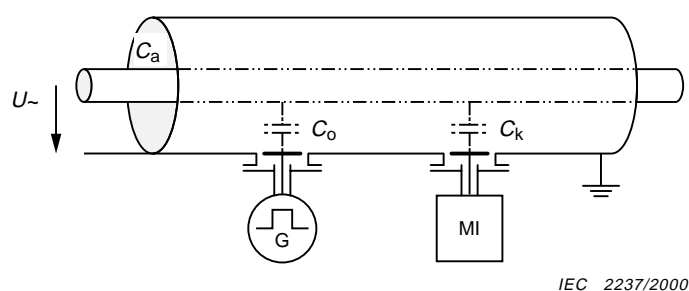


IEC 2236/2000

Figure 4b – Coupling device CD in series with the test object

Components

- U_{\sim} high-voltage supply
- G step voltage generator
- C_0 calibration capacitor
- Z_{mi} input impedance of measuring system
- CC connecting cable
- C_a test object
- C_k coupling capacitor
- CD coupling device
- C_s stray capacitance
- MI measuring instrument
- Z filter

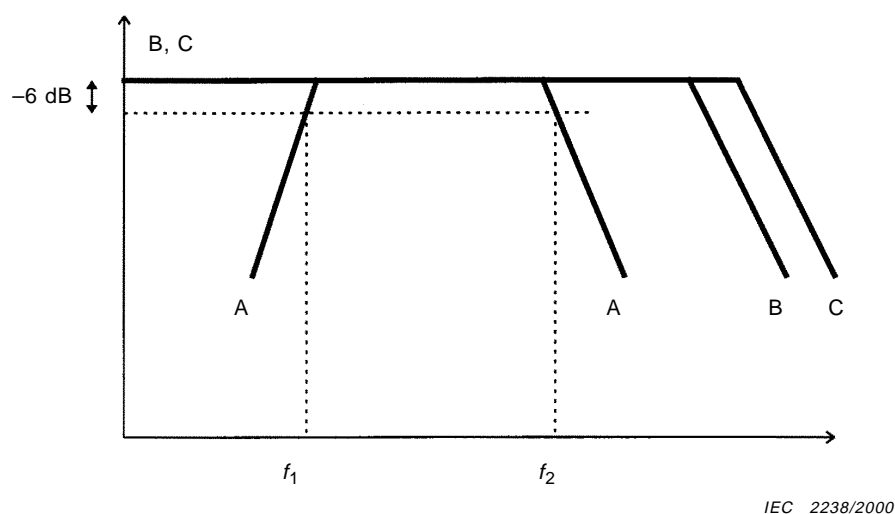


Components

- U_{\sim} high-voltage supply
- MI measuring instrument
- C_a test object
- C_k coupling capacitor
- C_o calibration capacitor
- G step voltage generator

Figure 4c – Test circuit for measurement in GIS

Figure 4 – Connections for the calibration of the complete test arrangement



Key

- A bandpass of the measuring system
- B amplitude frequency spectrum of the PD pulse
- C amplitude frequency spectrum of calibration pulse
- f_1 lower limit frequency
- f_2 upper limit frequency

Figure 5 – Correct relationship between amplitude and frequency to minimize integration errors for a wide-band system

Annex A (normative)

Performance test on a calibrator

A.1 General

Calibrators as described in clause 6 are used to evaluate the **scale factor** k of a measuring system used to quantify PD quantities. As the characteristics of such calibrators can change with time of application, periodical checks of these characteristics (rise time t_r , accuracy of quoted charge q) should be made at regular time intervals and after repairs. The following procedures are proposed to check such calibrators.

A.2 Reference method

The charge produced by the calibrator shall be compared with the charge produced by a reference calibrator. The charge shall be measured with the same measuring system in both cases.

The reference calibrator shall be traceable to national standards.

NOTE The measuring system used may be a PD measuring system in accordance with this standard or a digital oscilloscope with capabilities of integration (see figure A.1a), or a device with electronic integration.

The result of the test shall be determined as the mean of at least 10 measurements.

A.3 Alternative method

As shown in figure A.1a, with the output terminals of the calibrator under test loaded by a resistor R_m , the voltage $u_m(t)$ can be measured by a calibrated digital oscilloscope of **bandwidth** not less than 50 MHz. The value of R_m should be selected between 50 Ω and 200 Ω . Connections between the calibrator and R_m as well as to the oscilloscope shall be short. The input resistance of the oscilloscope can contribute to the value of R_m . The test circuit, including the measuring resistor R_m , shall be such that oscillations on the recorded waveform have decayed to less than 2 % of the average step magnitude within the time used for the integration.

The result of the test shall be determined as the mean of at least 10 measurements.

