



BSI Standards Publication

Rotating electrical machines

Part 27-2: On-line partial discharge measurements
on the stator winding insulation

National foreword

This British Standard is the UK implementation of EN IEC 60034-27-2:2024. It is identical to IEC 60034-27-2:2023. It supersedes PD IEC/TS 60034-27-2:2012 and BS IEC 60034-27-2:2023, which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/2, Rotating electrical machinery.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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English Version

Rotating electrical machines - Part 27-2: On-line partial
discharge measurements on the stator winding insulation
(IEC 60034-27-2:2023)

Machines électriques tournantes - Partie 27-2: Mesurages
en fonctionnement des décharges partielles effectués sur le
système d'isolation
(IEC 60034-27-2:2023)

Drehende elektrische Maschinen - Teil 27-2: Online
Teilentladungsmessungen an der
Ständerwicklungsisolierung drehender elektrischer
Maschinen
(IEC 60034-27-2:2023)

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Europäisches Komitee für Elektrotechnische Normung

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European foreword

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- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2027-01-11

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Annex ZA

(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60034-27-1	2017	Rotating electrical machines - Part 27-1: Off-line partial discharge measurements on the winding insulation	EN IEC 60034-27-1	2018
IEC 60034-27-3	-	Rotating electrical machines - Part 27-3: Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines	EN 60034-27-3	-
IEC 60060-1	-	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	-
IEC 60068-2-6	-	Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal)	EN 60068-2-6	-
IEC 60068-2-27	-	Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock	EN 60068-2-27	-
IEC 60112	-	Method for the determination of the proof and the comparative tracking indices of solid insulating materials	EN IEC 60112	-
IEC 60270	2000	High-voltage test techniques - Partial discharge measurements	EN 60270	2001
IEC 62271-1	-	High-voltage switchgear and controlgear - Part 1: Common specifications for alternating current switchgear and controlgear	EN 62271-1	-
IEC TS 62478	-	High voltage test techniques - Measurement of partial discharges by electromagnetic and acoustic methods	-	-
ISO 8528-9	-	Reciprocating internal combustion engine - driven alternating current generating sets - Part 9: Measurement and evaluation of mechanical vibration	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

**Part 27-2: On-line partial discharge measurements
on the stator winding insulation**

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Draft	Report on voting
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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 International Standard 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.

A list of all parts in the IEC 60034 series, published under the general title *Rotating electrical machines*, can be found on the IEC website.

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

Partial Discharge (PD) on-line measurement of rotating electrical machines has gained widespread acceptance as it could reveal the presence of localized weak points of the stator insulation system and also various arcing and sparking phenomena. Nevertheless, 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 have an International Standard (IS) to give defined guidelines to the users of on-line PD measurements to assess the condition of their insulation systems.

On-line PD measurements are recorded with the rotating electrical machine experiencing all of the operating stresses; thermal, electrical, environmental and mechanical. Due to the realistic stress impact on the winding during measurement and due to the fact that the measurement is performed during all kinds of normal operation like base load and peak load, PD on-line testing could identify changes of the winding insulation system at a premature stage and enables real-time condition assessment as part of predictive maintenance strategies.

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. The trending information provides a good measure for early indication of a change in insulation condition. This gives time for planning further standstill examination in terms of visual inspection and off-line testing during next inspection outage.

This document does not deal with on-line 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.

Limitations: PD on-line tests on stator windings produce comparative, rather than absolute measurements. This creates a fundamental limitation for the interpretation of PD data. Therefore, acceptance criteria with simple limits for new or rewound stator windings cannot be established as the following reasons demonstrate:

- There are many types of PD sensors as well as recording and analysing instruments. Generally, they are incompatible and will produce different results for the same PD activity.
- Even with the same measuring system, the high frequency partial discharge pulses will interact with the winding capacitance and inductance on their way from point of origin to the measuring point, e.g. at the winding terminals. Thus, PD measurements taken at machines with different winding design and rating produce different PD results, even though the actual type of PD source is the same.
- Different types of winding defects produce different PD magnitudes and have different impact on insulation destruction. There is no strong correlation between high PD and high risk of insulation failure.
- PD activity may occur close or far from the PD sensor. In general, if the PD source is inside the winding coils far away from the PD sensor, it will produce a smaller response at the PD sensor at the terminals compared to a PD source at the phase connections nearby due to pulse 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, alone or even in combination. In order to more comprehensively describe the condition of the stator insulation, PD measurements are required to be supplemented by other electrical tests. Also, determining the root cause of an insulation deterioration process using PD pattern recognition, especially if more than one process is occurring, is still somewhat subjective, although the digital analysing technology is evolving rapidly.

