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TECHNICAL SPECIFICATION

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Rotating electrical machines –
Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines

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Rotating electrical machines –
Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines

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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 60034-27-2, which is a technical specification, has been prepared by IEC technical committee 2: Rotating machinery.

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

Enquiry draft	Report on voting
2/1636/DTS	2/1649/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.

NOTE A table of cross-references of all IEC TC 2 publications can be found on the IEC TC 2 dashboard on the IEC website.

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- replaced by a revised edition, or
- amended.

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INTRODUCTION

For many years, the measurement of partial discharges (PD) has been employed as a sensitive means of assessing the quality of new insulation as well as a means of detecting localized sources of PD in used electrical winding insulation arising from operational stresses in service. Compared with other dielectric tests (i.e. the measurement of dissipation factor or insulation resistance) the differentiating character of partial discharge measurements allows localized weak points of the insulation system to be identified. Especially on-line PD measurements are not only sensitive to partial discharges but also to various arcing and sparking phenomena.

With regard to condition assessment of rotating machines, the measurement of partial discharges can provide information on:

– points of weakness in the insulation system;
– degradation processes;
– maintenance measures and intervals between overhauls.

Although the PD testing of rotating machines has gained widespread acceptance, it has emerged from several studies that not only are there many different methods of measurement in existence but also the criteria and methods of analysing and finally assessing the measured data are often very different and not really comparable. Consequently, there is a need to give some guidance to those users who are considering the use of PD measurements to assess the condition of their insulation systems.

Partial discharge testing of stator windings can be divided into two broad groups:

a) off-line measurements, in which the stator winding is isolated from the power system and a separate power supply is employed to energize the winding;
b) on-line measurements, in which the rotating machine is operating normally and connected to the power system.

Both of these approaches have advantages and disadvantages with respect to one another. A detailed discussion of PD off-line testing is provided in IEC/TS 60034-27, whereas this technical specification is confined to on-line techniques. The approach to deal with PD on- and off-line measurement techniques in two different technical specifications is considered necessary to render each specification sufficiently concise to be of use by non-specialists in the field of PD measurement.

PD on-line measurements are recorded with the rotating machine experiencing all of the operating stresses; thermal, electrical, environmental and mechanical. On-line PD testing has the following advantages:

– the voltage distribution across the winding is the same as during operation;
– the measurements are made at operating temperature;
– normal mechanical forces are present.

Due to the realistic stress impact on the winding during measurement and due to the fact that the measurement is performed during normal operation, on-line PD testing has become very popular. Since no service interruption is required, once the PD sensors are installed during a scheduled unit outage, and no external power source is needed, on-line testing is usually cost effective compared to off-line PD measurement. Condition changes of the stator winding insulation system can be identified and evaluated at an early stage based on a real-time condition assessment and thus condition-based and predictive maintenance strategies can be improved.

Empirical limits verified in practice can be used as a basis for evaluating test results. Furthermore, PD trend evaluation and comparisons with machines of similar design and similar insulation system measured under similar conditions, using the same measuring equipment, are recommended to ensure reliable assessment of the condition of the stator winding insulation.

This technical specification does not deal with online PD measurements on converter driven electrical machines because different measuring techniques are needed to distinguish between noise from the converter and PD from the winding. For this purpose IEC/TS 61934 may apply.

Limitations

On-line PD tests on stator windings produce comparative, rather than absolute measurements. This creates a fundamental limitation for the interpretation of PD data, and implies that simple limits for allowable PD cannot be established unless many precautions are taken. For the same reasons, PD acceptance criteria for new or rewound stator windings cannot be established unless many precautions are taken. The reasons for the difficulty to set absolute limits for PD include:

- There are many types of PD sensors as well as recording and analyzing instruments. Generally they are incompatible and will produce different results for the same PD activity.
- Even with the same measuring system, partial discharges will interact with the winding capacitance, inductance and/or surge impedance to produce different voltage and current pulses. Thus PD measurements from machines with different ratings and/or winding connections may produce different PD results, even though the actual amount of damage may be the same.
- Different types of defects can produce different PD magnitudes, even with the same amount of damage.
- PD may occur close or far from the PD sensor. In general if the PD is physically far from the PD sensor, it will produce a smaller response at the PD sensor due to attenuation.

Users should also be aware that there is no evidence that the time to failure of the stator winding insulation can be estimated using any PD quantity, even in combination with other electrical tests. Also, determining the root cause of an insulation deterioration process using pattern recognition, especially if more than one process is occurring, is still somewhat subjective, although the technology is evolving rapidly.

Noise and disturbance may have a great impact on the detected signals, especially for on-line PD measurements. Cross-coupling of PD and noise on one phase can obscure PD on another phase. With some measuring systems, this can make objective interpretation of the test results difficult.

Users of PD measurement should be aware that, due to the principles of the method, not all insulation-related problems in stator windings can be detected by measuring partial discharges, e.g. insulation failures involving continuous leakage currents due to conductive paths between different elements of the insulation or pulse-less discharge phenomena.

