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TECHNICAL SPECIFICATION

colour inside

Electrical insulating materials and systems – Electrical measurement of partial discharges (PD) under short rise time and repetitive voltage impulses

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ELECTRICAL INSULATING MATERIALS AND SYSTEMS – ELECTRICAL MEASUREMENT OF PARTIAL DISCHARGES (PD) UNDER SHORT RISE TIME AND REPETITIVE VOLTAGE IMPULSES

FOREWORD

This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC TS 61934:2011. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC TS 61934 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is a Technical Specification.

This third edition cancels and replaces the second edition published in 2011. This edition constitutes a technical revision.

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

a) background information on the progress being made in the field of power electronics including the introduction of wide band gap semiconductor devices has been added to the Introduction;
b) voltage impulse generators; the parameter values of the voltage impulse waveform have been modified to reflect application of wide band gap semiconductor devices.
c) PD detection methods; charge-based measurements are not described in this third edition nor are source-controlled gating techniques to suppress external noise.
d) Since the previous edition in 2011, there have been significant technical advances in this field as evidenced by several hundreds of publications. Consequently, the Bibliography in the 2011 edition has been deleted in this third edition.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
112/578/DTS	112/610/RVDTS

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 Technical Specification 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/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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INTRODUCTION

Power electronics has been developed along with both control theory and semiconductor technology. Switching is one of the essential features of power electronics control. For higher efficiency and smoother operation, switching times of the latest devices such as an insulated-gate bipolar transistor (IGBT) tend to be shorter than microseconds. The introduction of wide band gap devices, such as those based on silicon carbide, can result in transients with rise times of the order of a few tens of nanoseconds. Such a short rise time may can cause transient overvoltage impulses or surges in systems. When the voltage impulses reach the breakdown strength of an air gap, partial discharge (PD) may can occur. In addition, the impulses are repetitive from power electronics modulation such as pulse width modulation (PWM). Since PD may can cause degradation of electrical insulation parts in the system, it is one of the most important parameters to be measured.

The first edition of IEC TS 61934 was issued in April 2006. Because of rapid development in this field, the revision activity for the latest information was approved by TC 112 at their Berlin meeting in September 2006. In addition to technical and editorial changes, practical experience obtained through round-robin test (RRT) is also presented in Annex C. The second edition of IEC TS 61934 was published in 2011. Owing to further advances in this area, a revision of the second edition was commenced formally in 2019 and has resulted in this third edition.

ELECTRICAL INSULATING MATERIALS AND SYSTEMS – ELECTRICAL MEASUREMENT OF PARTIAL DISCHARGES (PD) UNDER SHORT RISE TIME AND REPETITIVE VOLTAGE IMPULSES

1 Scope

This document is applicable to the off-line electrical measurement of partial discharges (PDs) that occur in electrical insulation systems (EISs) when stressed by repetitive voltage impulses generated from ~~electronic~~ power electronics devices.

Typical applications are EISs belonging to apparatus driven by power electronics, such as motors, inductive reactors ~~and windmill~~, wind turbine generators and the power electronics modules themselves.

NOTE ~~1~~ Use of this document with specific products ~~may~~ can require the application of additional procedures.

~~NOTE 2 The procedures described in this technical specification are emerging technologies. Experience and caution, as well as certain preconditions, are needed to apply it.~~

Excluded from the scope of this document are

– methods based on optical or ultrasonic PD detection,

– fields of application for PD measurements when stressed by non-repetitive impulse voltages such as lightning impulse or switching impulses from switchgear.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60034 (all parts), *Rotating electrical machines*~~

IEC 60270~~:2000~~, *High-voltage test techniques – Partial discharge measurements*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
repetitive voltage impulse
voltage impulse which is used as test voltage for the evaluation of switching surges from power electronics devices with a carrier or driven frequency

3.2
partial discharge
PD
localized electric discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor

~~[IEC 60270:2000, 3.1, modified]~~

3.3
partial discharge pulse
current pulse in an object under test that results from a partial discharge occurring within the object under test

Note 1 to entry: The pulse is measured using suitable detector circuits, which have been introduced into the test circuit for the purpose of the test.

Note 2 to entry: A detector in accordance with the provisions of this document produces a current or a voltage signal at its output related to the PD pulse at its input.

[SOURCE: IEC 60270~~:2000~~, 3.2, modified – "or voltage" has been deleted, the second part of the definition has been included in Note 1 to entry and Note 2 to entry has been revised.]

3.4
RPDIV
repetitive partial discharge inception voltage
minimum peak-to-peak impulse voltage at which more than five PD pulses occur on ten voltage impulses of the same polarity

Note 1 to entry: The RPDIV is a mean value for the specified test time and a test arrangement where the voltage applied to the test object is gradually increased from a value at which no partial discharges can be detected. Further explanation is mentioned in 8.

3.5
RPDEV
repetitive partial discharge extinction voltage
maximum peak-to-peak impulse voltage at which less than five PD pulses occur on ten voltage impulses of the same polarity

Note 1 to entry: The RPDEV is a mean value for a specified test time and a test arrangement where the voltage applied to the test object gradually decreases from a voltage at which PDs have been detected. Further explanation is mentioned in Clause 8.

3.6
impulse voltage polarity
polarity of the applied impulse voltage with respect to earth

~~[IEC 62068-1:2003, 3.10]~~

3.7
unipolar impulse
repetitive voltage impulse, the polarity of which is either positive or negative

~~[IEC 62068-1:2003, 3.8, modified]~~

~~NOTE The magnitude of the oscillation of the opposite polarity has to be less than 20 %.~~

[SOURCE: IEC 62068:2013, 3.11, modified – "repetitive" has been added.]

3.8
bipolar impulse
repetitive voltage impulse, the polarity of which changes from positive to negative or vice versa

~~[IEC 62068-1:2003, 3.9, modified]~~

3.9
impulse voltage repetition rate
inverse of the average time between successive impulses of the same polarity, whether unipolar or bipolar

[IEC 62068-1:2003, 3.11, modified]

3.10
impulse rise time
time for the voltage impulse to go to rise from 0 % to 100 % 10 % to 90 %

NOTE Unless otherwise stated, this is estimated as 1,25 times the time for the voltage to rise from 10 % to 90 %.

3.11
impulse decay time
time interval between the instants at which the instantaneous value of an impulse decreases from a specified upper value to a specified lower value

Note 1 to entry: Unless otherwise specified, the upper and lower values are fixed at 90 % and 10 % of the impulse magnitude.

3.12
impulse width
interval of time between the first and last instants at which the instantaneous value of an impulse reaches a specified fraction of impulse magnitude or a specified threshold

3.13
impulse duty cycle
ratio, for a given time interval, of the impulse width to the total time

3.14
peak partial discharge magnitude
largest magnitude of any quantity related to PD pulses observed in a test object at a specified voltage following a specified conditioning and test

Note 1 to entry: For impulse voltage tests, the peak magnitude of the PD pulse is the largest repeatedly occurring PD magnitude.

[SOURCE: IEC 60270:2000, 3.4, modified – In the term "largest repeatedly occurring" has been replaced with "peak", the definition has been revised and the Note to entry has been added.]

4 Measurement of partial discharge pulses during repetitive, short rise-time voltage impulses and comparison with power frequency

4.1 Measurement frequency

IEC 60270 describes the methods employed to measure the electrical pulses associated with PD in test objects excited by DC and alternating voltages up to 400 Hz. The methods used to measure PD pulses when the test object is subjected to supply voltage impulses have to shall be modified from the standard narrow-band and wide-band frequency methods described in IEC 60270.

To measure the PD during repetitive short rise time voltage impulses, it is necessary to avoid the induced current of the excited impulse voltage. One technique is current or electromagnetic wave measurement at ultra-high frequency, that is, higher than that of the frequency components associated with the impulse. Ultra-wide band (UWB) detection is often used with a high-pass filter for the suppression of the relatively lower frequency components of the impulse voltage. In principle, narrow-band measurement in the ultra-high frequency (UHF: 300 MHz to 3 GHz) region is also effective for the suppression of the impulse voltage. The other method is

~~the integration of PD current at a very low frequency compared to that of the impulse voltage.~~ Partial discharge measurement methods in this frequency range are described in IEC TS 62478.

NOTE Measurements in accordance with IEC TS 62478 cannot be calibrated in relation to apparent charge in pC, so a direct value-based comparison to measurements in accordance with IEC 60270 is not possible.

4.2 Measurement quantities

Measured quantities concern the RPDIV, the RPDEV, the peak partial discharge magnitude and partial discharge pulse repetition rate.

The RPDIV and RPDEV ~~may~~ can depend on PD measurement sensitivity and measurement circuit noise, therefore normalization, as indicated in Clause 7, is ~~needed~~ necessary. Moreover, they depend on the test object and the pulse deformation from the discharge site to the measurement point.

In this document, and consistent with IEC TS 62478, PD readings are reported in units of mV. In all cases, a sensitivity evaluation of the measuring system is necessary and shall be carried out according to Clause 7.

4.3 Test objects

4.3.1 General

Test objects behave predominantly as inductive, capacitive or distributed equivalent impedances according to the voltage supply frequency content. For some test objects, whether they are predominantly inductive, capacitive or distributed, impedances ~~may~~ can depend on the PD detection frequency range (not only on the voltage supply frequency). Test objects with distributed behaviour have transmission line characteristics which ~~may~~ can cause attenuation and distortion of the PD pulses as the pulses propagate through the test object. The following classification is effective only for low-frequency, narrow-band measurements.

4.3.2 Inductive test objects

Types of inductive test objects ~~may~~ can include:

– stator and rotor windings
– inductive reactors
– transformer windings
– motorettes and formettes: see ~~the IEC 60034 series~~ IEC 60034-18-1

4.3.3 Capacitive test objects

Types of capacitive test objects ~~may~~ can include:

– twisted pairs of winding wire
– capacitors
– packaging of switching devices
– power electronics modules and substrates
– isolated heat sinks
– main wall insulation models in stator coils and bars
– printed circuit boards
– optocouplers

4.3.4 Distributed impedance test objects

The following test objects ~~may~~ can have distributed equivalent impedance properties:

– cables
– busbars
– stator and rotor windings
– transformer windings
– turn insulation of stator and rotor windings
– bushings with capacitive voltage stress control.

4.4 Voltage impulse generators

4.4.1 General

Voltage impulse generators used in this document shall generate short rise time and repetitive voltage impulses with a low noise level. For a short rise time of impulses, semiconductor devices ~~may~~ can be used for switching in addition to conventional sphere electrode gaps. For repetitive impulses, the main capacitor shall be charged from a DC power supply in a short period of time. The ranges of rise time, repetition frequency and other parameters are described in 4.4.2.

The polarity of successive voltage impulses is important for PD behaviour. To simulate the turn-to-turn voltage of a motor driven by a PWM phase voltage, a bipolar repetitive voltage impulse voltage is preferable. When a bipolar generator is hard to obtain, a unipolar repetitive voltage impulse generator ~~may~~ can be used.

For PD measurements, voltage impulse generators shall suppress noise emission by means of sufficient electromagnetic shielding.

4.4.2 Voltage impulse waveforms

For the purpose of comparison between different insulating materials or design solutions, partial discharge measurements can be performed using appropriate voltage supply waveforms. The specification of the voltage impulse generator shall include amongst other factors:

– impulse voltage rise time
– impulse voltage polarity
– impulse voltage repetition rate
– impulse voltage width
– impulse duty cycle

Examples are given in Table 1. Rise times as short as 20 ns are exhibited by devices employing wide band gap semiconductor materials, e.g. SiC or GaN.

