



IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors

STANDARDS

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.113™-2023
(Revision of IEEE Std C57.113-2010)



IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors

Developed by the

Transformers Committee
of the
IEEE Power and Energy Society

Approved 8 November 2023

IEEE SA Standards Board

THIS IS A REDLINE DOCUMENT PRODUCED BY TECHSTREET, AN ASME COMPANY.

This document is intended to provide users with an indication of changes from one edition to the next. It includes a full-text version of the new document, plus an indication of changes from the previous version.

Redlines are designed to save time and improve efficiencies by using the latest software technology to find and highlight document changes. More professionals are using valuable new technologies like redlines, to help improve outcomes in a fast paced global business world.

Because it may not be technically possible to capture all changes accurately, it is recommended that users consult previous editions as appropriate. In all cases, only the current base version of this publication is to be considered the official document.

This Redline is produced solely by Techstreet. IEEE has not prepared this Redline and is not responsible for its accuracy.

Redline Processing Notes:

1. ~~Red Text~~ - Red strikethrough text denotes deletions.
2. Blue Text - Blue underlined text denotes modifications and additions.

Abstract: Wideband measurement of the apparent charge of partial discharges (PDs) that may occur in liquid-filled power transformers and shunt reactors excited by ac test voltages between 40 Hz and 400 Hz are discussed in this recommended practice. The major components of the PD measuring circuit, including the calibrator are specified in compliance with IEC 60270. The PD test procedure is described and recommendations for the evaluation of PD test results are presented.

Keywords: apparent charge, IEEE C57.113™, partial discharge, PD, power transformer, shunt reactor, wideband PD measurement

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2024 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 12 March 2024. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 979-8-8557-0498-3 STD26762
Print: ISBN 979-8-8557-0499-0 STDPD26762

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <https://www.ieee.org/about/corporate/governance/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers>), appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. IEEE Standards documents do not guarantee safety, security, health, or environmental protection, or guarantee against interference with or from other devices or networks. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon their own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus balloting process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE is the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group. Statements made by volunteers may not represent the formal position of their employer(s) or affiliation(s).

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and subcommittees of the IEEE SA Board of Governors are not able to provide an instant response to comments, or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile and Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

¹Available at: <https://development.standards.ieee.org/myproject-web/public/view.html>.

²Available at: <https://standards.ieee.org/thank-you/contact/>.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, neither IEEE nor its licensors waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

Patents

IEEE standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has

³Available at: <https://standards.ieee.org/about/contact>.

⁴Available at: <https://standards.ieee.org/standard/>

⁵Available at: <https://standards.ieee.org/about/sasb/patcom/materials>.

filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

Technologies, application of technologies, and recommended procedures in various industries evolve over time. The IEEE standards development process allows participants to review developments in industries, technologies, and practices, and to determine what, if any, updates should be made to the IEEE standard. During this evolution, the technologies and recommendations in IEEE standards may be implemented in ways not foreseen during the standard's development. IEEE standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

Participants

At the time this draft recommended practice was completed, the Dielectric Test on PD Measurement Working Group had the following membership:

Ali Naderian Jahromi, *Chair*
Janusz Szczechowski, *Vice Chair*

Tauhid Haque Ansari	Fernando Leal	Hemchandra Shertukde
Dominique Bollinger	Harry Pepe	Dervis Tekin
Detlev Gross	Amitabh Sarkar	Ajith Varghese
David Larochelle	Dan Schwartz	Alexander Winter

The following members of the individual Standards Association balloting group voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