Noise and disturbance from electrical environment have a great impact to on-line PD measurement. Cross-coupling of PD and noise between different phases can make objective interpretation of the test results difficult. Therefore, different analogue and digital noise suppression techniques are used to improve PD measuring sensitivity and PD analysing tools.

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 on-line PD activity, e.g. insulation failures involving continuous leakage currents due to conductive paths between different electrical potential of the insulation system or fine main insulation cracks with too small PD activity compared to normal delamination PD or pulse-less discharge phenomena.

ROTATING ELECTRICAL MACHINES –

Part 27-2: On-line partial discharge measurements on the stator winding insulation

1 Scope

This part of IEC 60034-27 deals with on-line PD measurements and provides a common basis with standardized procedures if possible 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 document 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.

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 60034-27-1:2017, *Rotating electrical machines – Part 27-1: Off-line partial discharge measurements on the winding insulation*

IEC 60034-27-3, *Rotating electrical machines – Part 27-3: Dielectric dissipation factor measurement on stator winding insulation of rotating electrical machines*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60112, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials*

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

IEC 62271-1, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

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

ISO 8528-9: *Reciprocating internal combustion engine driven alternating current generating sets – Part 9: Measurement and evaluation of mechanical vibrations*

3 Terms and definitions

For the purposes of this document the terms and definitions given in IEC 60270 apply, together with the following.

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

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

3.2

on-line measurement

measurement taken with the rotating electrical machine in operation

3.3

off-line measurement

measurement taken with the rotating electrical 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.

3.4

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.

3.5

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

corona discharge

visible partial discharge adjacent to the surface of a bare conductor or the surface of an insulation of a conductor

3.7

slot discharges

discharges that occur between the outer surface of the slot portion of a coil or bar and the earthed core laminations due to high electrical field strength

3.8

vibration sparking

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

3.9

internal discharges

discharges that occur within the mainwall insulation

3.10

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

3.11

pulse magnitude distribution

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

3.12

pulse phase distribution

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

3.13

phase resolved partial discharge pattern

PRPD

PD distribution map of PD magnitude and number of PD pulses versus AC cycle phase position, for visualization of the PD behaviour during a predefined measuring time

3.14

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.

3.15

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.

3.16

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

3.17**PD magnitude** **Q**

magnitude associated with a PD pulse recorded by a measuring system

Note 1 to entry: In this document, the symbol Q is used as a placeholder for both definitions of charge, Q_m and Q_{IEC} as given in IEC 60034-27-1. This magnitude is usually derived from a stream of individual PD pulses.

4 Cause and effects of on-line 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 breakdown only partially bridges the insulation material. PD in general requires a gas volume or void volume to develop, e.g. cavities 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 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 always 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 may be different for off- and on-line PD measurements.

Further details on the nature of PD are given in Annex A.

5 Noise and disturbances

5.1 General

An important challenge with on-line PD measurement is separating stator-winding PD from electrical noise or disturbances as well as clustering the signal with respect to specific PD sources. In contrast to properly set-up off-line PD tests, in most on-line tests electrical disturbance pulses will often be present, and these disturbance pulses may be more frequent and of larger magnitude than the stator winding PD pulses, also the signals may be phase-locked to the AC power frequency voltage. If the disturbances are not adequately suppressed, or the test technician is not able to adequately identify what is a disturbance and what is PD from the stator, there is a great risk that the disturbance will be classified as stator PD. Consequently, the stator may be identified as having serious insulation problems, when in fact the insulation may be in good condition. If too many "false positive" indications occur, confidence is lost in the test, and future testing may not be routinely done, losing the benefit of on-line PD testing.

