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TECHNICAL SPECIFICATION

SPECIFICATION TECHNIQUE

colour inside

High voltage test techniques – Measurement of partial discharges by electromagnetic and acoustic methods

Techniques d'essais à haute tension – Mesurage des décharges partielles par méthodes électromagnétiques et acoustiques

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HIGH VOLTAGE TEST TECHNIQUES – MEASUREMENT OF PARTIAL DISCHARGES BY ELECTROMAGNETIC AND ACOUSTIC METHODS

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62478, which is a technical specification, has been prepared by IEC technical committee 42: High-voltage and high-current test techniques.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
42/325/DTS	42/333/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Partial discharges (PDs) generate electromagnetic and acoustic waves, emit light and produce chemical decomposition of insulation materials; these physical and chemical effects can be detected by various diagnostic methods and appropriate sensing elements (sensors). Besides the so-called ‘conventional’, electrical method described in IEC 60270, it is possible to detect and measure PDs with various ‘non-conventional’ methods (see Annexes A and B).

There is a special need to give recommendations for two used non-conventional methods, acoustic and electromagnetic ones, and this document is the first step in this direction.

HIGH VOLTAGE TEST TECHNIQUES – MEASUREMENT OF PARTIAL DISCHARGES BY ELECTROMAGNETIC AND ACOUSTIC METHODS

1 Scope

This document is applicable to electromagnetic (HF/VHF/UHF) and acoustic measurements of PDs which occur in insulation of electrical apparatus.

This specification deals with a large variety of applications, sensors of different frequency ranges and differing sensitivities. The tasks of PD location and measuring system calibration or sensitivity check are also taken into account.

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 TS 60034-27, *Rotating electrical machines – Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines*

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 terminological databases for use in standardization at the following addresses:

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

3.1
partial discharge
PD
complex physical phenomena consisting of a localized electrical discharge caused by partial breakdown of an insulating medium under the influence of the local electrical field stress

3.1.1
partial discharge current pulses
PD current pulses
extremely fast current pulses, whose rise time and pulse width depend on the discharge type, defect type, geometry and gas pressure

3.1.2
electromagnetic effects of PD
PD current pulses resulting in the emission of transient electromagnetic waves at very high frequency ranges

Note 1 to entry: The electromagnetic waves generated by PD signals propagate through the dielectric materials which surround the PD source; these signals can be detected by various antennas or transducers (sensors).

3.1.3
acoustic effects of PD
transient acoustic wave resulting from the super-heated gas channel produced, similar to lightning, by a PD current pulse

3.1.4
detection and measurement of effects of PD
activities that can be detected and measured using the following methods:

- electrical methods: conventional (according to IEC 60270) or electromagnetic (HF, VHF and UHF) methods
- acoustical methods
- optical methods
- chemical methods

Note 1 to entry: Measurement of PD activity is an important criterion for the evaluation of the dielectric condition of insulation systems of electrical apparatus.

Note 2 to entry: This document only discusses electromagnetic and acoustic methods.

3.2
PD measuring system
measuring system for unconventional PD detection consisting of sensing element, transmission path and measuring instrument

3.2.1
sensing element
sensor or antenna and connection link (e.g. electric or fiber optical cable) to the measuring instrument

3.2.2
transmission path
path characterized by the following parameters:

- distance from the location of the PD to the sensor
- type of PD signal transmission (conducted or field coupled)
- propagation characteristic of dielectric material(s) such as dispersion, attenuation, resonances, reflection, diffraction

3.2.3
PD measuring instruments
instruments that utilize various combinations of digital and analog techniques to display partial discharge signals in order to assist in their interpretation and evaluation

Note 1 to entry: The measured PD signals are influenced by different behavior of dielectric medium (gaseous, liquid or solid) for acoustic or electromagnetic signal propagation and offer different possibilities for data evaluation in the time and frequency domains, depending on different bandwidths of the sensing element and measuring instrument.