Stephen Antosz	Richard Jackson	Poorvi Patel
Donald Ayers	John John	Howard Penrose
Robert Ballard	Jimmy Johns	Harry Pepe
Peter Balma	Laszlo Kadar	Charles Pestell
Thomas Barnes	Gael Kennedy	Sylvain Plante
Barry Beaster	Zan Kiparizoski	Alvaro Portillo
Wallace Binder	Boris Kogan	Bertrand Poulin
Thomas Blackburn	Mathieu Lachance	Tom Prevost
William Boettger	Mikhail Lagoda	Ion Radu
Jeremiah Bradshaw	Chung-Yiu Lam	Scott Reed
Jeffrey Britton	Benjamin Lanz	Johannes Rickmann
Paul Cardinal	David Larochelle	Oleg Roizman
Ritwik Chowdhury	William Larzelere	Zoltan Roman
John Crouse	Moonhee Lee	Rodrigo Ronchi
Kurniawan Diharja	Wang Lei	Ryandi Ryandi
Huan Dinh	Aleksandr Levin	Mahesh Sampat
Hakim Dulac	Thomas Lundquist	Daniel Sauer
Evgenii Ermakov	Greg Luri	Roderick Sauls
Jorge Fernandez Daher	Balakrishnan Mani	Bartien Sayogo
Namal Fernando	Kumar Mani	Hyeong Sim
Bruce Forsyth	Richard Marek	Jerry Smith
Carl Fredericks	J. Dennis Marlow	Bradley Staley
George Frimpong	James McBride	Juan Thierry
Eduardo Garcia	Mark McNally	Eduardo Tolcachir
Shubhanker Garg	Ross McTaggart	Mark Tostrud
William Griesacker	Daleep Mohla	James Van De Ligt
Detlev Gross	Daniel Mulkey	Jason Varnell
Niklas Gustavsson	Ali Naderian Jahromi	John Vergis
Randy Hamilton	Jeffrey Nelson	David Wallace
John Harley	Joe Nims	Joe Watson
Roger Hayes	Lorraine Padden	Drew Welton
Sergio Hernandez	Bansi Patel	Ying Zhang
Thang Hochanh	Dhiru Patel	Peter Zhao
Werner Hoelzl		Igor Ziger

When the IEEE SA Standards Board approved this recommended practice on 8 November 2023, it had the following membership:

David J. Law, *Chair*
Ted Burse, *Vice Chair*
Gary Hoffman, *Past Chair*
Konstantinos Karachalios, *Secretary*

Sara R. Biyabani
Doug Edwards
Ramy Ahmed Fathy
Guido R. Hiertz
Yousef Kimiagar
Joseph L. Koepfinger*
Thomas Koshy
John D. Kulick

Joseph S. Levy
Howard Li
Johnny Daozhuang Lin
Gui Lin
Xiaohui Liu
Kevin W. Lu
Daleep C. Mohla
Andrew Myles

Paul Nikolich
Annette D. Reilly
Robby Robson
Lei Wang
F. Keith Waters
Karl Weber
Philip B. Winston
Don Wright

*Member Emeritus

Introduction

This introduction is not part of IEEE Std C57.113–2023, IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.

The detection of partial discharges (PDs) was introduced for quality assurance tests of high-voltage (HV) apparatus at the beginning of 1960. Originally this technique was based on the measurement of radio interference voltages (RIV) in terms of microvolts (μV) as recommended by NEMA TR1–2000 [B114], NEMA 107-1971 [B115], and CISPR 16-1-1993 [B42]. This quantity, however, is weighted according to the acoustical noise impression of the human ear, which is not a measure of the PD activity in the insulation of HV apparatus. Therefore, Technical Committee No. 42 of IEC decided to prepare a separate standard for PD measurements associated with the apparent charge, which was first published in 1968. Since that time, this technology has been considered as an indispensable tool for the enhancement of the reliability of HV apparatus. IEEE Std C57.113–2023 covers the wideband method for apparent charge measurements in compliance with IEC 60270-2015.

This revision of IEEE Std C57.113–2010 is a general update of this standard to reflect the current state of the art and has been revised to meet current IEEE Styles. Further, the old Annex on Noise identification was deleted; [Annex A](#) and [Annex B](#) were revised and updated; and [Annex F](#) on pattern recognition was substantially revised.

Acknowledgments

Grateful acknowledgment is made to Detlev Gross for permission to reprint [Figure A.1](#) through [Figure A.5](#) from “Acquisition and location of partial discharge—esp in transformers” PhD. Thesis, TU Graz, Austria, © 2016.

Contents

1. Overview.....	11
1.1 Scope.....	11
1.2 Purpose.....	11
1.3 Word usage.....	11
2. Normative references	12
3. Definitions.....	12
4. Specification of PD measuring circuits.....	13
4.1 General	13
4.2 Coupling capacitor	14
4.3 Measuring impedance.....	15
4.4 PD measuring instrument	15
4.5 PD calibrator.....	17
4.6 Maintaining the specified parameters of PD measuring circuits	18
5. PD test procedure	18
5.1 Calibration.....	18
5.2 PD measurement.....	19
Annex A (informative) Coupling.....	21
Annex B (informative) Response of PD measuring instruments	26
Annex C (informative) Calibration of PD measuring circuits	28
Annex D (informative) Basic sensitivity check	29
Annex E (informative) Bushing tap ratio measurement	30
Annex F (informative) PD pattern recognition.....	31
Annex G (informative) Bibliography	33

IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors

1. Overview

1.1 Scope

This recommended practice describes the test procedure for the detection and measurement by the wideband apparent charge method of partial discharges (PDs) occurring in liquid-filled power transformers and shunt reactors during dielectric tests, where applicable.