With reference to figure A.1a, the charge q generated by the calibrator is

$$q = \int i(t)dt = \frac{1}{R_m} \int u_m(t)dt$$

where

$i(t)$ is the current pulse generated by the calibrator;

$u_m(t)$ the voltage pulse measured by the oscilloscope.

Therefore, the accuracy of quantifying q is related to the accuracy of the integration procedure and to the accuracy of the value of R_m .

In figure A.1b, two typical records for $u_m(t)$ are provided for a calibrator with $C_0 = 141$ pF and $R_m = 33$ Ω and $R_m = 200$ Ω respectively. Note that too low R_m values can lead to an oscillating voltage pulse and can result in larger errors in integration (and hence to unacceptable uncertainty).

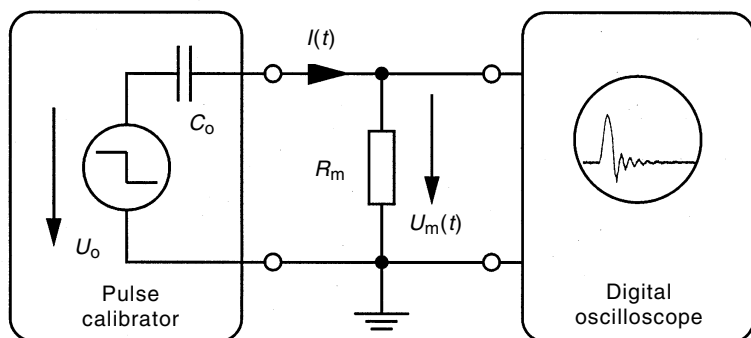
The actual rise-time t_r of the calibrator is approximately equal to the duration of the first (positive) voltage swing, if $R_m C_0 < t_r$. This inequality is, in general, always fulfilled for low R_m -values, if also $C_0 \leq 150$ pF.

The digitizer should be verified with a suitable method, for example the one outlined in A.2, on all ranges used in order to verify that it does not exhibit an overly large creepage in the response to fast steps. A creeping response can lead to large uncertainty for the charge calculated with numerical integration.

NOTE Integration of $u_m(t)$ can in general be made by built-in algorithms of digital oscilloscopes where $\int u_m(t) dt$ is calculated. As the accuracy of this integration procedure can be unknown, it is proposed to calibrate the oscilloscope as well as the algorithm used to compute q by replacing the calibrator under test by a step voltage source of amplitude U_{ref} in series with a reference capacitor C_{ref} . Consequently, current pulses $i(t)$ are produced with similar shape and charge to that of the pulses from the calibrator under test. As then

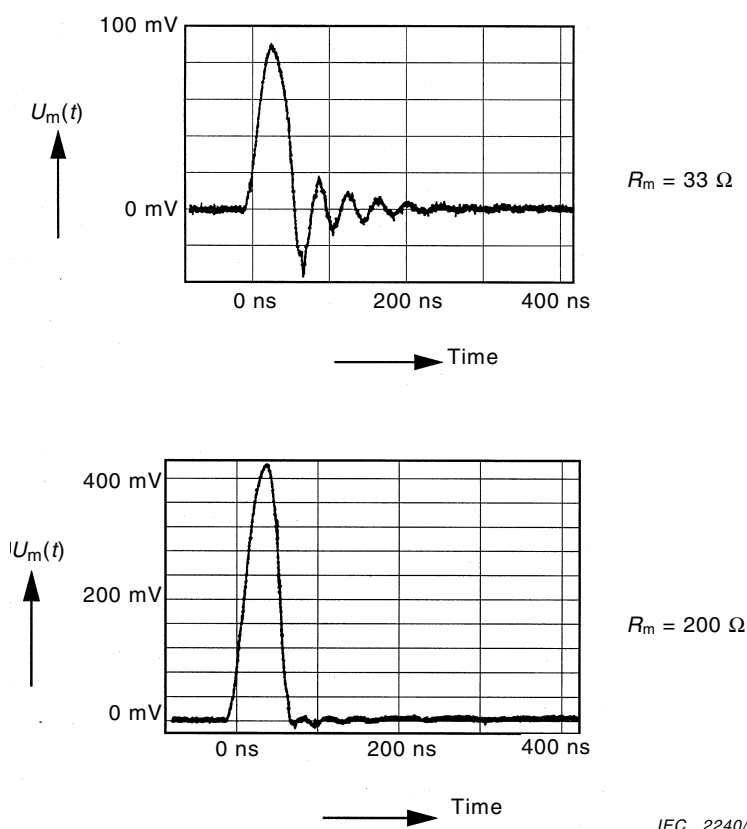
$$q_{ref} = U_{ref} \times C_{ref}$$

this reference charge magnitude q_{ref} is known with an uncertainty which is given by the uncertainties of U_{ref} and C_{ref} only. q_{ref} may thus be used to check the procedure as described before.