Table 1 – Example of parameter values of impulse voltage waveform without load

Characteristic	Range
Rise time	~~0,04~~ 0,02 µs to 1 µs
Repetition rate	1 Hz to 10 000 Hz
Voltage impulse width	0,08 µs to 25 µs
Shape	Square or triangular (preferred)
Polarity	Unipolar or bipolar (preferred)

The voltage impulse waveform depends not only on the voltage impulse generator specification but also on sample impedance. The voltage impulse waveform will change significantly with load. The voltage impulse generator ~~needs to~~ shall be designed to deliver the required wave shape to the load. As the capacitance of the sample increases, the rise time of the voltage impulse increases in general. ~~On the other hand,~~ The inductive test object, or distributed equivalent impedance mentioned in 4.3.4, can cause damped oscillation after the voltage impulse waveform in addition to the change of rise time. Examples of these distortions to the waveform, due to variations in sample impedance, can be found in IEC TS 60034-27-5:2021, 4.2.2. It is important to check and record the waveform of the impulse voltage across the tested electrical insulation, at the test object itself. In this case, it is strongly recommended that impulse and PD waveforms are observed with a wide band oscilloscope with at least 100 MHz bandwidth. It is noted that PD can occur during the voltage oscillation following the first impulse.

4.5 Effect of testing conditions

4.5.1 General

In general, PD-associated quantities ~~may~~ can depend upon specific features of the impulse waveform, for example the impulse rise time, the impulse decay time, the impulse repetition rate, the polarity and the number of oscillations in the impulse.

4.5.2 Effect of environmental factors

In general, PD-associated quantities ~~may~~ can be affected by the following factors:

- temperature
- humidity
- atmospheric pressure
- type of environment gas
- degree of contamination of the test object

NOTE PD phenomena ~~may~~ can change ~~with~~ and exhibit longer rise times in the case of high altitude, i.e., lower pressure.

4.5.3 Effect of testing conditions and ageing

PD-associated quantities ~~may~~ can be affected by

- voltage distribution
- position of PD occurrence
- previous voltage applications as well as the time between voltage applications
- operation time or time under stress of the test object

In addition, they ~~may~~ can vary as ageing of the electrical insulation occurs, that is, during operation of the EIS.

5 PD detection methods

5.1 General

Any PD pulse detection system where the test object is excited by voltage impulses requires strong suppression of the residual voltage impulse, measured by the PD detection circuit, and negligible suppression of the PD pulse. The PD pulse shall have a magnitude after processing by the detection system that is greater than the residual transmitted voltage impulse. The amount of impulse voltage suppression required will be dependent on the test voltage and the rise time of the impulse.

As the impulse voltage increases in amplitude, greater suppression is required in order to ensure that important PD pulse magnitudes are higher than the residual transmitted voltage impulse on the output of the detector. Similarly, as the rise time of the applied impulse voltage becomes shorter, the suppression shall be greater, due to the increased overlap of frequency spectra of supply impulse and PD pulse (see Annex A). PD pulse coupling devices shall be designed to ensure that important PD pulse magnitudes are higher than the residual transmitted voltage impulse on the output of the detector, or that the residual is clearly distinguishable from the PD pulses.

Annex A provides indications of the voltage impulse suppression action required by the coupling device. Suggestions for the amount of supply voltage impulse suppression ~~needed~~ necessary as a function of impulse magnitude and rise time are given.

Examples of PD pulses extracted from a supply voltage impulse through filtering techniques are reported in Annex B.

5.2 PD pulse coupling and detection devices

5.2.1 Introductory remarks

PD current or voltage pulses in a test object can be detected either by means of high-voltage capacitors, high-frequency current transformers (HFCTs) or electromagnetic couplers (e.g. antennae). The detectors, in conjunction with the rest of the measuring system, shall be able to suppress the impulse voltage to a magnitude less than that expected from the PD pulse (e.g. using appropriate filters).

Short low-inductance connections between the supply, the test object and the PD detector are required, since the voltage impulses and PD pulses contain high-frequency components. The impulse supply shall be as physically close to the test object as possible, in order to prevent attenuation and dispersion of the applied impulse due to the equivalent transmission parameters of the connecting leads. Since the PD is measured with a UWB detection system, earthing of the test object shall be made directly to the impulse voltage supply, with leads as short as possible and with low inductance. It is recommended that lead lengths should not exceed 1 m.

The following circuits are applicable for PD pulse detection.

5.2.2 Coupling capacitor with multipole filter

A coupling capacitor with a voltage rating exceeding that of the expected applied impulse voltage together with a filter that strongly attenuates the test voltage impulses can be used. The filter shall have at least three poles and special measures to inhibit cross-coupling of the input signal to the output. The filter can be designed using passive or active filtering technology. The coupling capacitor is connected to the test object high-voltage terminal (Figure 1). Annex A shows a schematic example of filter behaviour. Figure 2 reports an example of the ideal frequency spectra of PD pulse and impulse voltage before and after filtering for an 8th order filter. Note that real filters distort the PD pulse shape and can introduce extra frequency components.

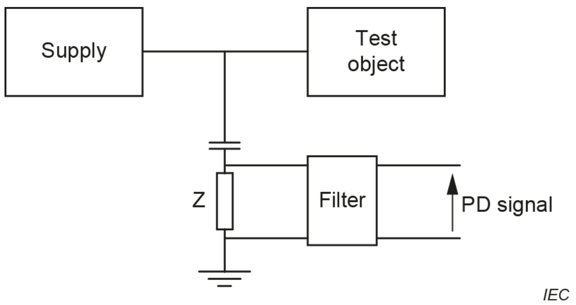
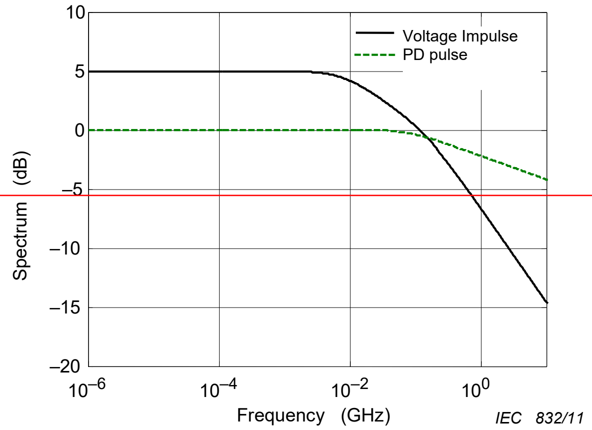
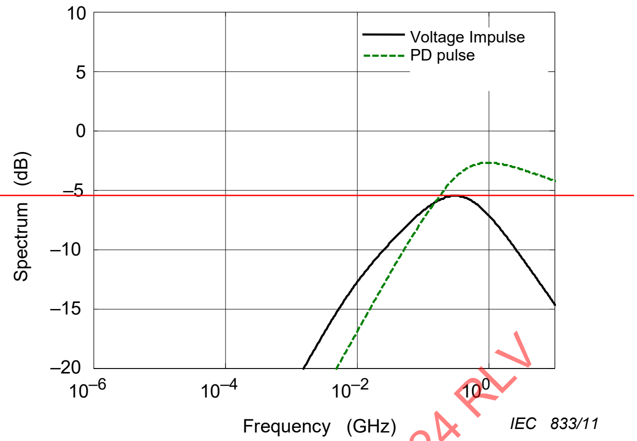


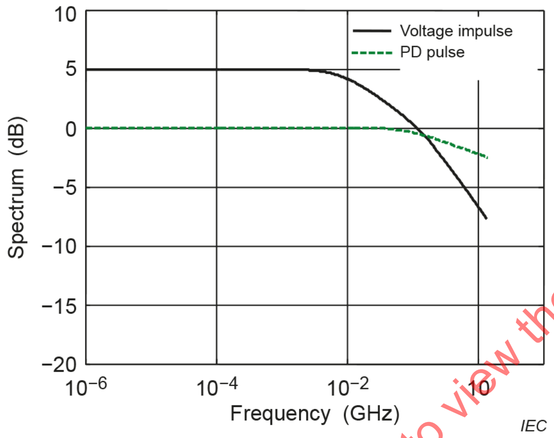
Figure 1 – Coupling capacitor with multipole filter



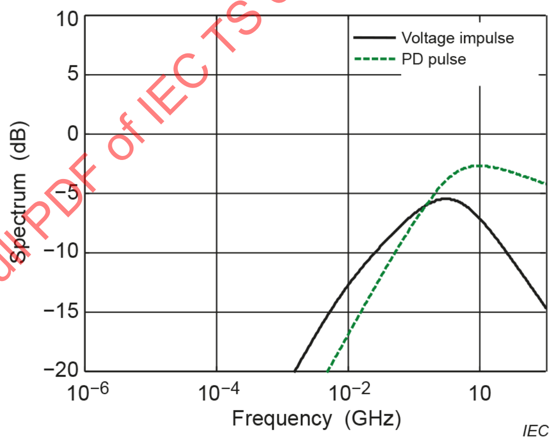
~~Figure 2a – Example of voltage impulse and PD pulse frequency spectra before filtering~~



~~Figure 2b – Example of voltage impulse and PD pulse frequency spectra after filtering~~



a) Example of voltage impulse and ideal PD pulse frequency spectra before filtering



b) Example of voltage impulse and ideal PD pulse frequency spectra after filtering

NOTE The impulse voltage rise time is 50 ns, the PD pulse rise time is 2 ns, the 8th order filter with filter cut-off frequency is equal to 500 MHz.

Figure 2 – Example of voltage impulse and ideal PD pulse frequency spectra before and after filtering

5.2.3 HFCT with multipole filter

An HFCT, together with a filter, can be used to detect PD pulses while suppressing the impulse voltage. Note that HFCTs ~~may~~ can have a very wide range of upper cut-off frequencies that ~~may~~ can affect the performance of this method, especially with impulse voltage rise times < 100 ns. The HFCT shall have a higher cut-off frequency than the voltage impulse frequency. The filter shall have at least three poles and special measures to inhibit cross-coupling of the input signal to the output. The filter can be implemented using passive or active filtering technology. The HFCT can be placed over the high-voltage cable between the impulse supply and the test object (Figure 3). In this case, the HFCT shall have sufficient electrical insulation to ensure that breakdown between the cable and the HFCT does not occur. Alternatively, the HFCT can be connected between the test object and earth (Figure 4). Only low-voltage insulation is then required. The latter arrangement is effective, in general, only if the metallic enclosure of the test object can be isolated from earth. Annex A shows a schematic example of filter behaviour.

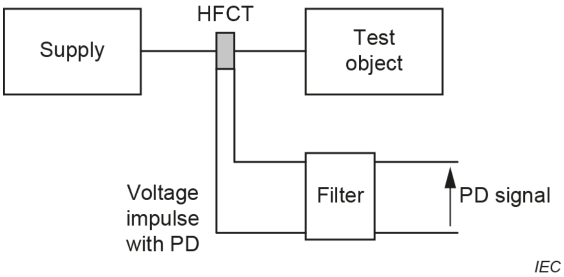


Figure 3 – HFCT between supply and test object with multipole filter

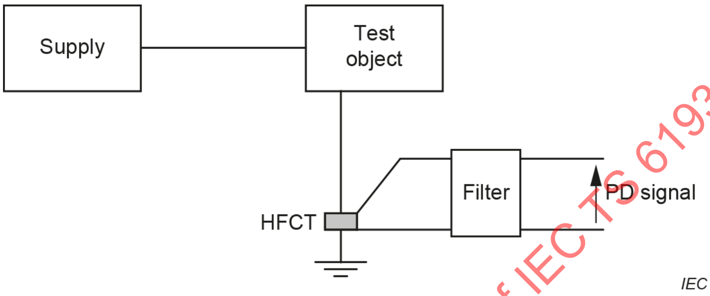


Figure 4 – HFCT between test object and earth with multipole filter

5.2.4 Electromagnetic couplers

Antenna-type couplers can be used to separate impulses from the supply from PD originating in the test object (Figure 5).