ROTATING ELECTRICAL MACHINES –

Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines

1 Scope

This part of IEC 60034, which is a technical specification, provides a common basis for

- measuring techniques and instruments;
- the arrangement of the installation;
- normalization and sensitivity assessment;
- measuring procedures;
- noise reduction;
- the documentation of results;
- the interpretation of results;

with respect to partial discharge on-line measurements on the stator winding insulation of non-converter driven rotating electrical machines with rated voltage of 3 kV and up. This technical specification covers PD measuring systems and methods detecting electrical PD signals. The same measuring devices and procedures can also be used to detect electrical sparking and arcing phenomena.

NOTE The main differences between on-line measurements and off-line measurements are due to a different voltage distribution along the winding and various thermal and mechanical effects related to the operation, like vibration, contact arcing or temperature gradients between stator copper and stator iron core. Furthermore, especially for hydrogen-cooled machines the gas and the gas pressure is different for off- and on-line PD measurements.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

3 Terms and definitions

For the purposes of this document the general terms and definitions for partial discharge measurements given in IEC 60270 apply, together with the following.

3.1
off-line measurement
measurement taken with the rotating machine at standstill, the machine being disconnected from the power system

Note 1 to entry: The necessary test voltage is applied to the winding from a separate voltage source.

3.2
on-line measurement
measurement taken with the rotating machine in normal operation

3.3
periodic on-line PD measurement
on-line PD measurement performed on the machine at regular intervals

3.4
continuous on-line PD measurement
on-line PD measurement performed on the machine with a measuring device continuously acquiring PD data

3.5
stress control coating
paint or tape on the surface of the groundwall insulation that extends beyond the conductive slot portion coating in high-voltage stator bars and coils

Note 1 to entry: The stress control coating reduces the electric field stress along the winding overhang to below a critical value that would initiate PD on the surface. The stress control coating overlaps the conductive slot portion coating to provide electrical contact between them.

3.6
conductive slot coating
conductive paint or tape layer in intimate contact with the groundwall insulation in the slot portion of the coil side, often called 'semiconductive' coating

Note 1 to entry: This coating together with adequate slot design provides electrical contact to the stator core, without shorting the core laminations.

3.7
corona discharge
visible partial discharge adjacent to the surface of a conductor in gases

3.8
slot discharges
discharges that occur between the outer surface of the slot portion of a coil or bar and the grounded core laminations due to high voltage

3.9
vibration sparking
interrupted surface currents between the outer surface of the slot portion of a bar and the grounded core laminations due to axially induced voltages on the conductive slot coating combined with bar vibrations

3.10
internal discharges
discharges that occur within the insulation system

3.11
surface discharges
discharges that occur on the surface of the insulation or on the surface of winding components in the winding overhang or the active part of the machine winding

3.12
pulse magnitude distribution
number of pulses within a series of equally-spaced windows of pulse magnitude during a predefined measuring time

3.13
pulse phase distribution
number of pulses within a series of equally-spaced windows of phase during a predefined measuring time

3.14
phase resolved partial discharge pattern
PD distribution map of PD magnitude vs. a.c. cycle phase position, for visualization of the PD behaviour during a predefined measuring time

3.15
PD sensor
general type of transducer, which can be used to detect PD signals from the machine winding

Note 1 to entry: A PD sensor typically consists of a high voltage coupling capacitor of low inductance design and a low voltage coupling device in series.

3.16
coupling device
usually an active or passive four-terminal network that converts the input currents to output voltage signals

Note 1 to entry: These signals are transmitted to the measuring device by a transmission system. The frequency response of the coupling device is normally chosen at least so as to efficiently prevent the test voltage frequency and its harmonics from reaching the measuring device.

3.17
resistance temperature detector
RTD
temperature detector inserted into the stator winding, usually between the top and bottom bar or between embedded coil sides in a given slot

3.18
largest repeatedly occurring PD magnitude Q_m
the largest magnitude recorded by a measuring system which has the pulse train response in accordance with 4.3.3 of IEC 60270, or the magnitude associated with a PD pulse repetition rate of a specified number of pulses per second, which can be directly inferred from a pulse magnitude distribution.

Note 1 to entry: A recommended pulse repetition rate is 10 pulses or more per second.

4 Nature of PD in rotating machines

4.1 Basics of PD

Generally, partial discharges (PD) can develop at locations where the dielectric properties of insulating materials are inhomogeneous. At such locations, the local electrical field strength may be enhanced. Due to local electrical over-stressing this may lead to a local, partial breakdown. This partial breakdown is not a total breakdown of the insulation system. PD in general requires a gas volume to develop, e.g. in gas filled voids embedded in the insulation, adjacent to conductors or at insulation interfaces.

A partial discharge can occur when the local field strength exceeds the dielectric strength of the insulating material. This process may result in numerous PD pulses during one cycle of the applied voltage.

The amount of charge transferred in the discharge is closely related to the specific properties of the inhomogeneity such as the dimensions, the actual breakdown voltage and the specific dielectric properties of the materials involved, e.g. surface properties, kind of gas, gas pressure, etc.