IEC 2239/2000

Figure A.1a – Measuring circuit



IEC 2240/2000

Figure A.1b – Calibration pulses $u_m(t)$ of a typical calibrator which is fed to measuring resistances $R_m = 33 \, \Omega$ and $R_m = 200 \, \Omega$ respectively ($q = 100 \, \text{pC}$)

Figure A.1 – Calibration of pulse calibrators

Annex B (informative)

Test circuits

Apart from energizing the test object with test voltage, the essential task of a **partial discharge** test circuit is to provide appropriate conditions for the detection of **partial discharges** within the test object at a specified **partial discharge test voltage**. This is best achieved when the various components composing the test circuit are co-ordinated so that the current pulses resulting from **partial discharges** have magnitudes and shapes that are most favourable for detection.

There are four basic circuits from which all other test circuits for the detection and measurement of **partial discharges** are derived. These circuits, which are shown in figures 1a to 1d, are briefly described below.

Note that, for these basic circuits, the minimum magnitude of any PD quantity which can be measured is dependent on the ratio C_k/C_a (see clause 9) and limited by disturbances.

The coupling device in the circuit of figure 1a is placed at the earth side of the coupling capacitor (but see note in 4.2). This arrangement has the advantage of being suitable for test objects having one earthed terminal, the test object being connected directly between the high-voltage source and earth. The filter or impedance between the test object and the high-voltage source serves to attenuate disturbances from the high-voltage source. It also increases sensitivity in the measurements by providing blocking of the PD current pulses from within the test object which would otherwise partly be bypassed through the source impedance.

In the circuit of figure 1b, the coupling device is placed at the earth side of the test object. The low-voltage side of the test object must therefore be isolated from earth (but see note in 4.2).

A protection circuit, designed to withstand the breakdown current in test objects which fail during test, should be combined with the coupling device.

For test circuits with low capacitance components, the circuit of figure 1b can provide a better sensitivity compared to that of figure 1a.

NOTE A circuit without a discrete coupling capacitor is sometimes used. The arrangement is similar to that shown in figure 1b, but the function of C_k is performed by stray capacitances. This arrangement may be suitable if the capacitance of the test object is small compared with the stray capacitance to earth. It may also be satisfactory if the terminal capacitance of the testing transformer is at least of the same order as C_a , provided that the filter is omitted.

The arrangement shown in figure 1c comprises a balanced circuit in which the instrument is connected between two coupling devices. The low-voltage sides of both the test object and the coupling capacitor must be isolated from earth (but see note in 4.2). Their capacitances need not be equal but should preferably be of the same order, and for the best results their dielectric loss factors, particularly in relation to their frequency dependence, should be similar. The circuit, which is based on rejecting common-mode currents through C_a and C_{a1} but amplifying **partial discharge** currents originating in the test object, has the merit of partially rejecting external disturbances. To adjust this rejection an artificial discharge source may be coupled between the high-voltage terminal and earth.

The variable input impedances of the balancing coupling devices are then adjusted until a minimum reading of the instrument is obtained. Rejection ratios of about 3 (for totally unequal test objects) to 1 000 or even higher (for identical, well-screened test objects) are possible.

The arrangement shown in figure 1d comprises a combination of the two basic circuits of figures 1a and 1b. It includes two capacitances, either or both of which may be test objects. These are connected to two coupling devices. In the connection shown, the low-voltage side of both components is isolated from earth (but see note in 4.2). The two capacitances need not be equal but should preferably be of the same order. The principle is not based upon a balanced circuit, but makes a comparison of the direction of flow of pulse signals detected in the two coupling devices. (Common-mode signals will be detected as having equal polarities; **partial discharge** signals from either component will be detected as having opposite polarities.) A gating system can then be used to discriminate between **partial discharge pulses** originating in the test object and disturbances from other parts of the test circuit.

From the basic circuits, many variations can be derived. The arrangement shown in figure 2, applicable to test objects fitted with capacitance graded bushings, is equivalent to that of figure 1a except that the bushing capacitance is used in place of the coupling capacitor C_k . If the bushing has a tapping, the coupling device is connected to this terminal; in this case, a relatively large capacitance C_m appears across the input impedance of the coupling device which can affect the sensitivity of the measurement.

Figure 3 shows a test circuit in which the test voltage is induced in the test object, for example a power transformer or an instrument transformer. In principle, it is equivalent to the arrangement shown in figure 1a.

Annex C (informative)

Measurements on cables, gas insulated switchgear, power capacitors and on test objects with windings

C.1 General

In principle, any of the test circuits described in annex B can be used for these test objects, that is for test objects with distributed capacitive and inductive elements. For some of these test objects, the test voltage may be induced; for example, the high-voltage winding of a transformer may be excited from the low-voltage winding (see figure 3).