1.2 Purpose

PD measurements in transformers and shunt reactors should preferably be made on the basis of measurement of the apparent charge. Relevant measuring systems are classified as narrowband or wideband systems. Both systems are recognized and widely used. Without giving preference to one or the other, it is the object of this document to describe the wideband method. General principles of PD measurements, including the narrowband method, are covered in IEC 60270 [2015](#) and IEC 60076-3-2013 [\[B72\]](#).^{6,7} ~~[\[B71\]](#)~~.^{1,2}

^{6,7}Information on references can be found in Clause 2.

^{1,2}The numbers in brackets correspond to those of the Bibliography in Annex [G](#), ~~[H](#)~~.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{8,9}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

⁸ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁹ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 60270-[2015](#), High-voltage test techniques—Partial discharge measurements. [10,11](#) ³

¹⁰ [IEC publications are available from the International Electrotechnical Commission \(<http://www.iec.ch/>\) and the American National Standards Institute \(<https://www.ansi.org/>\).](#)

¹¹ [This is the consolidated version of IEC 60270:2000+AMD1: 2015.](#)

³ ~~IEC publications are available from the Central Office of the International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH 1211, Geneva 20, Switzerland (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>)~~

IEEE Std 4TM, IEEE Standard Techniques for High Voltage Testing. ^{12,13 4,5}

IEEE Std C57.12.00TM, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (~~ANSI~~)

IEEE Std C57.12.90TM, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

IEEE Std C57.19.00TM, IEEE Standard Requirements and Test Procedures for Power Apparatus Bushings.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* ~~: Glossary of Terms & Definitions~~ should be consulted ~~referenced~~ for terms not defined in this clause. ^{14 6}

apparent charge level: Mean value of the apparent charge of partial discharge (PD) pulse trains measured in terms of picocoulomb (pC) by means of PD instruments.-

NOTE—As specified in 4.5. ^{15 7}

^{12 4} IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org>).

^{13 5} The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

¹⁴ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

~~⁶ The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>~~

^{15 7} Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

calibrating charge: Charge of artificial partial discharge (PD) pulses generated by PD calibrators.

NOTE—As specified in 4. [5](#) ~~6~~.

~~**frequency response:** Transfer impedance of the partial discharge (PD) measuring instrument versus the frequency characterized by the lower and upper limit frequency, f_1 and f_2 .~~

NOTE—As specified in 4.5.

PD calibrating circuit: Interconnection of the partial discharge (PD) calibrator with the test object and the PD measuring circuit intended for the determination of the scale factor, S_f .

NOTE—As specified in 4. [5](#) ~~6~~.

PD measuring circuit: Interconnection of the partial discharge (PD) measuring instrument with the measuring impedance and the coupling capacitor intended for measuring the apparent charge level.-

pulse train response: Reading of the partial discharge (PD) measuring instrument versus the repetition frequency of injected calibrating pulses.

NOTE—As specified in 4. [5](#) ~~6~~

specified apparent charge level: Apparent charge level permitted for the test object if subjected to the partial discharge (PD) test procedure and conditioning stated in IEEE Std C57.12.90 and IEEE Std C57.19.00.