5.2 Noise and disturbance sources

Consistent with IEC 60034-27-1, noise is defined to be non-stator winding signals that clearly are not pulses. Noise may be due to electronic devices within the PD detection system itself, for example thermal noise from semiconductive devices. Noise can also be from radio stations, radio transmitters, mobile telephones, power line carrier signals, etc. This noise is easily separated from pulse-like signals either visually on an oscillographic display or with the use of filters. Thus, it is not considered further in this document.

Disturbances are electrical pulses of relatively short duration that may have many of the characteristics of stator winding PD pulses – but in fact are not stator winding PD. Disturbances can be differentiated into two groups: In lower frequency range they preferably spread as electrical signals via metal conductors and in the very high frequency range they mainly distribute wireless as electromagnetic waves. Some of these disturbances are synchronized to the AC cycle, and some are not. Sometimes synchronized disturbance pulses can be suppressed based on their position with respect to the AC phase angle.

Examples of synchronized disturbances are:

- a) Partial discharges caused by, e.g. electrostatic precipitators or bushing discharges.
- b) Power tool operation such as from arc welding and commutator sparking (may also be unsynchronized).
- c) Transients caused by power electronics, for example converter fed motors or excitation systems. This disturbance may also be unsynchronized to the AC cycle..
- d) Poor electrical connections (leading to contact sparking) on the bus or cable connecting the rotating electrical machine to the power system.
- e) Poor electrical connections elsewhere in the plant that lead to contact sparking.
- f) PD in other apparatus connected to the motor or generator terminals, for example output bus, power cable, switchgear and/or transformers.
- g) Arcing or sparking sources within the motor or generator, such as stator core lamination sparking.

Examples of non-synchronized disturbances are:

- h) Power tool operation (arc welding and commutator sparking).
- i) Transients caused by power electronics, for example converter fed motors or static excitation systems.
- j) Slip ring sparking on the machine rotor.
- k) Overhead crane power rail sparking.

All of these disturbances create electrical pulses that the unwary may confuse with stator winding PD. With disturbances d), e), f), and g), the operator normally wants to know if such activity is occurring, because it may indicate other problems (beyond stator insulation problems) that may lead to equipment failure. Thus, some users may not class these examples as a disturbance, but rather as signals to be identified.

To reduce the risk of false indications of the stator winding insulation condition, many methods have been developed to help users to manually and/or automatically separate stator winding PD from disturbances. Many of the commercially available methods use one or more of the methods identified in Annex B.

6 Measuring techniques and instruments

6.1 General

The mechanism of gas physics of a partial discharge generates a transient charge movement which can be measured as an electrical pulse flowing as a transient current inside a conductive discharge circuit (see Figure 1). In addition, as each partial discharge is associated with an energy conversion process the measurement of a PD could also be performed by receiving the emission of light, acoustic signals, electromagnetic waves, or formation of chemical reactions. However, this clause deals solely with electrical methods of measuring partial discharges because the electrical measurement of partial discharges is the most commonly used method of assessing the condition of the winding insulation of rotating electrical machines. The electrical measurement can be carried out by using PD sensors detecting the conducted pulse signal components, or by using antennae detecting the electromagnetically radiated components of the pulse signals.

Partial discharge measuring systems can be divided into subsystems: PD sensor including the signal transmission system and PD measuring device, both of which significantly influence the PD measuring results. Selection of sensors, instrumentation and measuring technique is determined by the expected measurement parameters, which will be used for further analysis and interpretation of measurements.