Various antenna-type couplers can be used to detect an electromagnetic signal from the partial discharge site in the test object. For the separation of the PD signal from the impulse voltage, the couplers shall have suitable frequency characteristics.

An ultra-wide band (UWB) coupler can detect a PD signal with impulse noise. To suppress the impulse voltage, an electromagnetic ~~near-field~~ coupler with a fixed coupling impedance to the lead from the impulse supply to the test object can be effective (Figure 5).

Examples of noise levels of electromagnetic PD couplers are provided in Annex D.

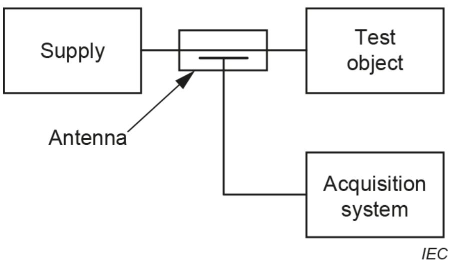


Figure 5 – Circuit using an electromagnetic coupler (e.g. an antenna) to suppress impulses from the test supply

5.2.5 Electromagnetic UHF antennae

Alternatively, an electromagnetic ~~coupler~~ UHF antenna can detect the radiated electromagnetic signals propagating through free space from the PD site in the test object (Figure 6). If the antenna has UWB characteristics including lower frequency component of voltage impulses, a filtering function is necessary to suppress the residual signal inside the acquisition system. Some double-ridged guide antennae (horn antennae) have a cut-off frequency above 0,5 GHz which ~~need no~~ do not require filters. UHF antennae with narrow-band characteristics, the centre frequency of which is higher than those of voltage impulse also do not ~~need~~ require a filter for the same reason. Note that the coupling efficiency will depend on the distance between the PD site and the antenna as well as the presence of any metallic shielding between the PD site and the antenna.

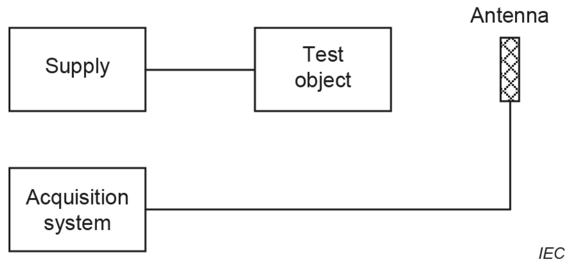
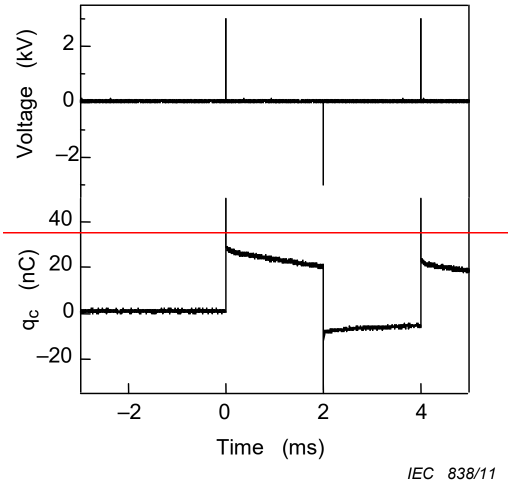


Figure 6 – Circuit using an electromagnetic UHF antenna

~~**5.2.5 Charge measurements**~~

~~For simple, unearthed capacitive test objects, such as twisted pairs (with equivalent capacitance C_s), it is possible to measure PD charge using both a detection capacitor with a capacitance C_d (C_d>>C_s) in series with the test object and a voltage detector with high input resistance R.~~

~~Charge builds up on the detecting capacitor through the charging current due to the impulse voltage rise. When the impulse voltage decays to zero, the capacitor charge is cancelled out by the opposite charge. Consequently, without PD, the voltage of the detecting capacitor shows the same shape of the applied impulse voltage, with amplitude scaled by the ratio C_s/C_d. When PD occurs during the impulse voltage, the PD charge decays to zero with the time constant RC_d, where R is the impedance of the measuring system. When the time constant is selected to be long enough with respect to the impulse voltage duration, charge decay can be observed after a single voltage impulse. Figure 7 shows an experimental example of impulse voltage and accumulated charge for a twisted pair sample. The charge measurement is meaningful as a PD detection tool only if the voltage impulses are bipolar and identical for both polarities. The sensitivity of PD measurement depends on the background noise in the same way as for conventional PD measurement. A schematic of the test circuit is shown in Figure 8.~~



NOTE Peak impulse voltage magnitude = 2,3 kV, impulse voltage repetition rate = 250 Hz.

Figure 7 – Example of waveforms of repetitive bipolar impulse voltage and charge accumulation for a twisted-pair sample

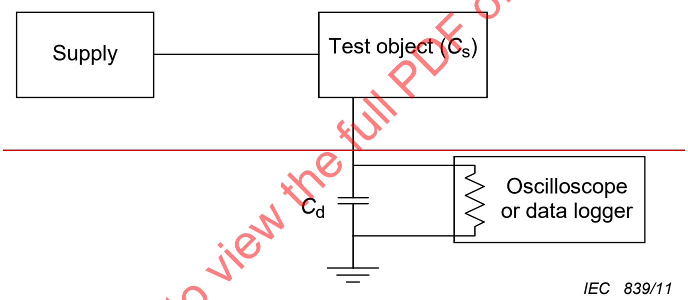
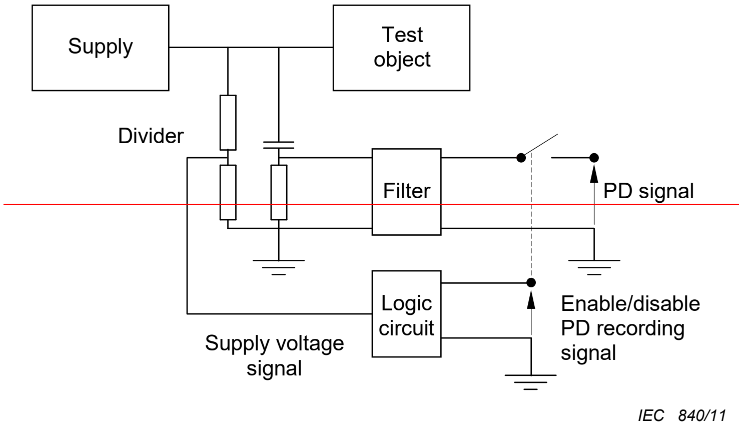


Figure 8 – Charge measurements

5.3 Source-controlled gating techniques

An alternative method to suppress the impulse voltage is to gate the PD signal electronically (from any of the above detectors) so that the signal is blocked from being displayed or registered for the duration of the initial portion of the short rise time of the impulse (Figure 9). With this method, any PD reaching the detector during the initial part of the impulse rise time will not be detected. Hence, only PD reaching the detector after the supply voltage commutation transient will be recorded.



~~Figure 9 – Example of PD detection using electronic source-controlled gating (other PD coupling devices can be used)~~

6 Measuring instruments

The results of a PD test are the RPDIV and RPDEV. The PD pulse repetition rate, the largest peak PD pulse magnitude at a specified test voltage and the test conditions ~~shall~~ can be measured as well. It should be pointed out that PD magnitude is only a relative measure of PD activity, given that PD pulses are attenuated and distorted when they travel from the source to the measurement point.

The PD signal output from the coupler and detection system can be recorded on a digital oscilloscope or pulse magnitude analyser. When using an oscilloscope, the PD output is normally displayed on one channel while a reduced magnitude version of the applied impulse voltage is recorded on another channel (Annex B). The magnitudes of the PD pulses as well as the temporal position in which they occur with respect to the impulse voltage are recorded. Note that the retrigger rate of the oscilloscope is recommended to be higher than that of the impulse voltage repetition rate.

Electronic pulse magnitude analysers can be used to measure the magnitude of the PD pulses and their repetition rate ~~(see 4.4 of IEC 60270:2000)~~.

Typical test circuits are shown in Figure 1 to ~~Figure 9~~ Figure 6.

7 Sensitivity check of the PD measuring equipment and high voltage source generator

7.1 General

The RPDIV, RPDEV and PD-associated quantities depend on the sensitivity of the measuring system to PD and how well the PD pulses can be distinguished from other electrical interference or noise (such as the residual signal from the voltage impulse itself). Thus the sensitivity of the PD measuring system shall be assessed and recorded. The sensitivity is measured in mV.

NOTE The PD is not measured in pC, since the procedure of IEC 60270 cannot be used for UWB PD detection systems (integration of the pulse current to yield the apparent charge cannot be performed as indicated in IEC 60270).

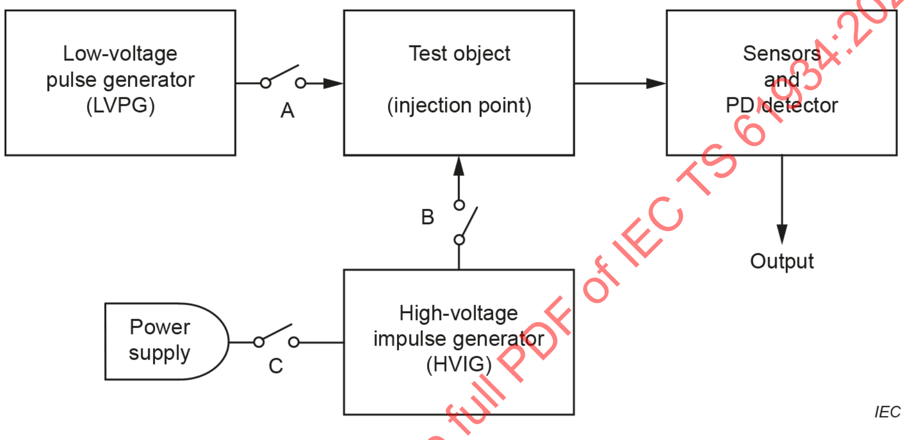
7.2 Test diagram for sensitivity check

A sensitivity check of a PD measuring system is performed using the test diagram shown in Figure 7. The output of the PD detector is measured step by step with different combinations of the low-voltage pulse generator (LVPG) and high-voltage impulse generator (HVIG) connected to a test object.

Pulse waveform from the LVPG shall be selected with respect to both the original PD pulses and the frequency limit of the detecting system. The rise time of the pulse waveform ~~may~~ can be selected around 1/*f*, where *f* is the upper frequency limit of the PD detection system. For example, if the upper cut-off frequency of the PD detection system is 100 MHz, the rise time of LVPG ~~may~~ can be less than 10 ns.

The location where the LVPG is connected to the circuit of the test object ~~shall~~ can be ~~cleared~~ used as injection point. For test objects having distributed equivalent impedance, such as motor and transformer windings, the propagation effects of PD pulses ~~may~~ can cause strong attenuation of the high-frequency components, thus only PD close to the measurement point ~~may~~ can be observed.