A detailed treatment of **partial discharge** measurements on objects with distributed elements, in which travelling wave and complex capacitive and inductive coupling phenomena take place, is beyond the scope of this standard. The following points, however, are of special importance and are particularly drawn to the attention of the relevant technical committees.

C.2 Attenuation and distortion phenomena

Due to attenuation and distortion of travelling waves within windings or along gas insulated switchgear and cables, the magnitude of **apparent charge** which is recorded at a terminal of the test object can differ in magnitude from that at the point where it originates. This difference is, in general, correlated with the band-pass characteristic of the measuring system. It can be possible to assess the effects by comparing the amplitude (and if possible the waveform) of the response to a calibration pulse when injected at the remote end of the test object and when injected at the end connected to the coupling device.

C.3 Resonance phenomena, reflections

The magnitude recorded at a terminal of a large power capacitor, winding, gas insulated switchgear or cable under test can be modified by resonance phenomena or by reflections at the terminals. This is especially important if the instrument used has a narrow-band frequency response. Reflection phenomena (for example, in cables) can be taken into account using special calibration techniques such as the use of double-pulse generators or their adverse effects avoided by the use of special techniques.

NOTE In PD measurements on large power capacitors there can also be problems to reach the desired sensitivity of the measurement.

C.4 Location of discharges

Various methods can be used to locate **partial discharges** in test objects with distributed elements. Some of these methods are based on simultaneous measurements at two or more terminals of the test object. Non-electrical methods as discussed in annex F may also be applicable.

Annex D (informative)

The use of radio disturbance (interference) meters for the detection of partial discharges

Instruments such as those specified by the International Special Committee on Radio Disturbance ("Comité International Spécial des Perturbations Radioélectriques, CISPR") of the IEC or similar organizations are in common use. Such instruments are often able to measure "radio disturbance voltages, currents and fields" (see CISPR 16-1:1993) within a large frequency range, based on different treatments of the input quantity. Within this standard, however, the expression "**radio disturbance meter**" is applied only for a specific radio disturbance (interference) measuring apparatus, which is specified for a frequency band of 150 kHz to 30 MHz (band B) and which fulfils the requirements for a quasi-peak measuring receiver.

The response of such **radio disturbance meters** to input voltage pulses of very short duration is first of all determined by the very well-defined overall passband-selectivity, i.e. the bandpass filter characteristics with a **bandwidth** Δf which is independent of the **midband frequency** f_m . This response is then weighted by a quasi-peak measuring circuit with a specified electrical charging time constant τ_1 and an electrical discharging time constant τ_2 , and by an output voltmeter, which, for conventional instruments, is of moving coil type, critically damped and having a mechanical time constant τ_3 . More modern instrumentation provides equivalent readings based on sophisticated electronic circuits.

For a constant and purely resistive input impedance, therefore, the characteristic of such instruments makes them respond basically to the charge of an input current pulse of very short duration, whose amplitude frequency spectrum is constant for **midband frequency** f_m used during the measurement. Due to the quasi-peak measuring circuit of this instrument, impulses having the same charge but different **pulse repetition rate**, will result in different readings on the instrument.

For very short duration and regularly repeated input current pulses, each of charge q , the meter reading U_{RDV} is given by:

$$U_{RDV} = \frac{q \times \Delta f \times Z_m \times f(N)}{k_i}$$

where

N is the pulse repetition frequency;

$f(N)$ is the non-linear function of N (see figure D.1);

Δf is the instrument bandwidth (at 6 dB);

Z_m is the value of a purely resistive measuring input impedance of the instrument;

k_i is the **scale factor** for the instrument ($= q/U_{RDV}$).

The **pulse repetition frequency** N is not equivalent to the **pulse repetition rate** n .

A **radio disturbance meter**, if designed as a quasi-peak voltmeter and specified for the frequency band B (0,15 MHz to 30 MHz) will have a **bandwidth** Δf of 9 kHz at 6 dB and time constants of $\tau_1 = 1$ ms, $\tau_2 = 160$ ms and $\tau_3 = 160$ ms.

For this instrument, short and constant pulses of $0,16 \mu\text{Vs}$ applied to the instrument with a regular **pulse repetition frequency** N of 100 per second will give the same reading as a sine-wave input of $1\,000 \mu\text{V}$ r.m.s. at the tuned frequency. The variation of the reading with N for this instrument is shown in figure D.1. Quantitatively, these instruments read $1 \mu\text{V}$ for $Z_m = 60 \Omega$, $N = 100$ and $q \approx 3 \text{ pC}$.

NOTE There is no generally applicable conversion factor between readings of **radio disturbance voltage**, as measured with a quasi-peak responding meter, and the **apparent charge**.

