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

**FOREWORD** ..................................................................................................................... 5

**INTRODUCTION** .................................................................................................................. 7

1 Scope.................................................................................................................................. 7

2 Normative references ........................................................................................................ 9

3 Terms and definitions ....................................................................................................... 9

4 Nature of PD in rotating machines ................................................................................ 11

4.1 Basics of PD .................................................................................................................. 11

4.2 Types of PD in rotating machines ............................................................................. 12

4.2.1 General .................................................................................................................... 12

4.2.2 Internal discharges ................................................................................................. 12

4.2.3 Slot discharges ........................................................................................................ 13

4.2.4 Discharges in the end-winding ............................................................................. 13

4.2.5 Conductive particles ............................................................................................... 13

4.3 Arcing and sparking ....................................................................................................... 14

4.3.1 General .................................................................................................................... 14

4.3.2 Arcing at broken conductors ................................................................................ 14

4.3.3 Vibration sparking ................................................................................................. 14

5 Noise and disturbance ..................................................................................................... 14

5.1 General ........................................................................................................................ 14

5.2 Noise and disturbance sources .................................................................................. 14

5.3 Frequency domain separation .................................................................................... 15

5.4 Time domain separation ............................................................................................. 16

5.5 Combination of frequency and time domain separation .......................................... 17

5.6 Gating .......................................................................................................................... 17

5.7 Pattern recognition separation ................................................................................... 18

6 Measuring techniques and instruments ......................................................................... 18

6.1 General ........................................................................................................................ 18

6.2 Pulse propagation in windings .................................................................................... 19

6.3 Signal transfer characteristics .................................................................................... 19

6.4 PD sensors .................................................................................................................. 22

6.4.1 General .................................................................................................................... 22

6.4.2 Design of PD sensors ............................................................................................. 22

6.4.3 Reliability of PD Sensors ....................................................................................... 23

6.5 PD measuring device ................................................................................................. 23

6.6 PD measuring parameters ......................................................................................... 23

6.6.1 General .................................................................................................................... 23

6.6.2 PD magnitude .......................................................................................................... 23

6.6.3 Additional PD parameters ...................................................................................... 24

7 Installation of PD on-line measuring systems .............................................................. 24

7.1 General ........................................................................................................................ 24

7.2 Installation of PD sensors ........................................................................................... 24

7.3 Outside access point and cabling .............................................................................. 25

7.4 Installation of the PD measuring device ................................................................... 26

7.5 Installation of operational data acquisition systems ............................................... 26

8 Normalization of measurements .................................................................................... 27
8.1 General ............................................................................................................................ 27
8.2 Normalization for low frequency systems ................................................................. 27
  8.2.1 General .................................................................................................................... 27
  8.2.2 Normalization procedure ..................................................................................... 27
8.3 Normalization / sensitivity check for high & very high frequency systems .......... 29
  8.3.1 Specification for the electronic pulse generation ..................................................... 29
  8.3.2 Configuration of the machine .............................................................................. 30
  8.3.3 Sensitivity check .................................................................................................... 30
9 Measuring procedures .................................................................................................... 30
  9.1 General ..................................................................................................................... 30
  9.2 Machine operating parameters ................................................................................. 31
  9.3 Baseline measurement .............................................................................................. 31
    9.3.1 General ................................................................................................................ 31
    9.3.2 Recommended test procedure ........................................................................... 31
  9.4 Periodic on-line PD measurements .......................................................................... 32
  9.5 Continuous on-line PD measurements ..................................................................... 33
10 Visualization of measurements .................................................................................... 33
  10.1 General ................................................................................................................... 33
  10.2 Visualization of trending parameters ...................................................................... 33
  10.3 Visualization of PD patterns .................................................................................. 34
11 Interpretation of on-line measurements ........................................................................ 37
  11.1 General .................................................................................................................. 37
  11.2 Evaluation of basic trend parameters .................................................................... 37
  11.3 Evaluation of PD patterns ....................................................................................... 38
    11.3.1 General ............................................................................................................. 38
    11.3.2 PD pattern interpretation .................................................................................. 38
  11.4 Effect of machine operating factors ....................................................................... 39
    11.4.1 General ............................................................................................................ 39
    11.4.2 Machine operating factors ............................................................................... 39
    11.4.3 Steady state load conditions ............................................................................ 39
    11.4.4 Transient load conditions ............................................................................... 40
12 Test report ..................................................................................................................... 41
Annex A (informative) Examples of Phase Resolved Partial Discharge (PRPD) pattern .... 44
Bibliography ...................................................................................................................... 55

Figure 1 – Time domain disturbance separation by time of pulse arrival ....................... 16
Figure 2 – Combined time and frequency domain disturbance separation (TF-map) ........ 17
Figure 3 – Idealized frequency response of a PD pulse at the PD source and at the machine terminals; Frequency response of different PD measuring systems: a) low frequency range, b) high frequency range, c) very high frequency range ................. 21
Figure 4 – Measuring object, during normalization ......................................................... 28
Figure 5 – Arrangement for sensitivity check ................................................................. 29
Figure 6 – Recommended test procedure with consecutive load and temperature conditions .................................................................................................................. 32
Figure 7 – Example of visualization of trending parameters ......................................... 34
Figure 8 – Example of a Φ-q-n partial discharge pattern, with colour code for the pulse number H(n)/s .................................................................................................................. 35
Figure 9 – Example of a three phase, phase shifted $\Phi$-q-n plot .............................................36
Figure A.1 – Stylized examples of PD phase resolved patterns .............................................44
Figure A.2 – Example of internal void discharges PRPD pattern, recorded during laboratory simulation .............................................................................................................45
Figure A.3 – Example of internal delamination PRPD pattern, recorded during laboratory simulation .............................................................................................................46
Figure A.4 – Example of delamination between conductor and insulation PRPD pattern, recorded during laboratory simulation .............................................................................................................47
Figure A.5 – Slot partial discharges activity and corresponding PRPD pattern, recorded during laboratory simulation .............................................................................................................47
Figure A.6 – Corona activity at the S/C and stress grading coating, and corresponding PRPD pattern, recorded during laboratory simulation .............................................................................................................48
Figure A.7 – Surface tracking activity along the end arm and corresponding PRPD pattern, recorded during laboratory simulation .............................................................................................................48
Figure A.8 – Gap type discharge activities and corresponding PRPD patterns, recorded during laboratory simulations .............................................................................................................49
Figure A.9 – Example of internal void discharges PRPD pattern, recorded on-line ................50
Figure A.10 – Example of internal delamination PRPD pattern, recorded on-line ...................51
Figure A.11 – Example of delamination between conductor and insulation PRPD pattern, recorded on-line .............................................................................................................51
Figure A.12 – Degradation caused by slot partial discharges activity and corresponding PRPD pattern recorded on-line .............................................................................................................52
Figure A.13 – Degradation caused by corona activity at the S/C and stress grading coating and corresponding PRPD pattern, recorded on-line .............................................................................................................53
Figure A.14 – Surface tracking activity along the end arm and corresponding PRPD pattern, recorded on-line .............................................................................................................53
Figure A.15 – Degradation caused by gap type discharges and corresponding PRPD patterns, recorded on-line .............................................................................................................54
Figure A.16 – PRPD pattern recorded on-line, illustrating multiple PD sources .....................54
INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

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

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publications”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

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:

<table>
<thead>
<tr>
<th>Enquiry draft</th>
<th>Report on voting</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/1636/DTS</td>
<td>2/1649/RVC</td>
</tr>
</tbody>
</table>

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.

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.

A bilingual version of this publication may be issued at a later date.

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