PD sensitivity and the effect of noise ~~may~~ can be assessed in steps, as addressed in Figure 7 and 7.3 to 7.5:



	A	B	C	Subclause
PD detection sensitivity check	Closed	Opened and Closed	Opened	7.3
Background noise check	Closed	Closed	Opened	7.4
Detection system noise check	Opened	Closed	Closed	7.5

Figure 7 – Test diagram for sensitivity check

7.3 PD detection sensitivity check

Disconnect the HVIG from the test object and measure the output of the PD detector while increasing the output of the LVPG. Measure the minimum output voltage of the LVPG at which the PD detector shows a detectable signal. This is the sensitivity of the PD detection system.

7.4 Background noise check

Connect the unenergized HVIG to the test object and measure the output of the PD detector while increasing the output of the LVPG. Measure the minimum output voltage of the LVPG at which the PD detector shows a detectable signal. This is the background noise of the PD detection circuit.

7.5 Detection system and HVIG noise check

Disconnect the LVPG and apply the voltage impulse of the HVIG to the test object. Measure the output of the PD detector under PD-free conditions. For example, replace the test object with a PD-free capacitance that has about the same high-frequency capacitance as the test object. Record the output of the PD detector with voltage impulse used for the PD measurement. This is the detection system noise, or residual of the HVIG.

NOTE It is possible that the test described in 7.5 ~~may~~ will not be feasible if appropriate capacitors are not available. In such cases, reference ~~should~~ can be made to the results of 7.3.

7.6 Sensitivity report

PD sensitivity is presented as the relation between the outputs of the LVPG and HVIG. An example of the possible behaviour of PD sensitivity is shown in Figure 8.

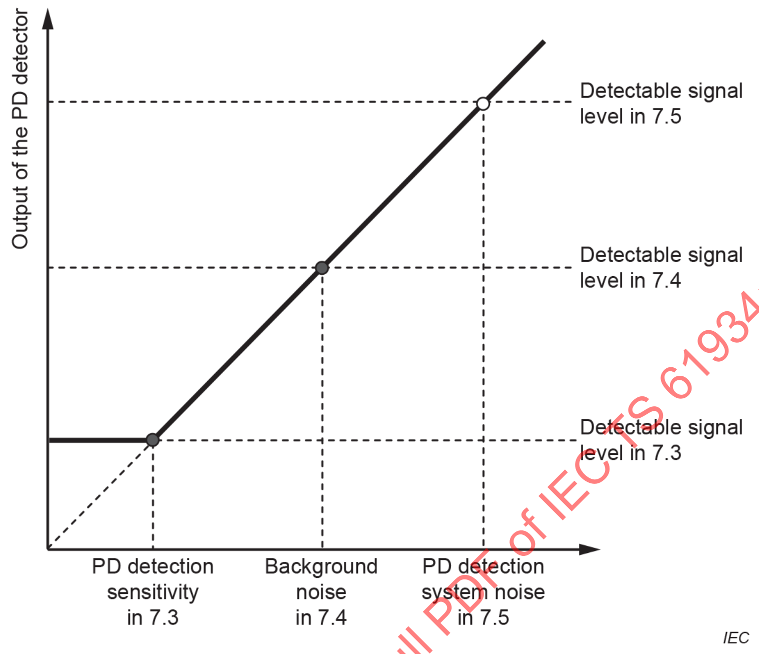


Figure 8 – Example of relation between the outputs of LVPG and PD detector

8 Test procedure for increasing and decreasing the repetitive impulse voltage magnitude

The background noise and detection limits shall first be measured using the procedures set out in Clause 7. For PDIV, PDEV, RPDIV and RPDEV measurements, the voltage amplitude of repetitive impulse shall rise continuously or step-by-step with a low voltage and then fall. One method, known as the step-by-step (SBS) method, for determining the PDIV, RPDIV, RPDEV and PDEV is as follows (Figure 9):

- Decide minimum and maximum impulse voltages, voltage step, number of impulses with same magnitude and repetition frequency before the test.
- With the preliminary test the minimum voltage shall be selected as no PD is detected.
- With the preliminary test the maximum voltage shall be selected as every voltage impulse causes PD pulses.
- Set a voltage impulse generator with the parameters mentioned above, if necessary.
- Start the repetitive impulse of the minimum voltage.
- Repeat the repetitive impulse with increased voltage steps successively.
- PDIV is the impulse voltage when the first PD pulse is detected.
- RPDIV is the minimum impulse voltage when a mean of five PD pulses occurs on ten voltage impulses of the same polarity. When less than ten impulses are tested with the same voltage, the ratio of PD pulses to voltage impulses ~~may~~ can be used.
- After maximum voltage the repetitive impulses fall with a decreased voltage step.
- RPDEV is the maximum voltage at which a mean of five PD pulses occurs on ten voltage impulses of the same polarity.

– PDEV is the impulse voltage when no PD pulse is detected.

Other methods of determining these quantities are also possible.

~~Note that the PDIV and PDEV may be highly variable when this sequence is repeated.~~

Generally, PD activity is unstable around either the inception or extinction voltage or both. So RPDIV and RPDEV are recommended with an averaging treatment of unstable PD pulse behaviour. Nevertheless, experience suggests there can still be some scattering. In order to suppress the scattering, improvement of SBS parameters can be effective. For example, large numbers of impulses and low increments/decrements in voltage can lead to more stable results. At least five repeated RPDIV and RPDEV measurements are recommended. See Annex C for practical examples.

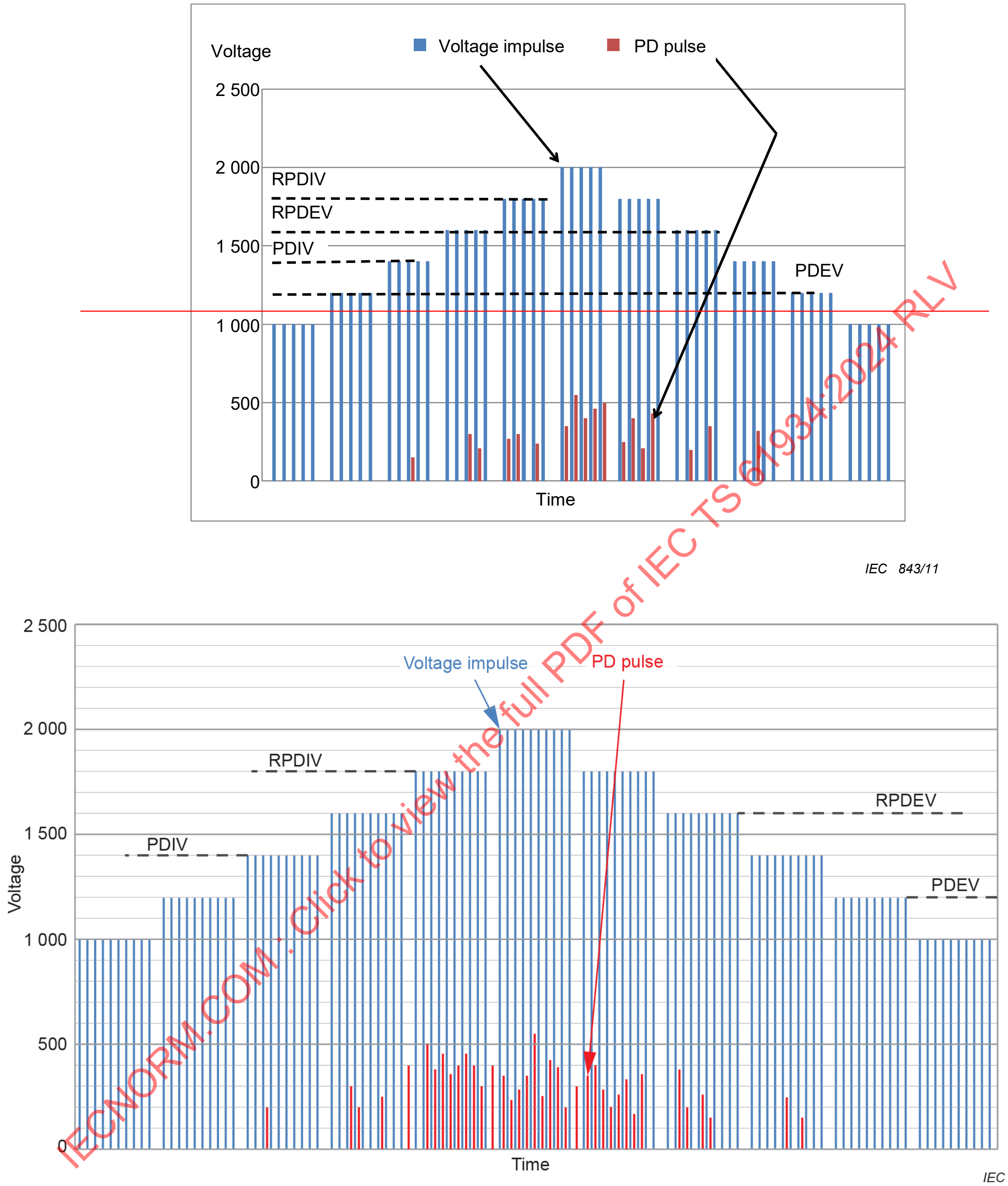


Figure 9 – Example of increasing and decreasing the impulse voltage magnitude

9 Test report

The following quantities shall be reported:

– PD sensitivity level (see Clause 7)

– background noise level

– detection system noise level

– RPDIV, RPDEV and minimum PD detection level in mV

– parameters of applied voltage impulses reported in Clause 8
– shape of the impulse voltage with load reported in 4.4.2
– testing conditions reported in 4.5.2 and 4.5.3.

Reporting of the following parameters is optional:

– peak partial discharge magnitude at a specified applied voltage
– maximum (peak-to-peak) test impulse voltage level
– operation time or time under stress of the test object
– state of cleanliness of the test object (e.g. no cleaning, factory shipment cleanliness)

Annex A
(informative)

Voltage impulse suppression required by the coupling device

A schematic representation of the possible overlap of voltage impulse and PD pulse frequency spectra is shown in Figure A.1. The steeper the voltage impulse the larger the overlap area between the two spectra. The cut-off frequency for an optimal voltage impulse suppression coupling device is indicated in Figure A.1. The action of a filter is displayed in Figure A.2. Impulse voltage and PD pulse magnitude are damped by the filter transfer function, $H(f)$, f being the frequency. The filter cut-off frequency should be selected in such a way that, after filtering, the PD signal magnitude exceeds the voltage impulse magnitude within the bandwidth of the PD detector. A broadband PD detector is generally required for this purpose.

A typical example of acceptable impulse voltage attenuation as a function of voltage magnitude and rise time is reported in Figure A.3. Note that attenuation depends on the voltage impulse magnitude and the rise time.