If **radio disturbance meters** of quasi-peak type are used for PD measurements, a coupling device as defined in 4.3.2 has to be used in combination with this instrument. Consequently, it should be calibrated and checked in the actual circuit by using **partial discharge** calibrators according to clause 5. It is recommended that this be done by the application of regularly repeated pulses q_0 having a **pulse repetition frequency** N equal to approximately twice the frequency of the test voltage.

This will enable the instrument to give an approximation of the value of the **apparent charge** during an actual test near the inception voltage where the number of pulses per cycle is small. The **apparent charge magnitude** under these conditions is then approximately equal to q_0 multiplied by the ratio of the instrument reading during the test to that during the calibration. This relationship also applies over a limited range of **pulse repetition rates** where the variation of readings due to the factor $f(N)$ is small.

Whenever measurements are performed with a **radio disturbance meter**, the records from the test should include the readings obtained in microvolts and the determined equivalent **apparent charge** in picocoulombs together with relevant information concerning the determination of the **scale factor**.

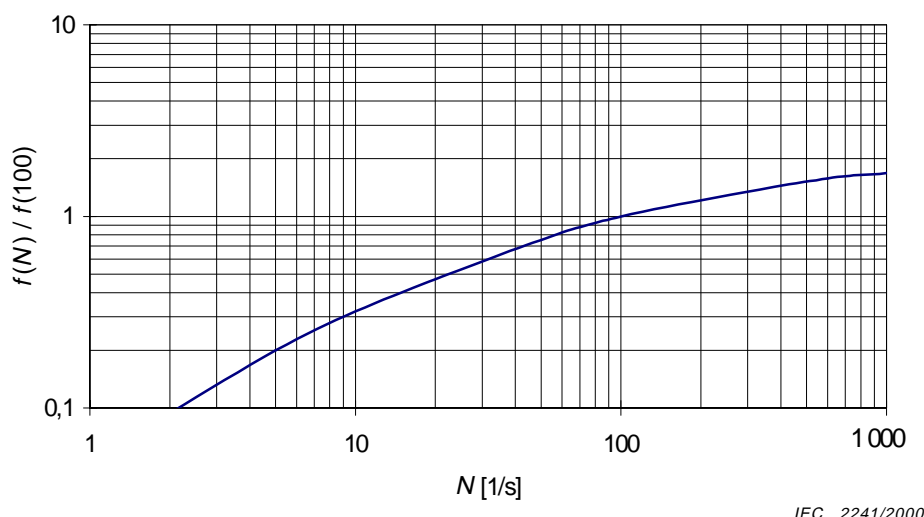


Figure D.1 – Variation of CISPR radio disturbance meter reading $f(N)$ with repetition frequency N , for constant pulses

Annex E (informative)

Guidelines to digital acquisition of partial discharge quantities

E.1 General

The main objective of applying digital techniques to PD measurements is based on recording a **PD pulse** quantified by at least its **apparent charge** q_i and its instantaneous value of the test voltage u_i occurring at the time instant t_i or, for alternating voltages, phase angle of occurrence ϕ_i within a voltage cycle of the test voltage. As, however, the quality of hardware and software used can limit the accuracy and resolution of the measurement of these parameters, this annex provides recommendations which are relevant for capturing and registration of the discharge sequences.

The main objective can be subdivided in two sub-objectives:

- the recording, storage and evaluation of at least one or more of the **PD pulses** related quantities;
- the post-processing of the recorded data to evaluate and to display additional parameters and dependencies (for example, statistical data of the PD activity within time-windows or in the course of time; application of numerical techniques to reduce the disturbance level; presentation of results by graphical displays; evaluation of parameters, which may be used for an in-depth analysis of the insulation quality of the test object, etc.).

NOTE Digital measuring systems are often supplemented by computers to aid the storage and evaluation of quantities related to **PD pulses**.

This second sub-objective is not discussed in this standard. However, the attention of the technical committees is drawn to these possibilities.

In the case of time behaviour analysis of PD quantities, a compression of recorded data can be applied. For this purpose, different data reduction methods can be used. Manufacturers of digital systems should, however, indicate the principles used for data compression.

E.2 Instructions for processing analogue apparent charge signals

The main feature of a **digital PD-instrument** is its ability to process the individual response signals of the analogue **apparent charge** instruments. In general, the peak value of these response signals can be assumed to be proportional to the individual charge q_i of a PD current pulse. Whereas for analogue instruments these peak values are displayed by oscilloscopes or peak voltmeters, the digital instrument must quantize and store, with adequate accuracy, the individual peak values q_i (and polarities, if possible) together with time t_i or **phase angle** ϕ_i of occurrence. As the shape of a response signal is strongly dependent on the measuring system characteristics and somewhat dependent on the shape of the individual PD current pulse, the processing procedure must be suited to the shape of the response signals, so that it can recognize the (positive or negative) peak value which can be assumed to be proportional to the individual charge q_i of the PD event.