3.3
PD measurement system checks
complex combination of equipment whose proper and correct operation is ascertained by performance checking methods

3.3.1
performance check
check serving to assure correct functioning of the entire measuring system, from sensor to PD measuring instrument, typically by injection of an artificial signal

Note 1 to entry: The time and frequency domain characteristics of the injected artificial signal(s) used for the performance check are chosen to appropriately emulate the PD phenomenon being measured along with the parameters of the PD measuring system, e.g. bandwidth, type of sensor, etc.

Note 2 to entry: In carrying out the performance check, it is not necessary to emit electromagnetic or acoustic waves into the test object, that is to say, single-port checks are possible.

3.3.2
sensitivity check
check used to establish the quantitative correlation between the apparent charge of the PD event (in units e.g. pC) and the quantity measured and displayed by the electromagnetic or acoustic PD measurement system, typically by injection of an artificial signal

Note 1 to entry: The time and frequency domain characteristics along with the amplitude of the artificially injected signal(s) used for the sensitivity check are typically derived from a laboratory measurement in which the output of the electromagnetic or acoustic PD measurement system is simultaneously compared with the measurement of an actual PD source in an IEC 60270 test set-up.

Note 2 to entry: In carrying out the sensitivity check, it is necessary to emit electromagnetic or acoustic waves into the test object in order to emulate actual PD signals.

3.4
quantities and units

3.4.1
sensor output voltage
response of electromagnetic or acoustic sensor expressed in V or dBmV

3.4.2
sensor effective aperture
ratio between maximum sensor output power and power density of the incoming electrical field

Note 1 to entry: The sensor effective aperture is expressed in mm^2.

Note 2 to entry: In this case the measured quantity is the pulse energy arising from a transient electric field produced by the PD signal.

3.4.3
sensor effective height
sensor effective length
ratio between the sensor's output voltage magnitude (in V) to the incoming electric field strength (in V/mm)

Note 1 to entry: The sensor effective height is expressed in mm^2.

Note 2 to entry: The typical output consists of a transient voltage pulse.

3.4.4
antenna factor
inverse of the effective height or length defined as ratio between incoming electric field strength (in V/mm) to the sensor's output voltage magnitude (in V)

Note 1 to entry: The antenna factor is expressed in mm^{-1}.

4 Electromagnetic PD phenomena

4.1 Physical background

The short rise times of PD pulse currents (<1 ns) excite electromagnetic waves ranging from HF up to the UHF range (3 MHz up to 3 GHz) and exceeding in several insulation materials. The propagation velocity of the resulting UHF waves is dependent on the resulting ε_r, e.g. in oil estimated to about $2/3 \times c_0$ or 2×10^8 m/s (c_0 denoting the speed of light in a vacuum). The measurement frequency range depends on the specific apparatus.

4.2 Transmission aspects

Metal parts of apparatus enclosures can act as waveguides or resonators and effects such as dispersion, attenuation, cavity resonances, standing waves, reflection and diffraction all influence the propagation of the PD pulse signals and the pulse characteristics respectively.

Transmission path characteristics typically depend on

- material characteristics and dimensions,
- electromagnetic impedance and dielectric behavior of the surrounding dielectric medium,
- distance between source and sensor.

4.3 Measuring systems

4.3.1 Electric/electromagnetic fields

Non-conventional PD measurement systems based on radio frequency (RF) techniques operate in two different modes; one uses the frequency range in the HF/VHF area and the other uses the frequency range in the UHF area. In the HF and VHF range electric, magnetic and electromagnetic field (e.g. TEM_{00}) can typically be measured. In the UHF range predominantly the electromagnetic field modes (e.g. TEM_{xx}) are measured.

4.3.2 Frequency ranges

HF nominally covers the frequency range from 3 MHz to 30 MHz and VHF the frequency range from 30 MHz to 300 MHz. Typical measuring bandwidths for narrow band measurement in the HF and VHF range up to 3 MHz, for wide band measurement in the VHF range, typically 50 MHz and higher, respectively.

