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Interested committees:

Title: Draft BS EN 60270 Ed.4.0 High-voltage test techniques - Charge-based partial discharge measurements.

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- iii) requires additional national guidance or information

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This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



42/400/CD

COMMITTEE DRAFT (CD)

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SECRETARIAT:

Canada

SECRETARY:

Mr Howard G. Sedding

OF INTEREST TO THE FOLLOWING COMMITTEES:

TC 2,TC 14,TC 20,TC 36,TC 112,TC 122

PROPOSED HORIZONTAL STANDARD:

☒

Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

FUNCTIONS CONCERNED:

☐ EMC

☐ ENVIRONMENT

☐ QUALITY ASSURANCE

☐ SAFETY

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TITLE:

High-voltage test techniques - Charge-based measurement of partial discharges

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE TEST TECHNIQUES –

CHARGE-BASED MEASUREMENT OF PARTIAL DISCHARGES

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International Standard IEC 60270 has been prepared by IEC technical committee 42: High-Voltage and High-Current Measurement Techniques.

This fourth edition cancels and replaces the third edition published in 2000, and Amendment 1:2015. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Use with alternating voltages up to 500 Hz or with direct voltage
- b) Clear focus on charge-based Partial Discharge measurements
- c) Streamlined performance checks for Partial discharge measurement system components
- d) Improved normative Annex for Performance tests on calibrators

e) Revised and new informative Annexes

The text of this International Standard is based on the following documents:

Draft	Report on voting
42/XX/FDIS	42/XX/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

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This Consolidated version of IEC 60270 bears the edition number 3.1. It consists of the third edition (2000-12) [documents 42/162/FDIS and 42/165/RVD] and its corrigendum 1 (2001-10), and its amendment 1 (2015-11) [documents 42/338/FDIS and 42/340/RVD]. The technical content is identical to the base edition and its amendment.

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

HIGH-VOLTAGE TEST TECHNIQUES – CHARGE-BASED MEASUREMENT OF PARTIAL DISCHARGES

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 500 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). It has the status of a horizontal standard in accordance with IEC Guide 108.

This horizontal standard is primarily intended for use by technical committees in the preparation of standards in accordance with the principle laid down in IEC Guide 108. One of the responsibilities of a technical committee is, wherever applicable, to make use of horizontal standards in the preparation of its publications. The contents of this horizontal standard will not apply unless specifically referred to or included in the relevant publications. 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.

NOTE 1 IEC 60270 defines and provides guidance for charge-based direct electrical PD measurements at the terminals of the equipment under test in differentiating from other PD measurement and detection methods, e.g. acoustic PD techniques or electromagnetic methods in elevated frequency ranges as e.g. ultra-high frequency band (UHF).

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*

IEC TS 62478, *High voltage test techniques – Measurement of partial discharges by electromagnetic and acoustic methods*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

partial discharge (PD)

localized electrical discharge that only partially bridges the insulation between conductors and which may or may 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 accompanied by emission of acoustic transients (sound), electromagnetic waves, optical signals (light), heat, and associated chemical reactions. For further information, see annex F.

3.2

partial discharge pulse (PD pulse)

produced by a partial discharge occurring within the object under test, measured using suitable detector circuits introduced into the test circuit.

NOTE A **partial discharge** which occurs in the test object produces a current pulse at its origin. 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 PD pulse.

3.3

quantities related to partial discharge pulses

3.3.1

apparent charge q

of a PD pulse is that charge which, if injected between the terminals of the test object in a specified test circuit, would result in the same reading on the measuring instrument as the PD pulse itself, typically expressed in units of picoCoulombs (pC) or nanoCoulombs (nC).

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

3.3.4

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

is given by

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

where t_i is the time measured between the preceding positive going zero crossing of the test voltage and the partial discharge pulse and T is the period of the test voltage, with the phase angle being expressed in degrees ($^\circ$).

3.3.5

apparent average discharge current I

is a derived quantity consisting of 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:

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

and is generally expressed in coulombs per second (C/s) or in amperes (A).

3.3.6

apparent discharge power P

is a derived quantity, generally expressed in watts (W), consisting of 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 the 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.

3.3.7

radio interference or radio disturbance meter

is a specialized measurement receiver utilizing weighted quasi-peak RF measurements on frequency B in accordance with CISPR 16-1.

NOTE This type of instrument was commonly known as 'RIV' or 'radio interference voltage' or 'radio influence voltage' meter in earlier times, having been applied to search for HV equipment producing high levels of corona which in turn would interfere with LW and MW broadcast transmission.

3.3.8

radio disturbance voltage U_{RDV}

the output reading of a radio interference meter, generally expressed in μV .

For further information, see 4.6 and Annex D.