To demonstrate this problem, in figure E.1 three output voltage signals caused by two consecutive **partial discharge** phenomena are shown. Figures E.1a and E.1b show output signals of a typical wide-band measuring system, the frequency characteristics of which are provided in the figure caption. The output signals of figure E.1c are typical for a simple narrow-band measuring system with $\Delta f \approx 10$ kHz and $f_m \approx 75$ kHz, for which the response is nearly symmetrical with respect to the voltage baseline. Though none of the three responses are yet significantly influenced by **superposition error**, i.e. the resolution time T_r is still adequate for both instruments, correct evaluation of the first peak's magnitude and polarity becomes difficult, as several peaks of the signal with different polarity are present. For wide-band systems, this first peak is often used to determine both q and the polarity of **partial discharge** current pulse. For the narrow-band response of figure E.1c, polarity information is generally indeterminate, and the largest peak of the response is the best measure of q . For both systems, however, only one peak (or q_i) value shall be quantized and recorded as the **apparent charge** value within the **pulse resolution time** T_r of the measuring system.

Figures E.1a and E.1b demonstrate a difficulty sometimes encountered with wide-band measuring systems: the duration and shape of a PD input current pulse, which is influenced by the discharge mechanism and the test object design, can be such that the second peak of the response signal is of larger magnitude than the first peak. Polarity-recognition as well as correct capturing of the first peak-amplitude is, therefore, difficult in such situations and the response of a particular manufacturer's PD instrument will depend on its design. Manufacturers of digital PD instruments should indicate the principle used to acquire, quantize and to record the correct magnitudes and polarities. The manufacturer shall also demonstrate proper function of the instruments by special test procedures.

E.3 Recommendations for recording test voltage, phase angle ϕ_i and time t_i of occurrence of a PD pulse

To identify the shape of a power frequency test voltage $u(t)$, the digital instrument should quantize the test voltage at least during those time-periods during which q_i -values are recorded. Continuous quantization of every period of the test voltage is, however, recommended.

As the phase ϕ_i or time instant t_i of alternating voltage systems has to be quantified with reference to the occurrence of the positive zero-crossing of the test voltage $u(t)$, it is necessary that the measuring system gives a true representation of the phase of the test voltage.

If the deviation of the instantaneous value of the test voltage, as read by the digital **partial discharge** instrument, from the instantaneous value read by a reference measuring system is less than 5 % of the peak value of the voltage, the digital instrument is also deemed able to record the phase of the test voltage. The appropriate **scale factors** for the two voltage measuring systems shall have been applied. The reference measuring system shall consist of a suitable instrument connected to the low-voltage arm of a voltage divider approved in accordance with IEC 60060-2 for alternating voltage. It should be independently demonstrated that the reference measuring system has a phase error less than 5 degrees.

For quantization of the test voltage, a rated resolution of at least 8 bits is recommended. The sampling rate of the quantization shall be at least 100 samples per cycle of the power frequency test voltage or 4 000 samples per second for direct test voltages. Since periodic sampling is recommended, interpolation may be used to determine test voltage values u_i , which occur at specific instants of time t_i between samples.