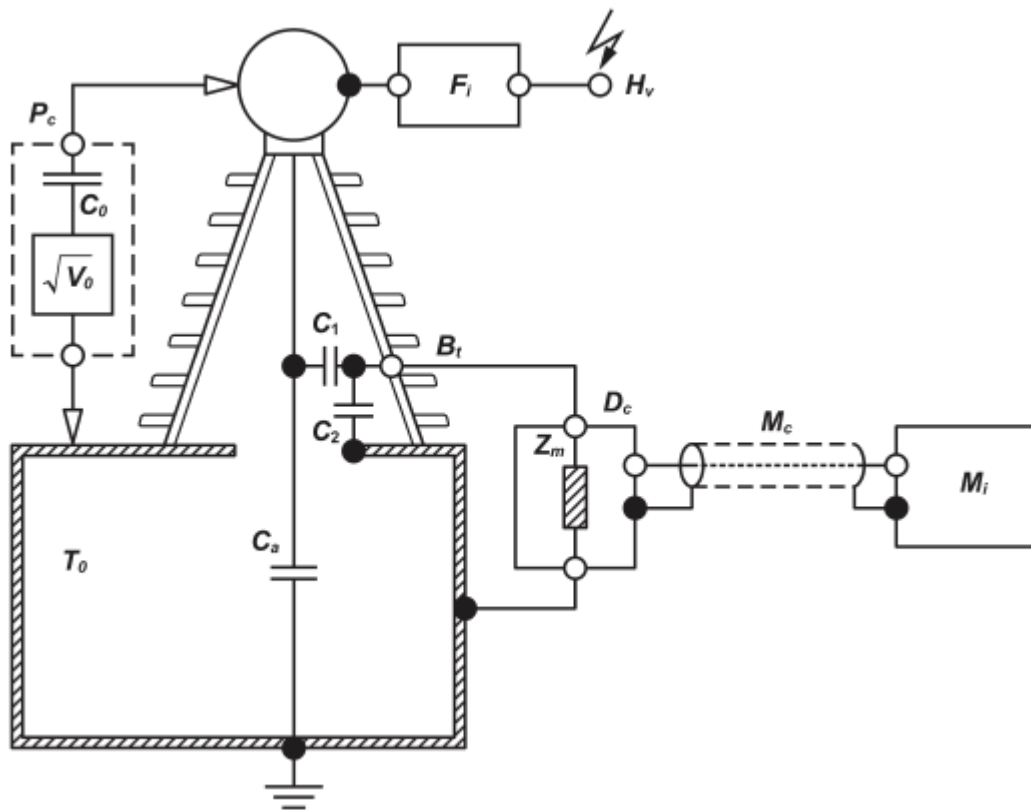
4. Specification of PD measuring circuits

4.1 General

To measure the apparent charge, the following major circuit components are required:

- Coupling unit, which captures the PD signal from the terminals of the test object
- Measuring instrument, which processes the captured PD pulses and evaluates the apparent charge level
- Associated high-voltage (HV) and low-voltage (LV) leads and measuring cables, which connect the individual components

Generally the coupling unit contains a coupling capacitor, C_c , which is connected in series with measuring impedance, Z_m . If the test object is equipped with capacitive graded bushings, the capacitance between HV conductor and bushing tap, C_1 , may substitute the coupling capacitor, C_c , as illustrated in Figure 1. [Refer to Annex A for details of coupling capacitor different designs and circuits.](#)



C_0 — Calibrating capacitor

C_1 — Capacitance between HV conductor and bushing tap

C_2 — Capacitance between bushing tap and grounded bushing flange

C_a — Virtual capacitance of the test object

D_c — Coupling device

F_i — Noise rejection filter

H_v — Connection to the HV test supply

M_c — Measuring cable

M_i — Measuring instrument

P_c — PD calibrator

T_o — Test object

V_0 — Step pulse generator

Z_m — Measuring impedance

Figure 1 — PD measuring circuit using the bushing tap coupling mode

The HV connection leads between the test object and coupling capacitor should be PD-free up to the highest applied ac test voltage level. The ground connection leads should be kept as short as possible in order to reduce the inductance and thus to reduce ~~minimize~~ the impact of electromagnetic interferences disturbing sensitive PD measurements. Optional HV and LV filters may also be utilized to reduce the influence of environmental disturbances.

4.2 Coupling capacitor

The coupling capacitor, C_c , is intended for the decoupling of the high-frequency PD signal from the terminals of the test object at low attenuation, due to the high-pass filter characteristics of this unit. Additionally, the ac test voltage level appears extremely reduced at the output of C_c . This response is also achieved, if instead of the coupling capacitor, C_c , the capacitance between HV conductor and bushing tap, C_1 , is utilized. To ~~reduce~~ ~~minimize~~ the impact of stray capacitances on PD test results, the capacitance of C_c and C_1 ~~are normally larger than~~ ~~should exceed~~ 300 pF. However, with the appropriate quadrupole, smaller values of coupling capacitance can be feasible. Moreover, the coupling capacitor ~~these units~~ should be PD-free up to the maximum applied ac test voltage level.

4.3 Measuring impedance-

The measuring impedance, Z_m , is intended for the conversion of PD current pulses into equivalent voltage pulses. Using the classical coupling mode by means of a separate coupling capacitor, the measuring impedance, Z_m , is generally formed by a parallel connection of a resistor, R_m , with an inductor, L_m ; see Annex A.

If the bushing tap coupling mode according to Figure 1 is used, the measuring impedance, Z_m , consists of the parallel connection of a resistor, R_m , and an inductor, L_m . Both elements are additionally shunted by the capacitance between bushing tap and grounded bushing flange, C_2 ; see Annex A.

Moreover, passive and active elements could be utilized for PD signal filtering and overvoltage protection. All these elements are usually integrated in a terminating box, referred to in IEC 60270 as a coupling device, D_c .