3.4**largest repeatedly occurring PD magnitude Q_{IEC}**

the value recorded by a measuring system which has the pulse train response as specified in 4.3.3, commonly realized by a quasi-peak detector or a digital emulation of such a circuit, applicable for AC voltages.

3.5. peak apparent charge Q_{pk}

the largest value recorded by a PD measuring system, commonly realized by a peak detector or a digital emulation of such circuit, applicable for DC voltages.

3.6**specified partial discharge magnitude**

is the 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, this is the largest repeatedly occurring apparent charge q .

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.

3.7**background noise and interference/disturbances**

are extraneous signals detected during PD tests, which are not PD and do not originate in the test object.

NOTE 1 Background or electrical noise is defined as originating in the PD measurement equipment itself, i.e. thermal/Shot/1/f noise in resistors and amplifiers.

NOTE 2 Interference or disturbances may originate from external sources such as motor drives, thyristor control circuits, terrestrial broadcast stations, etc. Moreover, external interference can also arise from corona or surface discharges external to the test object; such PD-like interference can be extremely challenging to differentiate from PD signals within the test object. Refer to Annex G for further information.

3.8**test voltages related to partial discharge pulse quantities**

NOTE Voltages as defined in e.g. IEC 60060-1.

3.8.1**partial discharge inception voltage U_i**

the applied voltage at which repetitive partial discharges are first observed in the test object, after being gradually increased from a lower value at which no partial discharges are observed; in practice, the lowest applied voltage at which the magnitude of a PD pulse quantity becomes equal to or exceeds a specified minimum value.

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

3.8.2**partial discharge extinction voltage U_e**

the applied voltage at which repetitive partial discharges cease to occur in the test object, after being gradually decreased from a higher value at which PD pulse quantities are observed; in practice, 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.

3.8.3**partial discharge test voltage**

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

NOTE Partial discharges are usually measured at AC sinusoidal waveform. In real conditions, the test voltage also contains harmonics that modify the shape of the voltage waveform and can thus be considered as a disturbance affecting the PD pulse parameters and PD phase-resolved patterns. Such disturbances should be taken into account and documented during PD measurements. See Annex G for further information.

3.9 partial discharge measuring system

consists of a coupling device, a transmission system and a partial discharge measuring instrument

3.10 measuring system characteristics

3.10.1 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

3.10.2 lower and upper limit frequencies f_1 and f_2

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

3.10.3 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:

$$\Delta f = f_2 - f_1$$

3.10.4 superposition error

is caused when successive PD pulses overlap one another because the time interval between successive pulses is less than the duration (settling time) of a single pulse response; it is also known as 'pulse pile-up'.

NOTE 1 Superposition errors can be additive or subtractive depending on the pulse repetition rate of the incoming pulses in combination with the transient response of the detector circuit elements. 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 2 Superposition errors can attain levels of 100 % or more depending on the pulse repetition rate and the characteristics of the measuring system.

3.10.5 pulse resolution time t_{res}

is the shortest time interval between two consecutive PD pulses within which the PD measurement instrument is still able to resolve two separate pulses and for which the peak value of the resulting response does not change by more than 10% of the value for a single pulse

NOTE 1 The pulse resolution time is an indication of the PD measuring system's ability to resolve successive PD pulses and is inversely proportional to the lower frequency cut-off of the PD measurement bandwidth f_L .

NOTE 2 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.

3.10.6**dead time**

is defined as the time period following successful digital acquisition of a PD pulse during which the instrument does not accept or acquire signals or neglect detected pulses

NOTE 1 Dead time is closely related to pulse resolution time

NOTE 2 Especially for strongly oscillatory input signals, a dead time is introduced in order to avoid false or repeat triggering on successive oscillatory remnants of the same pulse.

3.10.7**noise modulation**

results from superimposition of an actual PD pulse with a simultaneously occurring noise signal leading to an incorrect registering of the peak amplitude of the PD signal.

NOTE Such noise modulation occurs when calibrating and measuring low amplitude PD pulses close to the noise floor and can cause apparent non-linearities in such cases.

3.10.8**integration error (of apparent charge measurement)**

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.

3.11**digital partial discharge instruments**

perform digital acquisition and evaluation of the PD data as described in Annex E

3.12**scale factor k**

is the factor by which the value of the instrument reading is to be multiplied to obtain the value of the input quantity

NOTE In modern digital PD measurement instruments, the scale factor is automatically calculated internally and therefore usually not accessible to the user. After calibration, the instruments display the result of the multiplication with the internal scale factor k .