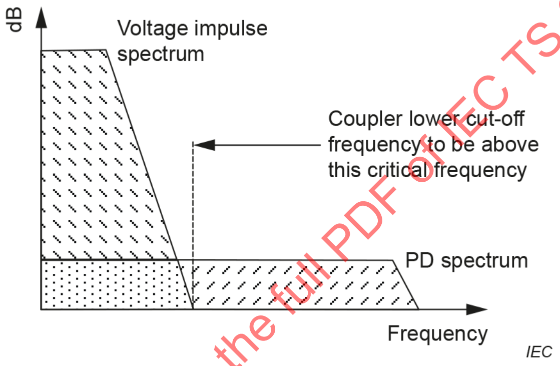


Figure A.1 – Example of overlap between voltage impulse and PD pulse spectra (dotted area)

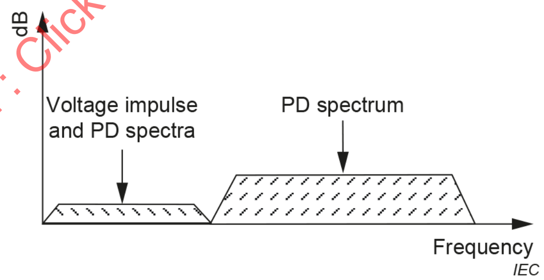
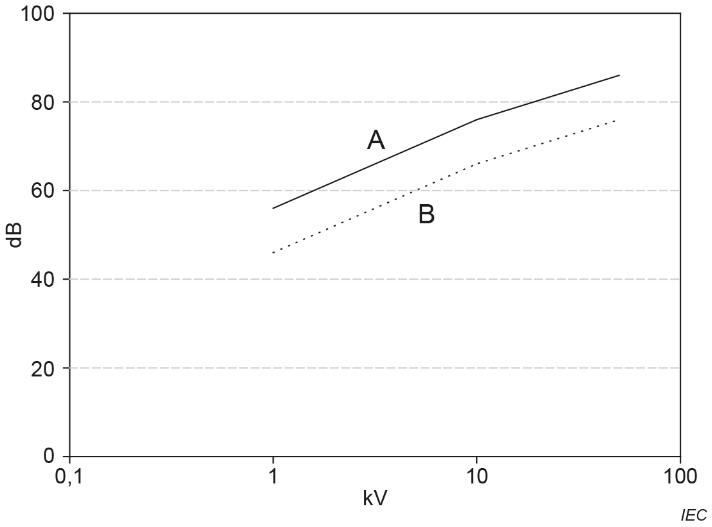


Figure A.2 – Example of voltage impulse and PD pulse spectra after filtering



Key

A voltage impulse rise time = 100 ns

B voltage impulse rise time = 1 000 ns

Figure A.3 – Example of impulse voltage damping as a function of impulse voltage magnitude and rise time

Annex B
(informative)

PD pulses extracted from a supply voltage impulse through filtering techniques

A typical example of PD pulses occurring during a supply voltage commutation transient for a square bipolar generator feeding a 400 V, 1 kW motor is shown in Figure B.1 and Figure B.2. In Figure B.1 the recorded signal is predominantly noise due to impulse supply voltage switching. Figure B.2 is obtained using an antenna as a coupling device and a high-pass filter (four poles), with the cut-off frequency at 400 MHz. The filtered signal is predominantly a PD pulse generated inside the test object where the supply voltage commutation has been suppressed effectively through filtering. Figure B.3 is the example of the attenuation achieved with an 8th order filter with the cut-off frequency at 400 MHz.

It should be noted that, in the absence of filtering, PD pulses cannot be detected as they are hidden by the noise produced by the voltage impulses.

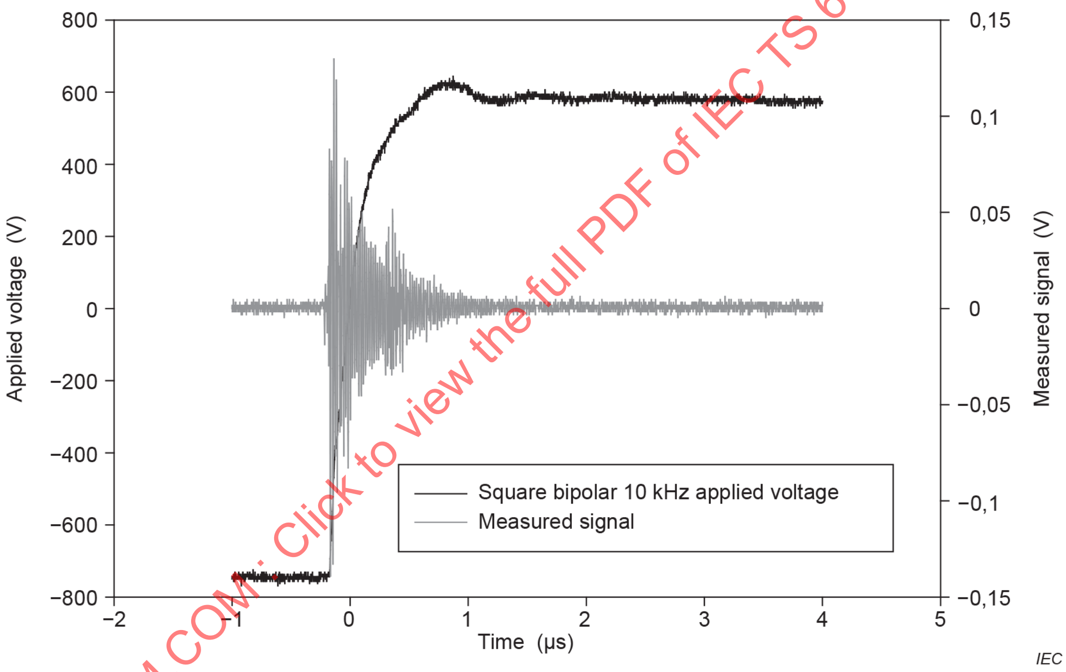


Figure B.1 – Power supply waveform and recorded signal using an antenna during supply voltage commutation

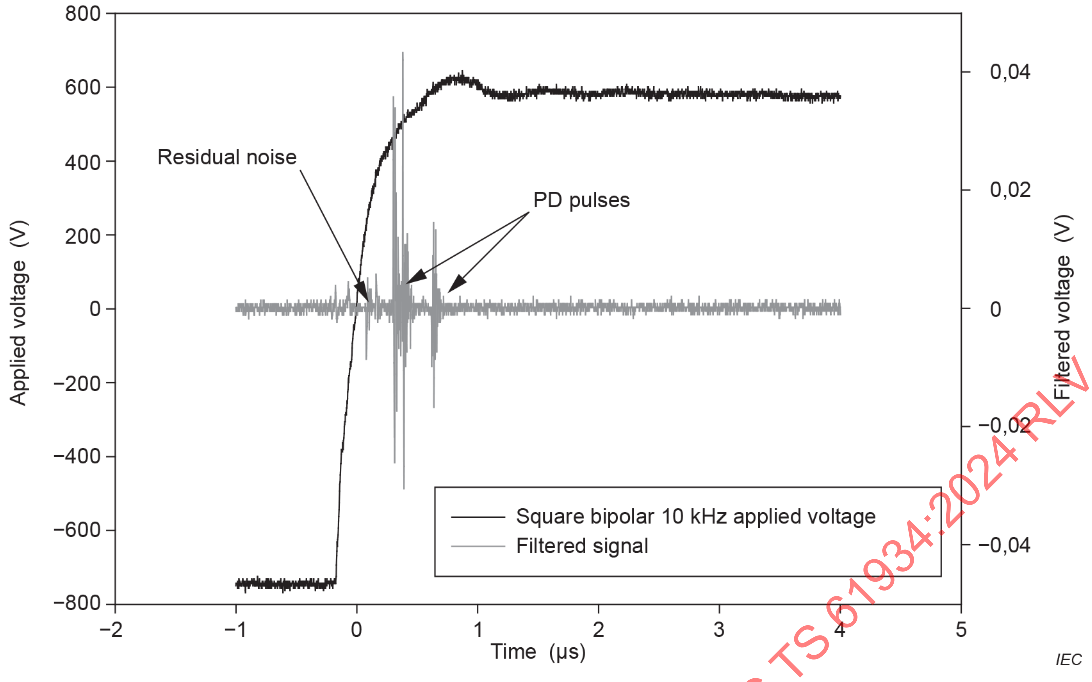


Figure B.2 – Signal detected by an antenna from the record of Figure B.1, using a filtering technique (400 MHz high-pass filter)

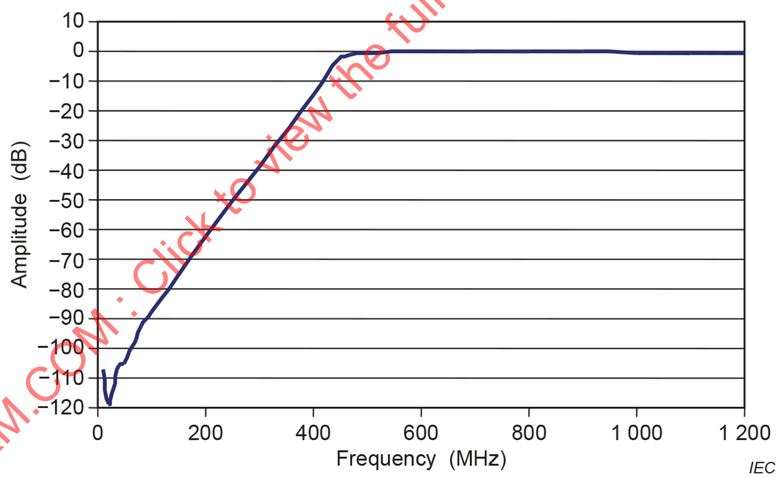


Figure B.3 – Characteristic of the filter used to pass from Figure B.1 to Figure B.2

Annex C
(informative)

Results of round-robin tests of RPDIV measurement

Round robin tests for RPDIV measurement were carried out with common sample and common voltage impulse pattern from 2008 by six members of IEC TC 112. The following are the test conditions and some of the test results.

The common sample comprised ten twisted-pairs made from the same batch of magnet wires. They were manufactured by one company and distributed to the six members. Ten twisted-pairs were measured ten times and the hundred RPDIV data were normalized with temperature and air pressure on a common data sheet template.

A voltage impulse was used having a triangular waveform with 0,1 µs in rise time and 3 ms in decay time. Ten voltage impulses with the same amplitude were generated with an interval of 20 ms. After a 100 ms pause, the amplitude of the impulse voltage was raised by 10 V and the ten impulses were applied as shown in Figure C.1. The amplitude started from 1,0 kV up to 2,0 kV. Even after PD was initiated, the sequence of impulses was continued up to 2 kV. The sequence of impulses was repeated ten times for each sample.