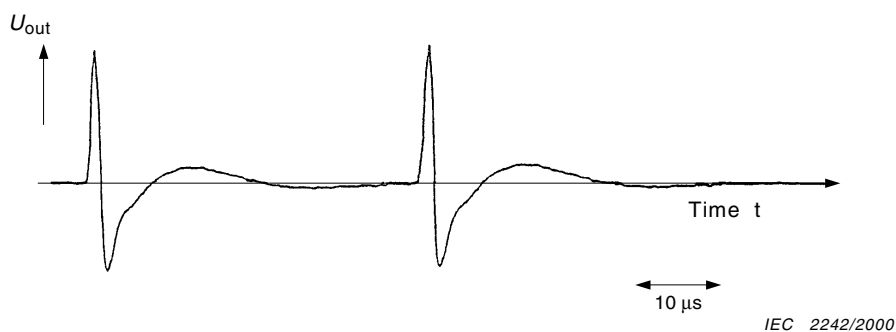


Figure E.1a – $\Delta f = 45 \dots 440$ kHz, short-duration input pulse

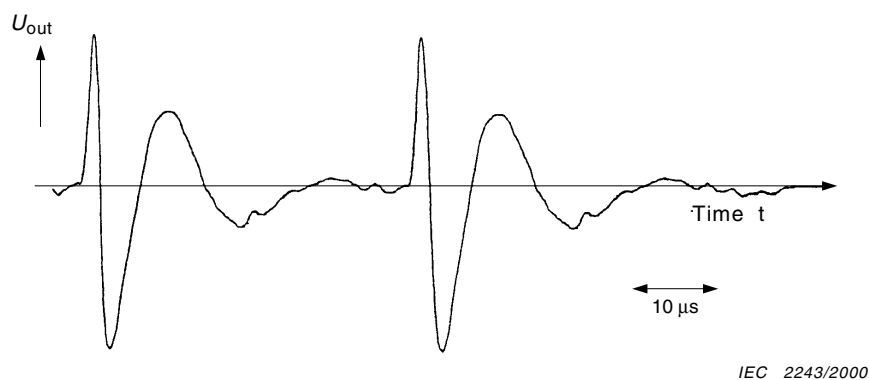


Figure E.1b – $\Delta f = 45 \dots 440$ kHz, lengthened input pulse

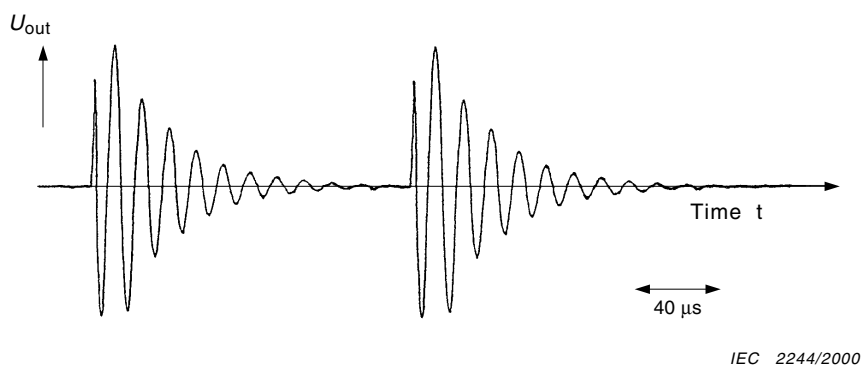


Figure E.1c – $\Delta f = 10$ kHz; $f_m = 75$ kHz

Figure E.1 – Output voltage signals U_{out} of two different PD measuring systems for apparent charge (double pulse)

Annex F (informative)

Non-electrical methods of PD detection

F.1 General

Non-electrical methods of **partial discharge** detection include acoustical, optical and chemical methods and also, where practicable, the subsequent observation of the effects of any discharges on the test object.

In general, these methods are not suitable for quantitative measurement of **partial discharge** quantities as defined in this standard, but they are essentially used to detect and/or to locate the discharges.

F.2 Acoustic detection

Aural observations made in a room with low noise level may be used as a means of detecting **partial discharges**.

Non-subjective acoustical measurements, usually made with microphones or other acoustic transducers in combination with amplifiers and suitable display units, may also be useful, particularly for locating the discharges. Directionally selective microphones with high sensitivity above the audible frequency range are useful for locating corona discharges in air. Acoustic transducers may also be used for locating discharges in gas insulated switchgear or oil-immersed equipment such as transformers; they may be either inside or outside the enclosure.

F.3 Visual or optical detection

Visual observations can be carried out in a darkened room, after the eyes have become adapted to the dark and, if necessary, with the aid of binoculars of large aperture. Alternatively, a photographic record can be made, but fairly long exposure times are usually necessary. For special purposes, photo-multipliers or image intensifiers are sometimes used.

F.4 Chemical detection

The presence of **partial discharges** in oil- or gas-insulated apparatus may be detected in some cases by the analysis of the decomposition products dissolved in the oil or in the gas. These products accumulate during prolonged operation, so chemical analysis may also be used to estimate the degradation which has been caused by **partial discharges**.

F.5 Reference documents

For additional information, see:

IEC 60567:1992, *Guide for the sampling of gases and of oil from oil-filled electrical equipment and for the analysis of free and dissolved gases*

IEC 60599:1999, *Mineral oil-impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis*

IEC 61181:1993, *Impregnated insulating materials – Application of dissolved gas analysis (DGA) to factory tests on electrical equipment*

Annex G (informative)

Disturbances

G.1 Sources of disturbances

Quantitative measurements of **partial discharge** magnitudes are often obscured by interference caused by disturbances which fall into two categories:

- Disturbances which occur even if the test circuit is not energized. They can be caused for example by switching operations in other circuits, commutating machines, high-voltage tests in the vicinity, radio transmissions, etc., including inherent noise of the measuring instrument itself. They can also occur when the high-voltage supply is connected, but at zero voltage.
- Disturbances which only occur when the test circuit is energized, but which do not occur in the test object. These disturbances usually increase with increasing voltage. They can include for example **partial discharges** in the testing transformer, on the high-voltage conductors, or in bushings (if not part of the test object). Disturbances can also be caused by sparking of imperfectly earthed objects in the vicinity or by imperfect connections in the area of the high voltage, for example, by spark discharges between screens and other high-voltage conductors, connected with the screen only for testing purposes. Disturbances can also be caused by higher harmonics of the test voltage within or close to the **bandwidth** of the measuring system. Such higher harmonics are often present in the low-voltage supply due to the presence of solid-state switching devices (thyristors, etc.) and are transferred, together with the noise of sparking contacts, through the test transformer or through other connections, to the test and measuring circuit.