3.13**accumulated apparent charge q_a**

sum of the apparent charge q of all individual pulses exceeding a specified threshold level, and occurring during a specified time interval Δt

3.13**PD pulse count m**

total number of PD pulses which exceed a specified threshold level within a specified time interval Δt

3.14**Phase resolved PD pattern (PRPD)**

display of the apparent charge q versus the phase angle φ_i of the PD pulses recorded during a specified time interval Δt

499 NOTE See Annex E Figure E.4 Conceptual diagram of phase-resolved PD pattern (PRPD) diagram.

500 4 Test circuits and measuring systems

501 4.1 General requirements

502 In this clause, basic test circuits and measuring systems for partial discharge quantities are
503 described, and information on the operating principle of these circuits and systems is
504 provided. The test circuit and measuring system shall be calibrated as specified in clause 5
505 and shall meet the requirements specified in clause 7.

506 The relevant technical committee may also recommend a particular test circuit to be used for
507 particular test objects. It is recommended that the technical committees use apparent charge
508 as the quantity to be measured wherever possible, but other derived quantities may be used
509 in particular specific situations.

510 A number of derived quantities such as 'PD pulse repetition rate n ', 'average apparent
511 discharge current', 'apparent discharge power', etc. may be derived using appropriate
512 algorithms employed by the charge-based PD measurement instrument, either in real-time or
513 via post-processing. These derived quantities may be desirable for characterizing or
514 quantifying certain aspects of the test object's PD behaviour, i.e. assessing risk or fulfilling
515 acceptance criteria, and may be specified by the relevant equipment committees.

516 If not otherwise specified by the relevant technical committee, any of the test circuits
517 mentioned in 4.2 and any of the measuring systems as specified in 4.3 are acceptable. In
518 each case, the most significant characteristics of the measuring system (f_1 , f_2 , T_r , see 3.9.2
519 and 3.10.5) as applied, shall be recorded.

520 For tests with direct voltage, see clause 11.

521 4.2 Test circuits for alternating voltages

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

- 525 – a test object, which can usually be regarded as a capacitor C_a (see, however, annex C);
- 526 – a coupling capacitor C_c , which shall be of low inductance design, or a second test object
527 C_{a1} , which shall be similar to the test object C_a . C_c or C_{a1} should exhibit a sufficiently low
528 level of partial discharges at the specified test voltage to allow the measurement of the
529 specified partial discharge magnitude. A higher level of partial discharges can be tolerated
530 if the measuring system is capable of distinguishing the discharges from the test object
531 and the coupling capacitor and measuring them separately;
- 532 – a measuring system with its input impedance (and sometimes, for balanced circuit
533 arrangements, a second input impedance);
- 534 – a high-voltage supply, with sufficiently low level of background noise (see also clauses 9
535 and 10) to allow the specified partial discharge magnitude to be measured at the specified
536 test voltage;
- 537 – high-voltage connections, with sufficiently low level of background noise (see also
538 clauses 9 and 10) to allow the specified partial discharge magnitude to be measured at the
539 specified test voltage;
- 540 – A 'blocking impedance' (filter) may be introduced at the high voltage supply input
541 connection to the PD measurement circuit whose purpose is to reduce or eliminate
542 interference originating in the HV power supply itself.

543 NOTE For each of the basic PD test circuits shown in figures 1 and 3, the coupling device of the measuring system
544 can also be placed at the high-voltage terminal side, so that the positions of the coupling device with C_c or C_{a1} 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 or 'quadrupole'

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 an active or passive four-terminal network ('quadrupole') whose function is to convert the current i_{PD} , arising from PD in the test object and circulating in the specified test circuit through coupling capacitor C_c , to an output voltage. This output voltage signal is then transmitted to the PD measuring instrument by means of a transmission system. The coupling device is normally designed so that its frequency response prevents the test voltage frequency and its harmonics from reaching the PD measuring 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_c and C_{DUT} 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.

NOTE 3 The relevant technical committee may provide recommendations concerning the withstand capability of components in the specified test circuit in the case of breakdown (flashover).

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:

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

597

Table 1 – Pulse train response of PD instruments

N (1/s):	0,1	0,2	0,5	1	2	5	10	50	≥ 100
R (%):	>2	>5	>17	>35	>5 5	>76	>8 5	>94	>95
	<8	<12	<27	<45	<6 5	<86	<9 5	<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 measuring 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 the significant frequency parameters f_1 , f_2 and Δf are:

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

$$f_2 \leq 1 \text{ MHz};$$

$$100 \text{ kHz} \leq \Delta f \leq 900 \text{ kHz}.$$

NOTE 1 Combinations of different coupling devices with the measuring instrument can alter the transfer impedance. The overall response should, however, always fulfil the recommended values.

NOTE 2 For test objects with windings like transformers and electrical machines the acquired frequency band may be reduced down to a few 100 kHz and even below. The upper limit frequency f_2 to be accepted for such kinds of test objects should be specified by the relevant Technical Committee.

NOTE 3 The pulse resolution time T_r is small and is typically 5 μs to 20 μs .

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.

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 μs are typical. The pulse resolution time for consecutive PD pulses is less than 10 μs .

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.

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.