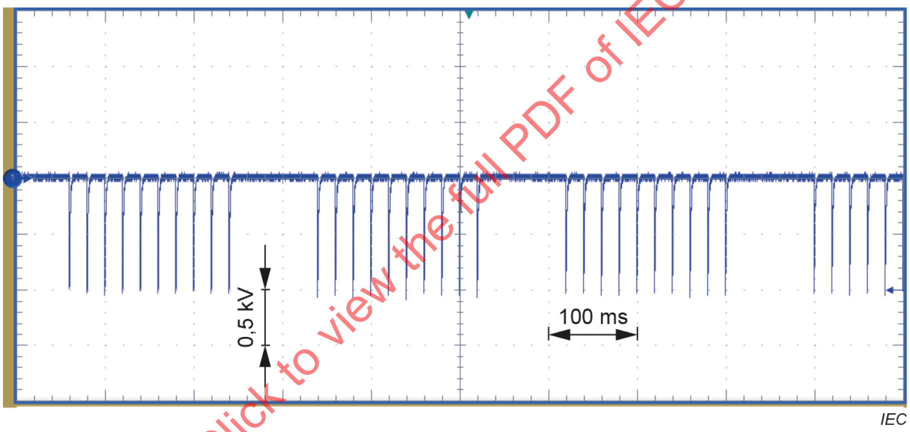
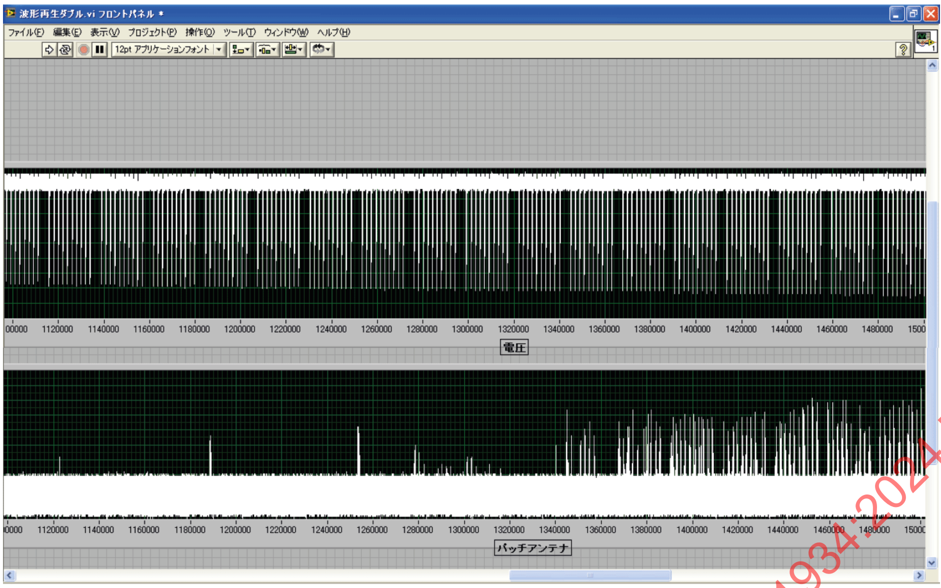


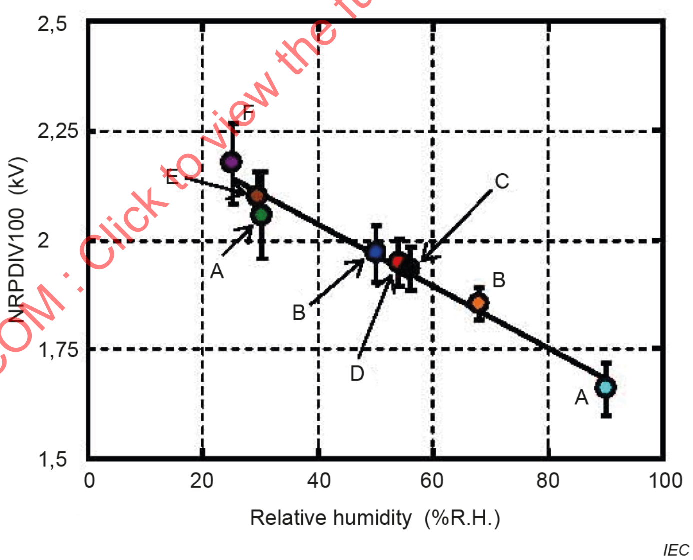
Figure C.1 – Sequence of negative voltage impulses used for RRT



PD pulses are shown in the bottom and voltage impulses in the top and of the figure.

Figure C.2 – PD pulses corresponding to voltage impulses

Figure C.2 shows PD pulses detected with an UHF narrow-band antenna (1,8 GHz) corresponding to the sequence of voltage impulses. Figure C.3 shows the variation of normalized RPDIV (NRPDIV) with relative humidity during the test from the six members.



Key

A to F participants of the RRT

Figure C.3 – Dependence of normalized RPDIV on 100 data (NRPDIV/100) on relative humidity

Annex D
(informative)

Examples of noise levels of practical PD detectors

Table D.1 shows examples of the PD detector output voltage of background noise levels of practical sensors used to detect PD during fast rise time voltage surges. All of these sensors are of the electromagnetic coupler type (5.2.4). Table D.1 also shows examples of magnitudes of PD detector output when each sensor detects PD. These detected PD levels depend on how close the antennae are to the PD site, and in the case of couplers, the effective capacitance of the test object. The severity of the PD will also influence the detected magnitude for all types of sensors. Thus actual detected PD magnitudes ~~may~~ can vary widely.

Table D.1 – Examples of bandwidths and noise levels for practical PD sensors

Detection system type	Frequency range	Typical background noise level	Typical detected PD magnitudes
Microwave patch antenna	~~1,8~~ 1,6 GHz ± 200 MHz	7 µV	> 50 mV
Directional electromagnetic coupler	100 MHz to 1 000 MHz	10 mV	> 100 mV
Spiral UHF antenna	700 MHz to 1 000 MHz	5 µV to10 µV	> 100 µV

Bibliography

~~IEC 62068-1:2003, *Electrical insulation systems – Electrical stresses produced by repetitive impulses – Part 1: General method of evaluation of electrical endurance*~~

~~Regarding the definition of "(repetitive) partial discharge inception" and "extinction voltage", as well as applications of the methodologies described in this technical specification (referring only to rotating machines), the following papers can be considered:~~

~~KAUFHOLD, M., BORNER, G., EBERHARDT, M., SPECK, J., "*Failure mechanisms of the interturn insulation of low-voltage electric machines fed by pulsed controlled inverters*", IEEE Electrical Insulation Magazine, Vol. 12, n.5, pp. 9-15, October 1996~~

~~YIN, W. "*Dielectric properties of an improved magnet wire for inverter-fed motors*", IEEE Electrical Insulation Magazine, Vol. 13, n.3, Vol. 13, pp. 17-23, August 1997~~

~~CAMPBELL, R.J., STONE, G.C. "*Examples of Stator Winding Partial Discharges due to Inverter Drives*", Proc. IEEE ISEI, pp 231-234, Anaheim CA, April 2000~~

~~BIDAN, P., LEBEY, T. NEACSU, C. "*Development of a new off-line test procedure for low-voltage rotating machines fed by adjustable speed drive*", IEEE Trans. on Dielectrics and Electrical Insulation, Vol.10, n. 2, pp 168-175, April 2003~~

~~CASADEI, D. CAVALLINI, A., FABIANI, D. ROSSI, C., SERRA, G., MONTANARI, G.C. "*The influence of power-electronic waveforms on partial discharge inception in low-voltage rotating machines*", Proc. CWIEME, pp. 39-44, Berlin, Germany, June 2003~~

~~FABIANI, D., MONTANARI, G.C. CAVALLINI, A. MAZZANTI, G. "*Relation between space charge accumulation and partial discharge activity in enameled wires under PWM-like voltage waveforms*", IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 11, n. 3, pp. 393-405, June 2004~~

~~KIMURA, K., USHIRONE, S., KOYANAGI T., HIKITA, M. "*PDIV Characteristics of Twisted-Pair of Magnet Wires with Repetitive Impulse Voltage*", IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 14, n.3, pp. 744-750, June 2007~~

IEC 60034-18-1, *Rotating electrical machines – Part 18-1: Functional evaluation of insulation systems – General guidelines*

IEC TS 60034-27-5:2021, *Rotating electrical machines – Part 27-5: Off-line measurement of partial discharge inception voltage on winding insulation under repetitive impulse voltage*

IEC 62068:2013, *Electrical insulating materials and systems – General method of evaluation of electrical endurance under repetitive voltage impulses*

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

IEC TS 61934

Edition 3.0 2024-01

TECHNICAL SPECIFICATION

colour inside

Electrical insulating materials and systems – Electrical measurement of partial discharges (PD) under short rise time and repetitive voltage impulses

IEC TS 61934:2024-01(en)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRICAL INSULATING MATERIALS AND SYSTEMS – ELECTRICAL MEASUREMENT OF PARTIAL DISCHARGES (PD) UNDER SHORT RISE TIME AND REPETITIVE VOLTAGE IMPULSES

FOREWORD

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IEC TS 61934 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is a Technical Specification.

This third edition cancels and replaces the second edition published in 2011. This edition constitutes a technical revision.

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

a) background information on the progress being made in the field of power electronics including the introduction of wide band gap semiconductor devices has been added to the Introduction;
b) voltage impulse generators; the parameter values of the voltage impulse waveform have been modified to reflect application of wide band gap semiconductor devices.
c) PD detection methods; charge-based measurements are not described in this third edition nor are source-controlled gating techniques to suppress external noise.

d) Since the previous edition in 2011, there have been significant technical advances in this field as evidenced by several hundreds of publications. Consequently, the Bibliography in the 2011 edition has been deleted in this third edition.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
112/578/DTS	112/610/RVDTS

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 Technical Specification 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/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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INTRODUCTION

Power electronics has been developed along with both control theory and semiconductor technology. Switching is one of the essential features of power electronics control. For higher efficiency and smoother operation, switching times of devices such as an insulated-gate bipolar transistor (IGBT) tend to be shorter than microseconds. The introduction of wide band gap devices, such as those based on silicon carbide, can result in transients with rise times of the order of a few tens of nanoseconds. Such a short rise time can cause transient overvoltage impulses or surges in systems. When the voltage impulses reach the breakdown strength of an air gap, partial discharge (PD) can occur. In addition, the impulses are repetitive from power electronics modulation such as pulse width modulation (PWM). Since PD can cause degradation of electrical insulation parts in the system, it is one of the most important parameters to be measured.

The first edition of IEC TS 61934 was issued in April 2006. Because of rapid development in this field, the revision activity for the latest information was approved by TC 112 at their Berlin meeting in September 2006. The second edition of IEC TS 61934 was published in 2011. Owing to further advances in this area, a revision of the second edition was commenced formally in 2019 and has resulted in this third edition.

ELECTRICAL INSULATING MATERIALS AND SYSTEMS – ELECTRICAL MEASUREMENT OF PARTIAL DISCHARGES (PD) UNDER SHORT RISE TIME AND REPETITIVE VOLTAGE IMPULSES

1 Scope

This document is applicable to the off-line electrical measurement of partial discharges (PDs) that occur in electrical insulation systems (EISs) when stressed by repetitive voltage impulses generated from power electronics devices.

Typical applications are EISs belonging to apparatus driven by power electronics, such as motors, inductive reactors, wind turbine generators and the power electronics modules themselves.

NOTE Use of this document with specific products can require the application of additional procedures.

Excluded from the scope of this document are

– methods based on optical or ultrasonic PD detection,
– fields of application for PD measurements when stressed by non-repetitive impulse voltages such as lightning impulse or switching impulses from switchgear.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
repetitive voltage impulse
voltage impulse which is used as test voltage for the evaluation of switching surges from power electronics devices with a carrier or driven frequency

3.2
partial discharge
PD
localized electric discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor

3.3
partial discharge pulse
current pulse in an object under test that results from a partial discharge occurring within the object under test

Note 1 to entry: The pulse is measured using suitable detector circuits, which have been introduced into the test circuit for the purpose of the test.

Note 2 to entry: A detector in accordance with the provisions of this document produces a current or a voltage signal at its output related to the PD pulse at its input.

[SOURCE: IEC 60270, 3.2, modified – "or voltage" has been deleted, the second part of the definition has been included in Note 1 to entry and Note 2 to entry has been revised.]

3.4
RPDIV
repetitive partial discharge inception voltage
minimum peak-to-peak impulse voltage at which more than five PD pulses occur on ten voltage impulses of the same polarity

Note 1 to entry: The RPDIV is a mean value for the specified test time and a test arrangement where the voltage applied to the test object is gradually increased from a value at which no partial discharges can be detected. Further explanation is mentioned in 8.

3.5
RPDEV
repetitive partial discharge extinction voltage
maximum peak-to-peak impulse voltage at which less than five PD pulses occur on ten voltage impulses of the same polarity

Note 1 to entry: The RPDEV is a mean value for a specified test time and a test arrangement where the voltage applied to the test object gradually decreases from a voltage at which PDs have been detected. Further explanation is mentioned in Clause 8.