For the case of disturbances with direct voltages, see 11.5.2.

G.2 Detecting disturbances

The voltage-independent sources can be detected by a reading on the instrument when the test circuit is not energized or/and the high-voltage supply is connected to the test circuit, but at zero voltage. The value read on the instrument is a measure of these disturbances.

The voltage-dependent sources of disturbance can be detected in the following manner: the test object is either removed or replaced by an equivalent capacitor having no significant **partial discharges** at the specified test voltage. The circuit should be recalibrated by the procedure given in clause 5. The circuit should then be energized up to the full test voltage.

If the disturbance level exceeds 50 % of the maximum permissible **partial discharge** magnitude as specified for the test object, then measures should be introduced to reduce the disturbances. One or more of the methods described herein may be used to reduce the disturbances. It is incorrect to subtract the disturbance level from the measured **partial discharge** magnitude.

The use of an oscilloscope as an indicating instrument or the evaluation of digitally acquired PD quantities can help the observer to distinguish between **partial discharges** in the test object and external disturbances, such as **background noise**, and can make it possible to determine the type of the disturbances or identify the type of **partial discharge**.

Other electrical or non-electrical detection methods (annex F) are often useful for locating corona on the high-voltage leads or discharges elsewhere in the test area. They can also give independent confirmation of disturbance and **partial discharges** in the test object.

G.3 Reduction of disturbances

G.3.1 Screening and filtering

Reduction of disturbances can be achieved by suitably grounding all conducting structures, which should also be free of sharp protrusions in the vicinity of the tests and by filtering the power supplies for the test and measuring circuits. Good reduction is achieved by testing in a shielded room where all electrical connections into the room are made through filters that suppress disturbances.

G.3.2 Balanced circuits

A balanced circuit, as shown in figure 1c, can attenuate disturbances as mentioned above and often enables the observer to distinguish discharges in the test object despite discharges in other parts of the test circuit.

G.3.3 Electronic processing and recovering of signals

Generally and especially under industrial conditions, the sensitivity is limited by the presence of disturbances. Various electronic methods do exist, which may be used individually or in combination in order to separate the true **partial discharge** signal from the disturbances. They should only be used with care and they should never remove or mask significant PD signals. Some of these methods are described below.

G.3.3.1 Time-window method

The instrument may be provided with a gate which can be opened and closed at pre-selected moments, thus either passing the input signal or blocking it. If the disturbances occur during regular intervals, the gate can be closed during these intervals. In tests with alternating voltage, the true discharge signals often occur only at regularly repeated intervals during the cycles of test voltage. The time window can be phase-locked to open the gate only at these intervals.

G.3.3.2 Polarity discrimination methods

Partial discharge signals originating within the test object can be distinguished from disturbances originating outside the test circuit by comparing the relative polarity of the pulses at the output of two coupling devices, as shown in figure 1d. A logic system performs the comparison and operates the gate of the instrument, as described above, for pulses of the correct polarity. Consequently, only those pulses which originate from the test object are recorded.

However, disturbances which are electromagnetically induced in the loop formed by C_a and C_k cannot be discriminated from the **partial discharges** unless additional means are applied.

G.3.3.3 Pulse averaging

Many disturbances in an industrial environment are random, whereas **partial discharges** often recur at approximately the same phase in each cycle of applied voltage. It is therefore possible to greatly reduce the relative level of randomly occurring disturbances by using signal-averaging techniques.

G.3.3.4 Frequency selection

Broadcast radio disturbance is limited to discrete bands but will still affect wide-band **partial discharge** detectors if the transmission frequency falls within the sensitive frequency band of the instrument. To reduce this type of interference, the gain of the instrument amplifier can be reduced by bandstop filters tuned to the frequencies where the disturbances occur. Alternatively, narrow-band instruments can be used which are tuned to a frequency at which the interference level is negligible.

G.4 Disturbance levels

No definite values for the magnitudes of disturbances can be given, but as a general guide, disturbances equivalent to individual **apparent charge magnitudes** of some hundreds of picocoulombs can be encountered in unscreened industrial testing areas, especially in the case of test circuits of large physical dimensions. By the use of techniques described in this annex, such disturbances can be considerably reduced.

In shielded test rooms with effective application of the methods to reduce disturbances as described in this annex, and with adequate precautions to suppress disturbances from the power supply and from other electrical systems, the ultimate limit of measurement is that of the measuring system itself or that given by minor imperfections in the screening, grounding or filtering; a limit quantified by an **apparent charge q** of about 1 pC is generally attainable.

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