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 Narrow-band instruments typically follow the superheterodyne ('superhet') principle, where a mixer multiplies the input signal with the signal of a local oscillator. The product is processed via an intermediate amplifier and a detector. An intermediate bandwidth of 100kHz and above offers sufficient pulse resolution time for PD pattern acquisition.

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 μs .

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 disturbances/interference 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 processing must be performed 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.

NOTE Such sources of error should be taken into account when evaluating such measurements and documented in the resulting report.

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

NOTE Saturation can occur when the repetition rate n is so low that the apparent 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 apparent 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 apparent discharge power may also be calculated by digital processing.

4.6 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 AM 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.

4.7 Ultra-wide-band instruments for PD detection

Partial discharges can also be detected by oscilloscopes or other instruments (e.g. transient recorders, spectrum analysers) 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.

For more information about such methods, see IEC TS 62478, High voltage test techniques – Measurement of partial discharges by electromagnetic and acoustic methods.

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 done to determine the scale factor k for the measurement of the apparent charge; in modern instruments, k is usually automatically calculated internally. 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 ± 10 % of the mean values.

Calibration of the PD measurement system, consisting of the PD measuring instrument(s) and the complete test circuit including the test object, 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).

The calibration process is only valid if the test object is predominantly capacitive in nature (see Annex C).

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 shall be performed at a level within the relevant range of the specified PD magnitude to assure as high a level of accuracy as practically possible.

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, calibration of the complete test arrangement is performed with the test object de-energized, with the PD measurement instrument set to the frequency range at which the PD measurement will be performed (see 4.3.3-5). For the calibration to remain valid, the calibration capacitor C_0 should not be larger than $0,1 C_{DUT}$, and the PD measurement must be performed with the same frequency-range settings used for the calibration. 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 there is a sufficiently low level of background interference (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 1 The requirement that the capacitor C_0 should be less than $0,1 C_{DUT}$ 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. If pulse generator G and injection capacitor C_0 are grouped in a combined unit, then it should be positioned on the high voltage terminal. In addition, the ground-return conductor shall have sufficiently low inductance (e.g. flat copper band) to avoid distortion of the calibration pulse and guarantee the specified rise-time of the voltage step.

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.

NOTE 2 For tall test objects, the connection leads between calibrator and terminals of the test object might exceed several meters. Thus the transfer of the charge from the calibrator to the test object may be reduced due to inevitable stray capacitances. The measurement uncertainty acceptable under this condition should be specified by the relevant Technical Committee.

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.

808 The parameters characterizing unipolar step voltage of magnitude U_0 shall satisfy the
809 following conditions (see Figure 6):

810	Rise time:	$t_r \leq 60 \text{ ns}$
811	Time to steady state:	$t_s \leq 200 \text{ ns}$
812	Step voltage duration:	$t_d \geq 5 \text{ } \mu\text{s}$
813	Deviation of the step voltage magnitude U_0 between t_s and t_d :	$\Delta U \leq 0,03 U_0$

814 The time parameters t_r , t_s and t_d are measured from the origin t_0 of the step voltage which
815 refers to the time instant when the rising voltage equals 10 % of U_0 (see Figure 6).

816 The time to steady state t_s is the shortest interval at which the deviation ΔU from U_0 falls to
817 less than 3 %.

818 The step voltage duration t_d is the instant after t_s at which the magnitude of the step voltage
819 decays below 97% of U_0 . After t_d , the voltage shall decrease continuously down to 10 % of U_0
820 within a time interval $\geq 100 \text{ } \mu\text{s}$.

821 The magnitude U_0 of the step voltage is the mean value occurring within the steady state
822 duration $t_d - t_s$.

823 For test objects represented by a lumped capacitance C_a the calibrating capacitor C_0 shall
824 satisfy the conditions $C_0 \leq 200 \text{ pF}$ and $C_0 \leq 0,1 C_{DUT}$.

825 For test objects represented by a characteristic impedance Z_c , such as power cables
826 exceeding a length of 200 m, the value of the calibrating capacitor shall satisfy the conditions
827 $C_0 \leq 1 \text{ nF}$ and $C_0 \times Z_c \leq 30 \text{ ns}$.

828 For calibrators manufactured before this document was published, whose time and voltage
829 parameters do not comply with the above specified values, the deviation of the measured values from
830 the specified values shall be stated in the test protocol.

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

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

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

845 NOTE 2 For high charge values and small values of the calibrating capacitor C_0 , the step voltage U_0 may reach
846 amplitudes on the order of 100 V. Such high voltages may overdrive/saturate the input amplifier of the PD
847 measurement instrument; therefore, appropriate checks should be made to avoid inaccuracies which may result
848 from such effects.

849 NOTE 3 Calibrators qualified under this clause can be applied to the calibration of systems for measuring the
850 apparent charge as well as to systems for measuring derived quantities.