3.6
impulse voltage polarity
polarity of the applied impulse voltage with respect to earth

3.7
unipolar impulse
repetitive voltage impulse, the polarity of which is either positive or negative

[SOURCE: IEC 62068:2013, 3.11, modified – "repetitive" has been added.]

3.8
bipolar impulse
repetitive voltage impulse, the polarity of which changes from positive to negative or vice versa

3.9
impulse voltage repetition rate
inverse of the average time between successive impulses of the same polarity, whether unipolar or bipolar

3.10
impulse rise time
time for the voltage to rise from 10 % to 90 %

3.11
impulse decay time
time interval between the instants at which the instantaneous value of an impulse decreases from a specified upper value to a specified lower value

Note 1 to entry: Unless otherwise specified, the upper and lower values are fixed at 90 % and 10 % of the impulse magnitude.

3.12
impulse width
interval of time between the first and last instants at which the instantaneous value of an impulse reaches a specified fraction of impulse magnitude or a specified threshold

3.13
impulse duty cycle
ratio, for a given time interval, of the impulse width to the total time

3.14
peak partial discharge magnitude
largest magnitude of any quantity related to PD pulses observed in a test object at a specified voltage following a specified conditioning and test

Note 1 to entry: For impulse voltage tests, the peak magnitude of the PD pulse is the largest repeatedly occurring PD magnitude.

[SOURCE: IEC 60270, 3.4, modified – In the term “largest repeatedly occurring” has been replaced with “peak”, the definition has been revised and the Note to entry has been added.]

4 Measurement of partial discharge pulses during repetitive, short rise-time voltage impulses and comparison with power frequency

4.1 Measurement frequency

IEC 60270 describes the methods employed to measure the electrical pulses associated with PD in test objects excited by DC and alternating voltages up to 400 Hz. The methods used to measure PD pulses when the test object is subjected to supply voltage impulses shall be modified from the standard narrow-band and wide-band frequency methods described in IEC 60270.

To measure the PD during repetitive short rise time voltage impulses, it is necessary to avoid the induced current of the impulse voltage. One technique is current or electromagnetic wave measurement at ultra-high frequency, that is, higher than the frequency components associated with the impulse. Ultra-wide band (UWB) detection is often used with a high-pass filter for the suppression of the relatively lower frequency components of the impulse voltage. In principle, narrow-band measurement in the ultra-high frequency (UHF: 300 MHz to 3 GHz) region is also effective for the suppression of the impulse voltage. Partial discharge measurement methods in this frequency range are described in IEC TS 62478.

NOTE Measurements in accordance with IEC TS 62478 cannot be calibrated in relation to apparent charge in pC, so a direct value-based comparison to measurements in accordance with IEC 60270 is not possible.

4.2 Measurement quantities

Measured quantities concern the RPDIV, the RPDEV, the peak partial discharge magnitude and partial discharge pulse repetition rate.

The RPDIV and RPDEV can depend on PD measurement sensitivity and measurement circuit noise, therefore normalization, as indicated in Clause 7, is necessary. Moreover, they depend on the test object and the pulse deformation from the discharge site to the measurement point.

In this document, and consistent with IEC TS 62478, PD readings are reported in units of mV. In all cases, a sensitivity evaluation of the measuring system is necessary and shall be carried out according to Clause 7.

4.3 Test objects

4.3.1 General

Test objects behave predominantly as inductive, capacitive or distributed equivalent impedances according to the voltage supply frequency content. For some test objects, whether they are predominantly inductive, capacitive or distributed, impedances can depend on the PD detection frequency range (not only on the voltage supply frequency). Test objects with distributed behaviour have transmission line characteristics which can cause attenuation and distortion of the PD pulses as the pulses propagate through the test object. The following classification is effective only for low-frequency, narrow-band measurements.

4.3.2 Inductive test objects

Types of inductive test objects can include:

– stator and rotor windings
– inductive reactors
– transformer windings
– motorettes and formettes: see IEC 60034-18-1

4.3.3 Capacitive test objects

Types of capacitive test objects can include:

– twisted pairs of winding wire
– capacitors
– packaging of switching devices
– power electronics modules and substrates
– isolated heat sinks
– main wall insulation models in stator coils and bars
– printed circuit boards
– optocouplers

4.3.4 Distributed impedance test objects

The following test objects can have distributed equivalent impedance properties:

– cables
– busbars
– stator and rotor windings
– transformer windings
– turn insulation of stator and rotor windings
– bushings with capacitive voltage stress control.

4.4 Voltage impulse generators

4.4.1 General

Voltage impulse generators used in this document shall generate short rise time and repetitive voltage impulses with a low noise level. For a short rise time of impulses, semiconductor devices can be used for switching in addition to conventional sphere electrode gaps. For repetitive impulses, the main capacitor shall be charged from a DC power supply in a short period of time. The ranges of rise time, repetition frequency and other parameters are described in 4.4.2.

The polarity of successive voltage impulses is important for PD behaviour. To simulate the turn-to-turn voltage of a motor driven by a PWM phase voltage, a bipolar repetitive voltage impulse voltage is preferable. When a bipolar generator is hard to obtain, a unipolar repetitive voltage impulse generator can be used.

For PD measurements, voltage impulse generators shall suppress noise emission by means of sufficient electromagnetic shielding.

4.4.2 Voltage impulse waveforms

For the purpose of comparison between different insulating materials or design solutions, partial discharge measurements can be performed using appropriate voltage supply waveforms. The specification of the voltage impulse generator shall include amongst other factors:

– impulse voltage rise time
– impulse voltage polarity
– impulse voltage repetition rate
– impulse voltage width
– impulse duty cycle

Examples are given in Table 1. Rise times as short as 20 ns are exhibited by devices employing wide band gap semiconductor materials, e.g. SiC or GaN.

Table 1 – Example of parameter values of impulse voltage waveform without load

Characteristic	Range
Rise time	0,02 µs to 1 µs
Repetition rate	1 Hz to 10 000 Hz
Voltage impulse width	0,08 µs to 25 µs
Shape	Square or triangular (preferred)
Polarity	Unipolar or bipolar (preferred)

The voltage impulse waveform depends not only on the voltage impulse generator specification but also on sample impedance. The voltage impulse waveform will change significantly with load. The voltage impulse generator shall be designed to deliver the required wave shape to the load. As the capacitance of the sample increases, the rise time of the voltage impulse increases in general. The inductive test object, or distributed equivalent impedance mentioned in 4.3.4, can cause damped oscillation after the voltage impulse waveform in addition to the change of rise time. Examples of these distortions to the waveform, due to variations in sample impedance, can be found in IEC TS 60034-27-5:2021, 4.2.2. It is important to check and record the waveform of the impulse voltage across the tested electrical insulation, at the test object itself. In this case, it is strongly recommended that impulse and PD waveforms are observed with a wide band oscilloscope with at least 100 MHz bandwidth. It is noted that PD can occur during the voltage oscillation following the first impulse.

4.5 Effect of testing conditions

4.5.1 General

In general, PD-associated quantities can depend upon specific features of the impulse waveform, for example the impulse rise time, the impulse decay time, the impulse repetition rate, the polarity and the number of oscillations in the impulse.

4.5.2 Effect of environmental factors

In general, PD-associated quantities can be affected by the following factors:

- temperature
- humidity
- atmospheric pressure
- type of environment gas
- degree of contamination of the test object

NOTE PD phenomena can change and exhibit longer rise times in the case of high altitude, i.e., lower pressure.

4.5.3 Effect of testing conditions and ageing

PD-associated quantities can be affected by

- voltage distribution
- position of PD occurrence
- previous voltage applications as well as the time between voltage applications
- operation time or time under stress of the test object

In addition, they can vary as ageing of the electrical insulation occurs, that is, during operation of the EIS.

5 PD detection methods

5.1 General

Any PD pulse detection system where the test object is excited by voltage impulses requires strong suppression of the residual voltage impulse, measured by the PD detection circuit, and negligible suppression of the PD pulse. The PD pulse shall have a magnitude after processing by the detection system that is greater than the residual transmitted voltage impulse. The amount of impulse voltage suppression required will be dependent on the test voltage and the rise time of the impulse.

As the impulse voltage increases in amplitude, greater suppression is required in order to ensure that important PD pulse magnitudes are higher than the residual transmitted voltage impulse on the output of the detector. Similarly, as the rise time of the applied impulse voltage becomes shorter, the suppression shall be greater, due to the increased overlap of frequency spectra of supply impulse and PD pulse (see Annex A). PD pulse coupling devices shall be designed to ensure that important PD pulse magnitudes are higher than the residual transmitted voltage impulse on the output of the detector, or that the residual is clearly distinguishable from the PD pulses.

Annex A provides indications of the voltage impulse suppression action required by the coupling device. Suggestions for the amount of supply voltage impulse suppression necessary as a function of impulse magnitude and rise time are given.

Examples of PD pulses extracted from a supply voltage impulse through filtering techniques are reported in Annex B.

5.2 PD pulse coupling and detection devices

5.2.1 Introductory remarks

PD current or voltage pulses in a test object can be detected either by means of high-voltage capacitors, high-frequency current transformers (HFCTs) or electromagnetic couplers (e.g. antennae). The detectors, in conjunction with the rest of the measuring system, shall be able to suppress the impulse voltage to a magnitude less than that expected from the PD pulse (e.g. using appropriate filters).

Short low-inductance connections between the supply, the test object and the PD detector are required, since the voltage impulses and PD pulses contain high-frequency components. The impulse supply shall be as physically close to the test object as possible, in order to prevent attenuation and dispersion of the applied impulse due to the equivalent transmission parameters of the connecting leads. Since the PD is measured with a UWB detection system, earthing of the test object shall be made directly to the impulse voltage supply, with leads as short as possible and with low inductance. It is recommended that lead lengths should not exceed 1 m.

The following circuits are applicable for PD pulse detection.

5.2.2 Coupling capacitor with multipole filter

A coupling capacitor with a voltage rating exceeding that of the expected applied impulse voltage together with a filter that strongly attenuates the test voltage impulses can be used. The filter shall have at least three poles and special measures to inhibit cross-coupling of the input signal to the output. The filter can be designed using passive or active filtering technology. The coupling capacitor is connected to the test object high-voltage terminal (Figure 1). Annex A shows a schematic example of filter behaviour. Figure 2 reports an example of the ideal frequency spectra of PD pulse and impulse voltage before and after filtering for an 8th order filter. Note that real filters distort the PD pulse shape and can introduce extra frequency components.