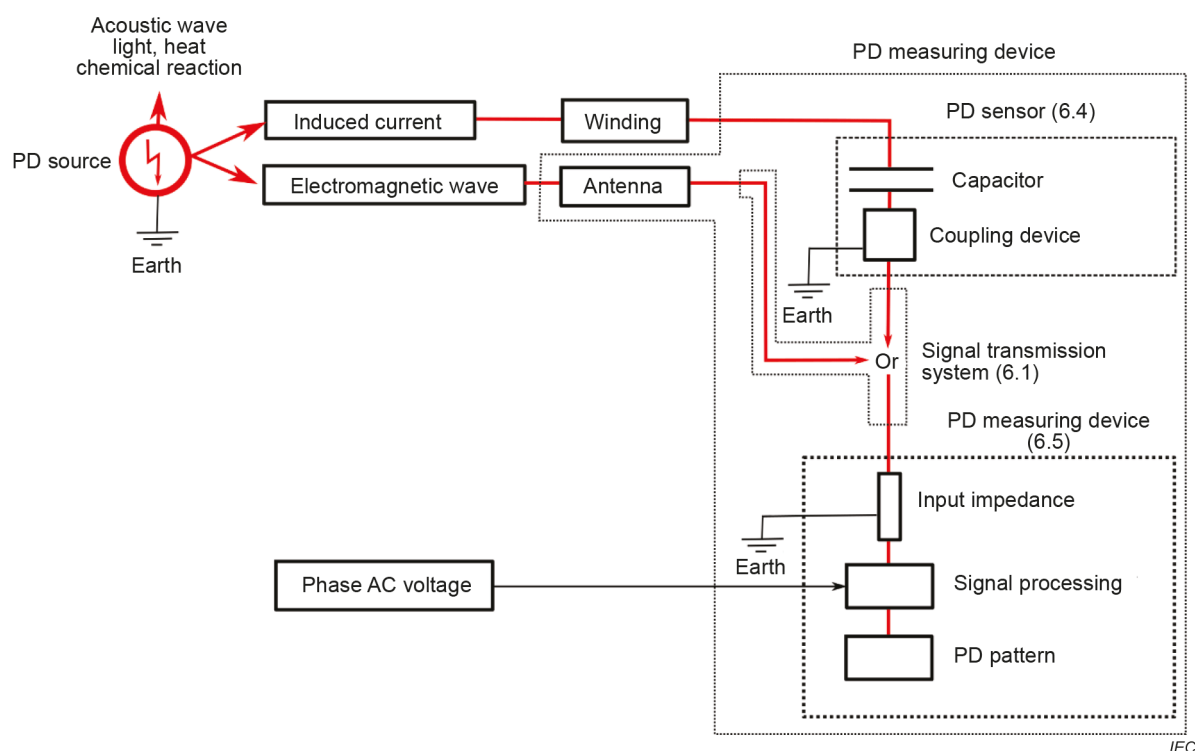


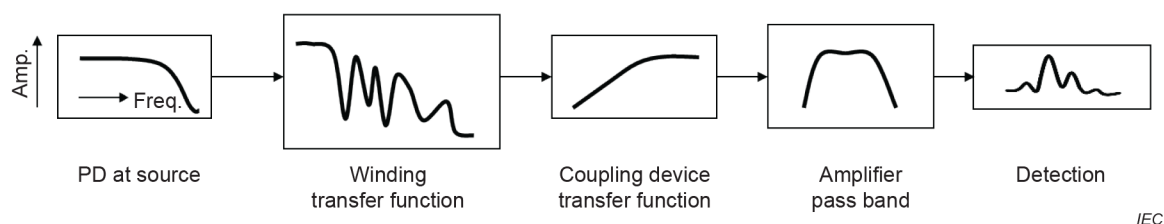
Figure 1 – Generic overview of PD measuring system and its subsystems

6.2 Pulse propagation in windings

At its origin a partial discharge current can be characterized as a transient pulse with a rise time of up to a few nanoseconds. For these short PD pulses with a high frequency spectrum, the stator windings represent objects with distributed elements in which travelling wave, complex capacitive and inductive coupling, and resonance phenomena occur (Figure 2). Therefore, PD pulse propagation phenomena need to be considered. Due to the attenuation, distortion, reflection and cross-coupling of travelling wave signals, the form and magnitude of the PD signal recorded at the location of the installed PD sensor differ from those at the point where it originates. With that in mind, the following points are very important for the measurement and subsequent interpretation of PD measurements taken on rotating electrical machines:

- the transmission function from the PD source to the PD sensor is unknown and depends on the specific design of the machine and the location of the PD source which determines the frequency response of the stator winding. Therefore, the energy at the source of the PD cannot be measured directly;
- the very high frequency components of the PD signals are subject to attenuation when travelling through the winding and, depending on the origin of the PD, might not be detectable at the location of the PD sensor.