Stator winding insulation systems for high voltage machines will normally have some PD activity, but are inherently resistant to partial discharges due to their inorganic mica components. However, significant PD in these machines is usually more a symptom of insulation deficiencies, like manufacturing problems or in-service deterioration, rather than being a direct cause of failure. Nevertheless, depending on the individual processes, PD in machines may also directly attack the insulation and thus influence the ageing process. The time to failure or failure probability may not always correlate with PD levels, but depends significantly on other factors, for example operating temperature, wedging conditions, bar vibrations, degree of contamination, etc.

The measurement and the analysis of the specific PD behaviour can be efficiently used for quality control of new windings and winding components and for early detection of insulation deficiencies caused by thermal, electrical, ambient and mechanical ageing factors in service, which might result in an insulation fault.

The main differences between on-line measurements and off-line measurements are due to a different voltage distribution along the winding and various thermal and mechanical effects related to the operation, like vibration, contact arcing or temperature gradients between stator copper and stator iron core. Furthermore, especially for hydrogen-cooled machines the gas and the gas pressure is different for off- and on-line PD measurements.

4.2 Types of PD in rotating machines

4.2.1 General

Partial discharges may develop throughout the stator winding insulation system due to specific manufacturing technologies, manufacturing deficiencies, normal in-service ageing, or abnormal ageing. Machine design, the nature of the materials used, manufacturing methods, operating conditions, etc. can profoundly affect the quantity, location, characteristics, evolution and the significance of PD. For a given machine, the existing PD sources may be identified and distinguished in many cases by their characteristic PD behaviour.

4.2.2 Internal discharges

4.2.2.1 Internal voids

Although manufacturing processes are designed to minimize internal voids, inevitably there is some void content. For example in a resin impregnated mica tape insulation system, that is commonly used in high voltage rotating machines, the mica in the insulation system prevents the partial discharges from developing into a complete breakdown. As long as internal voids are small and do not significantly enlarge, operational reliability is not reduced.

4.2.2.2 Internal delamination

Internal delamination within the main insulation can be caused by imperfect curing of the insulation system during manufacturing or by mechanical or thermal over-stressing during operation. Large voids may develop over a large surface resulting in discharges of relatively high energy, which may significantly attack the insulation. In particular, delamination will reduce the thermal conductivity of the insulation, which might lead to accelerated ageing or even a thermal runaway. Thus, delamination needs careful consideration when PD activity is being assessed.

4.2.2.3 Delamination between conductors and insulation

Thermal cycling may cause delamination at the interface of the conductor and the main insulation. This delamination can result in partial discharges which can relatively rapidly result in failure especially in multi-turn coils.

4.2.2.4 Electrical treeing

Electrical treeing in machine insulation is an ageing process in which fine erosion channels propagate through the epoxy around the mica barriers and may finally lead to electrical breakdown of the main insulation. Electrical treeing can start at any point of locally enhanced electric field within the insulation, e.g. rough structures of the inner conductor, insulation impurities, gas filled voids or delaminations in the insulation. This process is associated with internal partial discharge activity.

4.2.3 Slot discharges

Slot discharges in high voltage machines will develop when the conductive slot portion coating is damaged due to bar/coil movement in the slot or slot exit area, for example by a loss of wedging pressure due to settlement, erosion of the material, abrasion, chemical attack or manufacturing deficiencies. Higher discharges will develop when serious mechanical damage is already present, which may result in additional damage to the main insulation and eventually in an insulation fault. Slot discharges are generally caused by locally enhanced electric fields, and thus these processes occur only at the higher voltage end of each phase. The absolute time between detection of this phenomenon and final insulation failure is generally unknown. However, compared to other typical deterioration effects this time could be relatively short, especially in the presence of bar/coil vibrations. Thus, reliable detection at an early stage is necessary to decide if appropriate remedial actions are required.

4.2.4 Discharges in the end-winding

4.2.4.1 General

Partial discharges in the end-winding area may occur at several locations with high local electric field strengths. Such discharges usually occur at interfaces between different elements of the stator winding overhang.

4.2.4.2 Surface discharges

Surface discharges generally occur whenever the electrical field along a surface exceeds the breakdown field of the surrounding gas. This may occur if no stress control coating is applied or the stress control coating of the end-winding becomes ineffective because of poorly designed interfaces, contamination, porosity, thermal effects, etc. When reliable field grading is no longer assured surface discharges will develop, which may gradually erode the materials. This is normally a very slow failure mechanism, even though the PD behaviour might be subjected to relatively fast changes due to surface effects. Surface discharges usually result in a phase to ground fault.

4.2.4.3 Phase to phase discharges

PD may occur between phases, for example due to inadequate phase to phase clearances or at elements of the overhang support system like spacers or cords. Depending on specific design details these discharges may have large magnitudes and may either occur as surface discharges or internal discharges and thus the time between detection of this phenomenon and final insulation failure is uncertain. Phase to phase discharges may result in a phase to phase breakdown.

4.2.5 Conductive particles

Conductive particles, especially small particles, for example due to contamination of the winding, may result in a strong local concentration of partial discharges. This may result in a 'pinhole' in the insulation.