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TECHNICAL SPECIFICATION

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

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colour inside

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

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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