As a consequence of the above mentioned phenomena, not only the particular stator winding design but also the specific frequency response of the PD detection system, including PD sensor, measuring device and filter settings, will significantly influence the characteristics of the PD signal detected from the winding. Different measurements have to be performed in the same frequency range to be comparable to each other.



Idealized curves of each step are shown to illustrate the general behaviour.

Figure 2 – Cascade of frequency response channels

6.3 Signal transfer characteristics

Figure 3 shows schematically the frequency response of an idealized PD pulse at the origin of the PD within the winding (upper cut-off frequency f_{uPD0}) and the idealized frequency response at the terminals of the machine (upper cut-off frequency f_{uPDt}) after travelling from the PD source through the winding to the terminals. Due to possible attenuation of very high frequency components, the upper cut-off frequency of the PD signal arriving at the terminals (f_{uPDt}) will be significantly lower than that (f_{uPD0}) of the original PD pulse. The upper cut-off frequency f_{uPD0} depends on the type of gas, the gas density and the defect type.

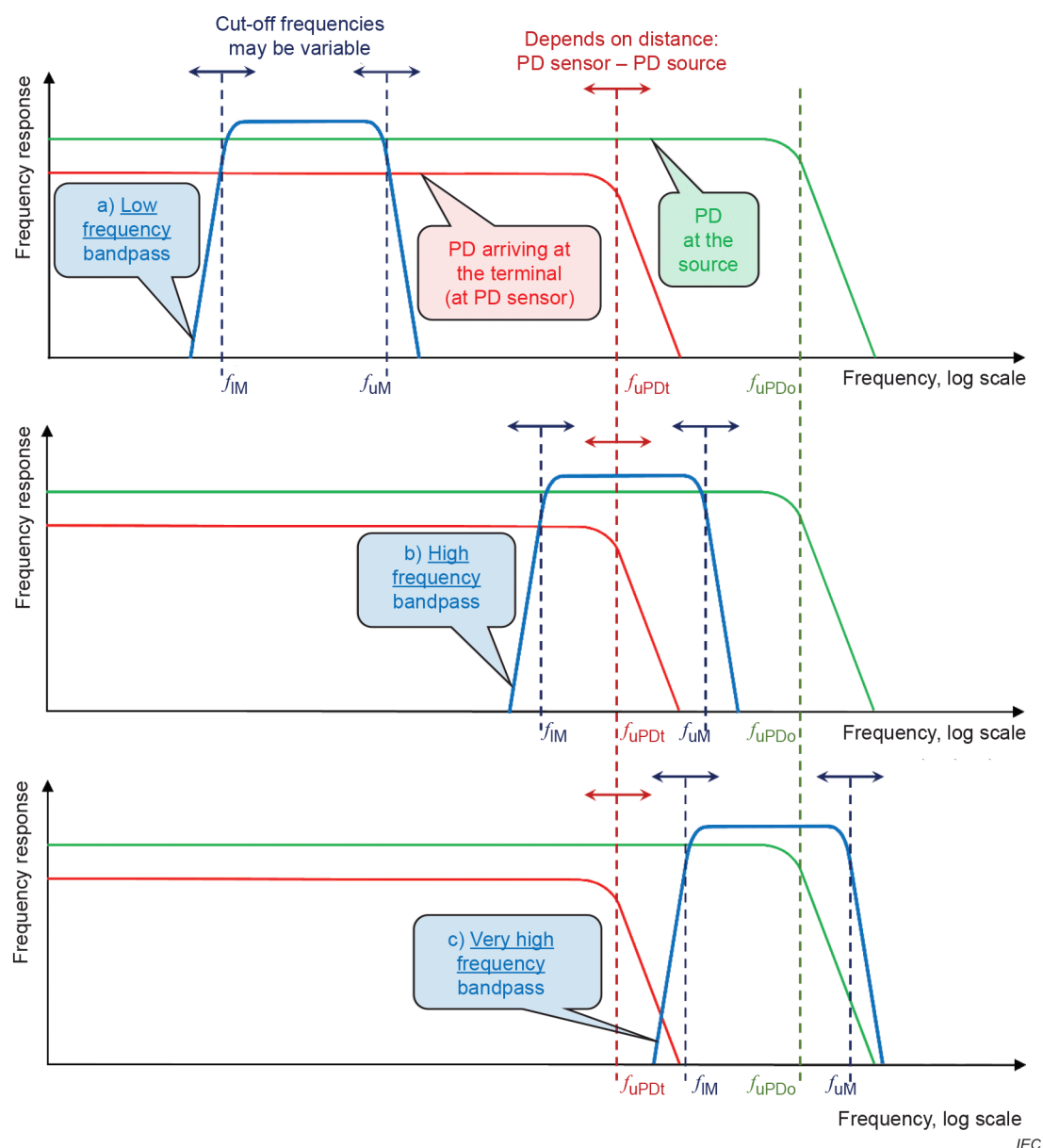


Figure 3 – Idealized frequency response of a PD pulse at the PD source and at the machine terminals; frequency response of different PD measuring systems: a) low frequency range, b) high frequency range, c) very high frequency range

The PD measuring system, including PD sensor, measuring leads and measuring instrument, shows band pass filter characteristics having specific lower and upper cut-off frequencies, mainly depending on the specific design of the PD sensor and the input impedance of the measuring device. In Figure 3 three examples a), b) and c) are shown for different frequency responses of PD measuring systems. For commercially available systems the cut-off frequencies, and thus the measuring bandwidth of the system, may vary over a wide range of frequencies. The characteristic frequency response of the complete measuring system has a considerable impact on the overall sensitivity of detection and the properties of the signal used for further analysis and interpretation.

It should be noted that Figure 3 only describes the fundamental relationships by showing idealized curves. Depending on the winding design and the measuring arrangement used, in practical cases there may be several effects that will influence the exact shape of the frequency response curves and therefore may also influence PD results, e.g. resonance phenomena in the frequency range of the PD measuring system, see Figure 2.

As discussed in IEC TS 62478, on-line PD measurements on rotating electrical machines use the following typical frequency ranges for the complete PD measuring system:

- a) In the low frequency (LF) range a typical bandwidth of about 1 MHz, or a few hundred kHz, is used, with lower cut-off frequencies of usually above 100 kHz and upper cut-off frequencies usually below 3 MHz. Measurement in that frequency range ensures good sensitivity not only for partial discharges in bars/coils close to the PD sensor but also for those that originate from further away in the winding. As the low frequency range is more subjected to noise and disturbance, which is especially present during on-line measurements (see Clause B.2), special procedures for noise and disturbance separation are needed.

A broad band measuring system using the full low frequency band width up to the MHz range can summarize most of the available PD energy content for further signal analysis and noise discrimination procedures independent of unavoidable local resonances of the pulse transfer spectrum. Since the upper cut-off frequency of the detection bandpass is significantly lower than the upper cut-off frequency of the pulse frequency response, the detected PD pulses are directly proportional to the low frequency components of the PD pulse. However, the pulse shape of the bandpass output signal is determined by the low frequency bandpass characteristics. Since the original shape of the PD pulse arriving at the sensor location is lost when using low frequency bandpass systems, a separation of disturbance signals by pulse shape analysis or time domain separation is limited.

- b) In the high frequency (HF) range a typical bandwidth of 3 MHz to 30 MHz is used. The lower cut-off frequencies may also be tuned well below 1 MHz to ensure good sensitivity for PD throughout the winding. However, often lower cut-off frequencies above 1 MHz are used to efficiently suppress typical disturbance signals that are present in the low frequency range.

PD detection in the high frequency range is less susceptible to noise and disturbance and can be efficiently used to characterize the PD pulses arriving at the PD sensor by their individual pulse shape and thus being able to discriminate between different PD sources according to their signal shape. In the case where the upper cut-off frequency of the detection system is well above the upper cut-off frequency of the PD signal arriving at the location of the PD sensor, the bandpass output signal will display the PD pulse shape but will no longer be directly proportional to the apparent charge of the PD pulse. Thus, PD results in the high frequency range are usually expressed in terms of voltage [mV]. Efficient methods of frequency and time domain disturbance separation can be applied according to Clause B.5. Time-of-flight measurements taken with individual pulses can be used to localize the PD or disturbance source within or outside of the machine, as long as the two sensors are more than 10 m apart assuming full 30 MHz bandwidth.