The UHF frequency range is nominally between 300 MHz to 3 GHz. The measuring mode applied in the UHF range is typically either the zero span mode at one or several individual frequencies with the resolution bandwidth typically between 3 MHz to 6 MHz, or the full bandwidth mode.

4.3.3 Sensors

4.3.3.1 General

Typically used sensors in the HF and VHF frequency range are based on capacitive, inductive and electromagnetic detection principle.

In the UHF frequency range, the sensors used are typically near-field antennas such as disc or cone shaped sensors along with field grading electrodes.

The sensor output signals are typically in the form of high frequency oscillating pulses. These signals can be displayed in the time domain as oscillating pulses with e.g. the maximum of the envelope the measured output quantity. In the frequency domain the signals are typically displayed as the spectrum resulting from the transient pulses. The measured output quantities in the frequency domain are the maximum magnitudes of the related characteristic spectral frequencies.

Sensors can be characterized as high frequency impedances consisting of a combination of capacitive, inductive and resistive component values. This high frequency impedance and the corresponding measuring frequency range determine the sensor's measuring mode and the resulting output is a function of its impedance and the magnitude of the related transient field component arising from the PD signal.

The measured quantity can be a transient voltage or current pulse value.

4.3.3.2 Type and characteristic

Some examples of sensors predominantly used in HF up to VHF frequency ranges:

- capacitors;
- current transformers;
- Rogowski coils;
- directional electromagnetic couplers;
- film electrodes;
- axial field couplers;
- transient earth voltage (TEV) probes;
- resistive couplers.

Some examples of sensors mainly used in the UHF range:

- disc and cone-shaped sensors;
- external window couplers;
- hatch couplers;
- barrier sensors;
- field grading electrodes;
- wave guide sensors;
- UHF antennas;
- directional electromagnetic couplers.

The output quantity of the sensors can be classified into the following groups:

- frequency characteristic, i.e. transfer function;
- polarity maintaining;
- directional;
- field magnitude dependent;
- sensitivity;
- installation dependent on geometry and location;
- mode dependent;
- transfer characteristic;
- monitored area which shall be in the range of the receiving area of the sensors.

4.3.3.3 Position

Sensors can be installed inside the high voltage component or externally mounted at dielectric apertures as e.g. inspection windows or valves. The sensors should be installed as close as possible to the particular PD detection area and inside the metallic enclosure or screen of the high voltage component.

In larger high voltage apparatus or systems it is beneficial to install multiple sensors to improve measurement sensitivity and to help in PD source detection and location. Multiple sensors can also be used for the sensitivity check of the arrangement.

The sensors should not have any negative impact to the dielectric design and functionality of the high voltage component.

4.3.4 Instrument related influences

4.3.4.1 Frequency and time domain signal processing

The output signals of the sensors can be processed in the time or frequency domain (see Figure 1).

Broadband time domain signal processing better represents the complete wave shape of the PD related pulse and enables detailed analysis of wave shape characteristics of individual single pulses (e.g. PD reflectometry, PD pulse shape analysis, etc.).

Narrow-band frequency domain signal processing may allow a better noise suppression capability should noise and external disturbances be present and consequently features an improved sensitivity in noisy environments. A single pulse wave shape analysis is not fully possible since bandwidth limitations in the processing path corrupts pulse shapes although derived statistical analysis as e.g. phase resolved PD pattern can be applied.

4.3.4.2 Processing bandwidth

The time domain processing uses a wide or ultra wide frequency range for signal processing. Filters to suppress single or multiple interferences are applied before signal processing. The signal is then processed from a wide band peak detector and displayed in the time domain typically synchronized with the phase of the applied high voltage.

Frequency domain processing is typically carried out either at various frequency spans or in zero span mode, essentially a tuned receiver centered at a fixed center frequency with a specific resolution bandwidth. The output of this zero span mode is typically displayed in the time domain e.g. similarly to a typical oscilloscope display or e.g. as a PD phase resolved pattern.