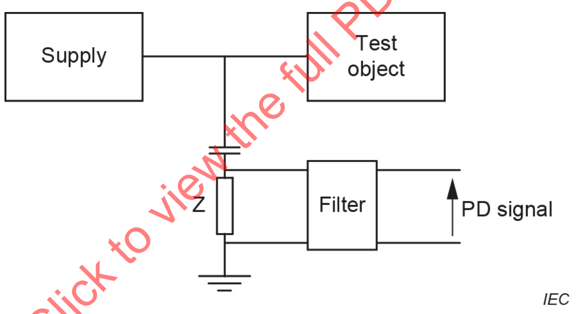
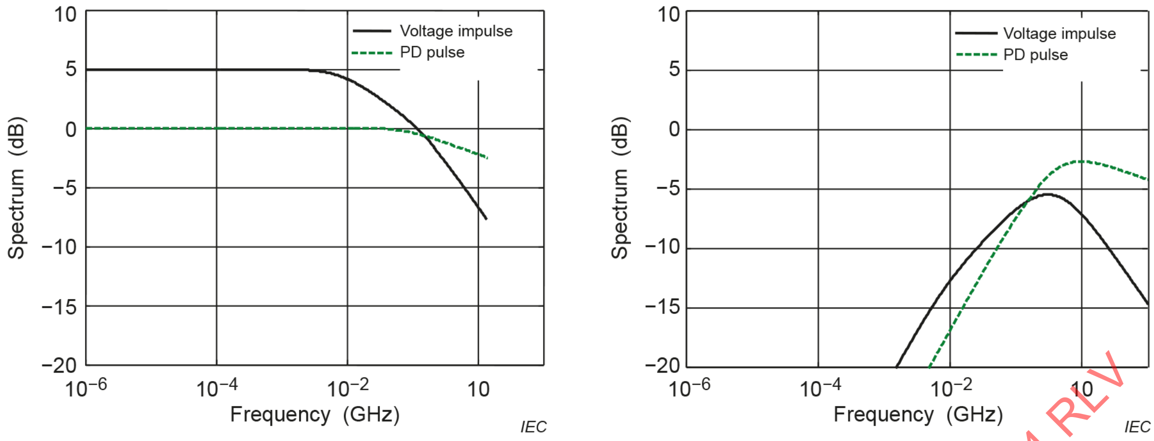


Figure 1 – Coupling capacitor with multipole filter



a) Example of voltage impulse and ideal PD pulse frequency spectra before filtering

b) Example of voltage impulse and ideal PD pulse frequency spectra after filtering

NOTE The impulse voltage rise time is 50 ns, the PD pulse rise time is 2 ns, the 8th order filter with filter cut-off frequency is equal to 500 MHz.

Figure 2 – Example of voltage impulse and ideal PD pulse frequency spectra before and after filtering

5.2.3 HFCT with multipole filter

An HFCT, together with a filter, can be used to detect PD pulses while suppressing the impulse voltage. Note that HFCTs can have a very wide range of upper cut-off frequencies that can affect the performance of this method, especially with impulse voltage rise times < 100 ns. The HFCT shall have a higher cut-off frequency than the voltage impulse frequency. The filter shall have at least three poles and special measures to inhibit cross-coupling of the input signal to the output. The filter can be implemented using passive or active filtering technology. The HFCT can be placed over the high-voltage cable between the impulse supply and the test object (Figure 3). In this case, the HFCT shall have sufficient electrical insulation to ensure that breakdown between the cable and the HFCT does not occur. Alternatively, the HFCT can be connected between the test object and earth (Figure 4). Only low-voltage insulation is then required. The latter arrangement is effective, in general, only if the metallic enclosure of the test object can be isolated from earth. Annex A shows a schematic example of filter behaviour.

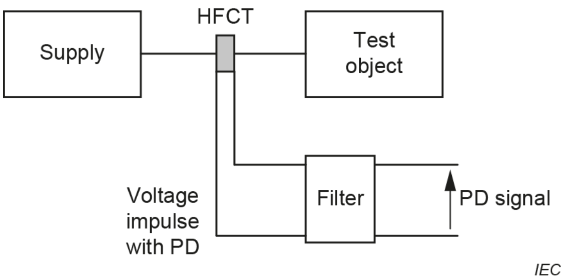


Figure 3 – HFCT between supply and test object with multipole filter

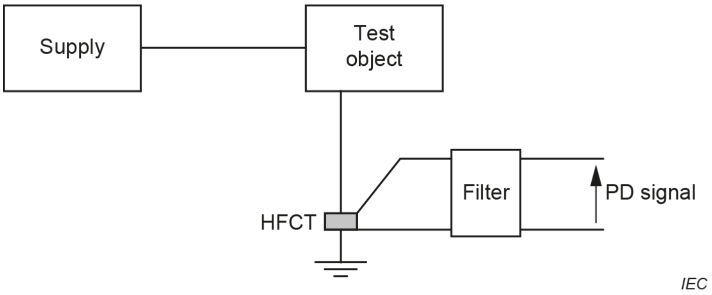


Figure 4 – HFCT between test object and earth with multipole filter

5.2.4 Electromagnetic couplers

Antenna-type couplers can be used to separate impulses from the supply from PD originating in the test object (Figure 5).

Various antenna-type couplers can be used to detect an electromagnetic signal from the partial discharge site in the test object. For the separation of the PD signal from the impulse voltage, the couplers shall have suitable frequency characteristics.

An ultra-wide band (UWB) coupler can detect a PD signal with impulse noise. To suppress the impulse voltage, an electromagnetic coupler with a fixed coupling impedance to the lead from the impulse supply to the test object can be effective (Figure 5).

Examples of noise levels of electromagnetic PD couplers are provided in Annex D.

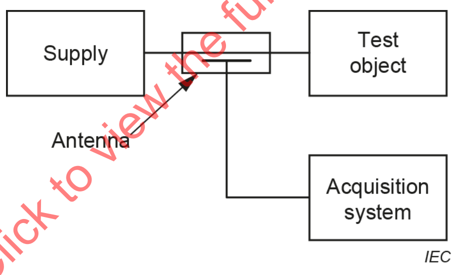


Figure 5 – Circuit using an electromagnetic coupler (e.g. an antenna) to suppress impulses from the test supply

5.2.5 Electromagnetic UHF antennae

Alternatively, an electromagnetic UHF antenna can detect the radiated electromagnetic signals propagating through free space from the PD site in the test object (Figure 6). If the antenna has UWB characteristics including lower frequency component of voltage impulses, a filtering function is necessary to suppress the residual signal inside the acquisition system. Some double-ridged guide antennae (horn antennae) have a cut-off frequency above 0,5 GHz which do not require filters. UHF antennae with narrow-band characteristics, the centre frequency of which is higher than those of voltage impulse also do not require a filter for the same reason. Note that the coupling efficiency will depend on the distance between the PD site and the antenna as well as the presence of any metallic shielding between the PD site and the antenna.

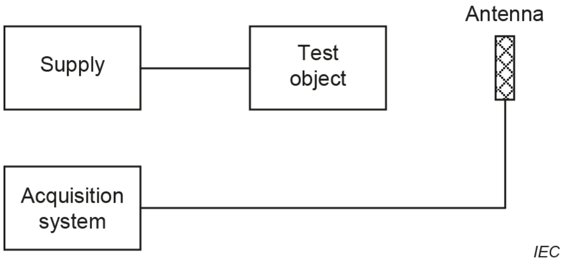


Figure 6 – Circuit using an electromagnetic UHF antenna

6 Measuring instruments

The results of a PD test are the RPDIV and RPDEV. The PD pulse repetition rate, the largest peak PD pulse magnitude at a specified test voltage and the test conditions can be measured as well. It should be pointed out that PD magnitude is only a relative measure of PD activity, given that PD pulses are attenuated and distorted when they travel from the source to the measurement point.

The PD signal output from the coupler and detection system can be recorded on a digital oscilloscope or pulse magnitude analyser. When using an oscilloscope, the PD output is normally displayed on one channel while a reduced magnitude version of the applied impulse voltage is recorded on another channel (Annex B). The magnitudes of the PD pulses as well as the temporal position in which they occur with respect to the impulse voltage are recorded. Note that the retrigger rate of the oscilloscope is recommended to be higher than that of the impulse voltage repetition rate.

Electronic pulse magnitude analysers can be used to measure the magnitude of the PD pulses and their repetition rate.

Typical test circuits are shown in Figure 1 to Figure 6.

7 Sensitivity check of the PD measuring equipment and high voltage source generator

7.1 General

The RPDIV, RPDEV and PD-associated quantities depend on the sensitivity of the measuring system to PD and how well the PD pulses can be distinguished from other electrical interference or noise (such as the residual signal from the voltage impulse itself). Thus the sensitivity of the PD measuring system shall be assessed and recorded. The sensitivity is measured in mV.

NOTE The PD is not measured in pC, since the procedure of IEC 60270 cannot be used for UWB PD detection systems (integration of the pulse current to yield the apparent charge cannot be performed as indicated in IEC 60270).

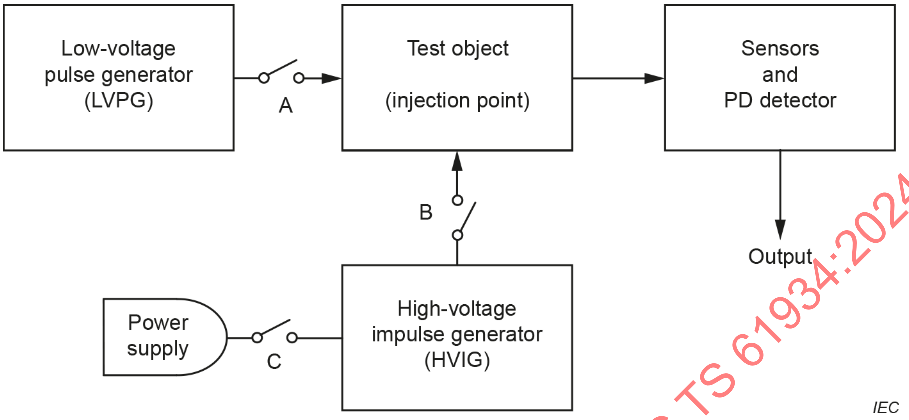
7.2 Test diagram for sensitivity check

A sensitivity check of a PD measuring system is performed using the test diagram shown in Figure 7. The output of the PD detector is measured step by step with different combinations of the low-voltage pulse generator (LVPG) and high-voltage impulse generator (HVIG) connected to a test object.

Pulse waveform from the LVPG shall be selected with respect to both the original PD pulses and the frequency limit of the detecting system. The rise time of the pulse waveform can be selected around $1/f$, where f is the upper frequency limit of the PD detection system. For example, if the upper cut-off frequency of the PD detection system is 100 MHz, the rise time of LVPG can be less than 10 ns.

The location where the LVPG is connected to the circuit of the test object can be used as injection point. For test objects having distributed equivalent impedance, such as motor and transformer windings, the propagation effects of PD pulses can cause strong attenuation of the high-frequency components, thus only PD close to the measurement point can be observed.

PD sensitivity and the effect of noise can be assessed in steps, as addressed in Figure 7 and 7.3 to 7.5:



	A	B	C	Subclause
PD detection sensitivity check	Closed	Opened and Closed	Opened	7.3
Background noise check	Closed	Closed	Opened	7.4
Detection system noise check	Opened	Closed	Closed	7.5

Figure 7 – Test diagram for sensitivity check

7.3 PD detection sensitivity check

Disconnect the HVIG from the test object and measure the output of the PD detector while increasing the output of the LVPG. Measure the minimum output voltage of the LVPG at which the PD detector shows a detectable signal. This is the sensitivity of the PD detection system.

7.4 Background noise check

Connect the unenergized HVIG to the test object and measure the output of the PD detector while increasing the output of the LVPG. Measure the minimum output voltage of the LVPG at which the PD detector shows a detectable signal. This is the background noise of the PD detection circuit.

7.5 Detection system and HVIG noise check

Disconnect the LVPG and apply the voltage impulse of the HVIG to the test object. Measure the output of the PD detector under PD-free conditions. For example, replace the test object with a PD-free capacitance that has about the same high-frequency capacitance as the test object. Record the output of the PD detector with voltage impulse used for the PD measurement. This is the detection system noise, or residual of the HVIG.

NOTE It is possible that the test described in 7.5 will not be feasible if appropriate capacitors are not available. In such cases, reference can be made to the results of 7.3.

7.6 Sensitivity report

PD sensitivity is presented as the relation between the outputs of the LVPG and HVIG. An example of the possible behaviour of PD sensitivity is shown in Figure 8.