NOTE 1 One of the sensors for time-of-flight measurements can be located on the output bus.

- c) In the very high frequency (VHF) range a typical bandwidth of a few hundred MHz is used with lower cut-off frequencies of typically 30 MHz and upper cut-off frequencies up to the 300 MHz range. As shown in Figure 3 c) the frequency response of such systems shows a pronounced overlap with the frequency response of the original PD pulse and therefore measurements in the very high frequency range ensure a good sensitivity to signals originating closer to the PD sensor. The PD sensor should be installed at the high voltage terminals and thus close to the coils/bars experiencing the highest electrical stress within the winding. The very high frequency range also provides a good signal to noise ratio and is therefore less susceptible to noise and disturbance. Because the upper cut-off frequency of the detection system is well above the upper cut-off frequency of the PD signal arriving at the location of the PD sensor, the measured signal will display the PD pulse shape but will no longer be directly proportional to the apparent charge of the PD pulse. Thus, PD results in the very high frequency range are usually expressed in terms of voltage (mV). As indicated in Figure 3 c), the capability to detect PD in this frequency range will be reduced due to the upper cut-off frequency of the PD impulses arriving at the PD sensor position (f_{uPDt}).

PD detection in the VHF range ensures a very short pulse resolution time since the shape of the original very short PD current pulse can be detected. Therefore, efficient methods of time and frequency domain disturbance separation such as time-of-pulse arrival, pulse shape analysis and TF maps can be applied according to Annex B. Pulse shape and time-of-flight analysis of individual pulses can be used to localize the PD source within or outside of the machine, as long as the two sensors are more than 2 m apart assuming full 300 MHz bandwidth.

- d) In the ultra high frequency (UHF) range lower cut-off frequencies of typically 300 MHz and upper cut-off frequencies of up to 3 GHz are used. PD sensors working in that frequency range are antennae, which detect electromagnetically radiated pulse signals. The signal energy detected by these sensors and thus the sensitivity of PD detection mainly depends on the specific location of the antenna, the distance between the antenna and the PD source and the bandwidth of the detection system. In general, the closer the antenna is located to the specific PD sources the better will be the sensitivity of PD detection. There is a high attenuation for pulse signals from PD sources within the slot and therefore shielded by the iron core.

NOTE 2 The upper cut-off frequency of the PD arriving at the PD sensor position (sensor) f_{UPDt} may significantly vary, depending on the distance between the PD sensor and the PD source. A small distance may result in a higher cut-off frequency, a large distance may result in a lower cut-off frequency due to attenuation phenomena.

Therefore, in case b) and especially in case c) the measuring system shows good sensitivity to PD sources closer to the sensor, depending on the lower cut-off frequency of the bandpass filter and the overlap of the frequency responses of the bandpass filter and the PD signal at the sensor location.

6.4 PD sensors

6.4.1 General

In principle PD can be detected by conducted or electromagnetically radiated pulse signals. In the case of conducted PD signals a separate capacitance is used to detect the PD signal arriving at the location of the installed PD sensor. The electromagnetically radiated pulse signal is attenuated, due to various screening effects by machine components as iron core with slots, conductive coatings, etc. Thus, the location of the antenna, the distance to the PD source and the specific bandwidth of the detection system significantly influence the detection sensitivity.

6.4.2 Design of PD sensors

PD sensors, which detect conducted pulse signals typically consist of a high voltage capacitance, often called coupling capacitor, and a low voltage coupling device in series.

As capacitance the following arrangements can be used:

- dedicated PD coupling capacitor;
- existing surge capacitor;
- capacitance of power cables leading to the machine.

In order to form a PD sensor these capacitances can be used together with the following coupling devices, designed for an appropriate frequency response:

- RLC networks;
- High frequency current transformers including isolation transformers and Rogowski coils.

PD sensors, which detect electromagnetically radiated pulse signals are typically antennae, which provide a characteristic sensitivity significantly depending on their place of installation and their specific frequency response function.