The wideband spectral mode processes the output of either a swept frequency receiver (i.e. super heterodyne) or a so-called ‘real-time spectrum analyzer’ as a power spectrum versus frequency. This can also be displayed as a spectrum of the measured signals (PD and other signals).

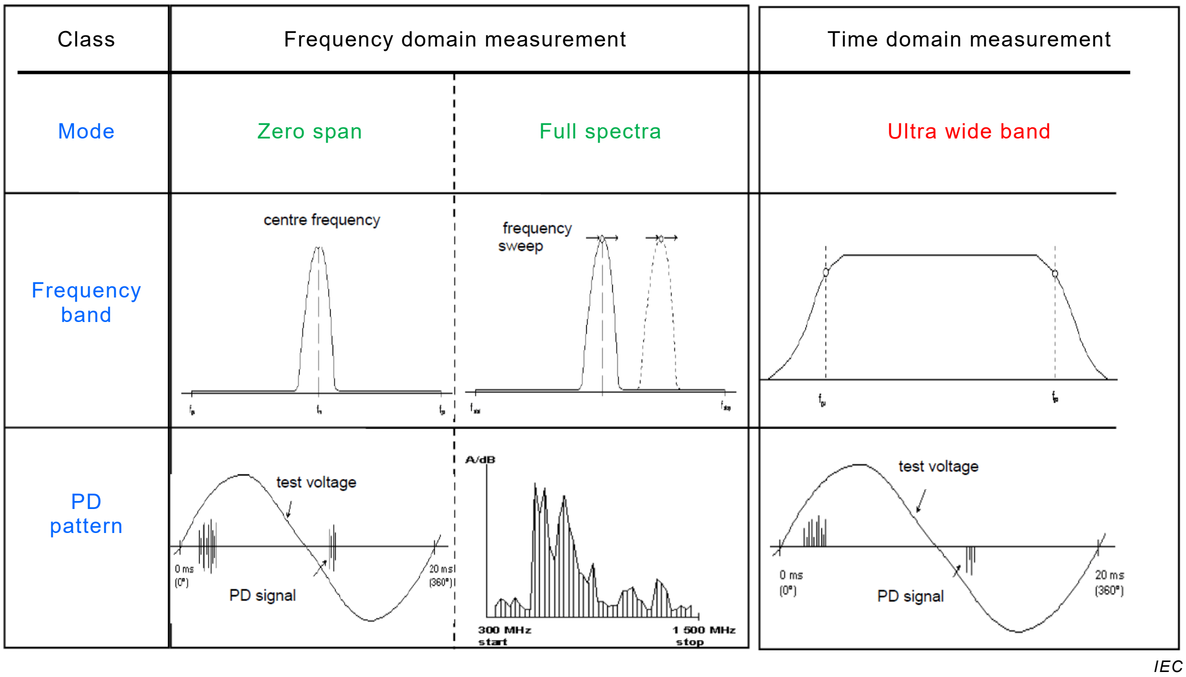

Figure 1 – Classification of instruments for signal processing

4.3.5 Instrument quantities

In HF and VHF ranges the instrument quantities are typically amperes or volts considering the application of inductive and capacitive couplers. The output of UHF sensors is also typically a voltage signal. These values measured by the instruments are in linear correlation to the measured electromagnetic field mode and the sensor transfer characteristic.

Derived quantities however should be in correlation to the PD parameters. This can be linear, when using the direct output voltage of the UHF sensor, or quadratic, e.g. by processing the power quantity (W) of the sensor signal, or the signal energy (J) as related to the defined measuring resistance

NOTE The UHF sensor can be described with its antenna characteristic in terms of its effective height (m), effective aperture (mm^2), antenna factor (1/m) or antenna gain (dBi).

4.3.6 Performance and sensitivity check

For detecting and measuring the electromagnetic waves emitted by partial discharges, different aspects of the method are shown in Figure 2.