Due to the high-pass filter characteristics of the series connection of either C_c or C_1 with the measuring impedance, Z_m , care should be taken that the specified lower limit frequency, f_l , of the complete PD measuring circuit is not substantially affected by the parameters of the PD coupling unit; see Annex A.

WARNING

In order to minimize any danger for the operator and the instrumentation, as well as to ensure an optimum signal transmission, the coupling device should always be located inside the HV test area. The coupling device shall be attached physically as close as possible to the bushing tap or to the coupling capacitor.

4.4 PD measuring instrument

For measuring the apparent charge, either ~~the~~ analog or ~~the~~ digital signal processing can be utilized. Independent from the measuring principle applied, the instrumentation is generally equipped with the following major units:

- Attenuator [or programmable gain amplifier](#), to adjust the magnitude of the input PD pulses
- Band-pass filter amplifier, to amplify and integrate the captured PD pulses
- Peak detector, to evaluate the apparent charge level

To [help](#) ensure comparable and reproducible PD test results, both the frequency response and the pulse train response of PD measuring instruments should be specified [and in accordance with the latest edition of IEC 60270](#).

4.4.1 Frequency response

To measure the apparent charge level the captured PD current pulses are integrated. For this purpose, usually a band-pass filter is utilized, characterized by the lower and upper limit frequency, f_1 and f_2 , and the bandwidth, Δf , given by Equation (1):

$$\Delta f = f_2 - f_1 \quad (1)$$

To keep the integration error as low as possible, the PD measurement is performed in a frequency range where the amplitude-frequency spectrum of the PD pulses is nearly constant; see Annex B.

From a practical point of view the lower limit frequency, f_1 , should be located around 100 kHz. Lower values may ~~reduce~~ ~~minimize~~ the impact of attenuation of PD pulses propagating along transformer windings. However, this may also lead to serious disturbances, such as iron core related noises as well as harmonics from the ac test facility. To reduce the impact of interferences in the low-frequency range the high-pass filter characteristics should be such that the attenuation is about 40 dB for frequencies around 25 kHz and at least 60 dB for frequencies below 15 kHz.

To ~~reduce~~ ~~minimize~~ the integration error, the upper limit frequency, f_2 , should be chosen around 300 kHz. To reduce interferences of radio broadcast stations, the attenuation should exceed 20 dB for frequencies above 500 kHz and at least 40 dB for frequencies above one MHz.

From the specified frequencies, f_1 and f_2 , it follows that the bandwidth, Δf , has a value of 200 kHz. A wider bandwidth would be useful for the localization of PD sites, but this may lead to an increasing measuring error, because the PD pulses may not be integrated as desired; see Annex B.

4.4.2 Pulse train response

To evaluate the apparent charge level of random distributed PD pulse trains, the pulse magnitudes should be ~~weighted~~ ~~averaged~~ in compliance with the IEC 60270. ~~This is accomplished if the characteristic charging time constant, τ_1 , and discharging time constant, τ_2 , of the peak detector, as part of the PD measuring instrument, satisfy the condition $\tau_1 \ll \tau_2 < 440$ ms.~~

~~NOTE 1— If the pulse train response differs significantly from those recommended in IEC 60270 the actual dependence of the reading, R_i , versus the pulse repetition rate, N , should be determined in order to judge the evaluation of the apparent charge level.~~

[NOTE 1 2](#)—To eliminate stochastically appearing noise pulses at comparatively low repetition rate, for instance one pulse per cycle of the applied ac test voltage, some PD detectors are equipped with special features for noise suppression which may reject pulses having a repetition rate below 100 Hz. Care should be taken when using this instrumentation because PD pulses of high magnitude may not be recognized if they do not ignite in each half-cycle of the applied ac test voltage. To avoid such erroneous measurements, a visualization of the phase-resolved PD pulses is strongly recommended using a suitable display unit, such as a scope or a computer.

[NOTE 2 3](#)—The specified pulse train response is appropriate only for ac test voltages where the frequency may range between 40 Hz and 400 Hz. For dc test voltages or test voltages composed by ac and dc voltages, it is recommended to evaluate the number versus the magnitude of PD pulses.

4.4.3 Display unit

In addition to the measurement of the apparent charge level by means of analog or digital meters it is strongly recommended to display the phase-resolved PD patterns by means of a suitable display unit, such as an oscilloscope or a computer. This may assist not only the identification and classification of harmful PD defects but also the discrimination of disturbing electromagnetic interferences, which are often not phase-correlated. [Current instruments offer both phase-resolved PD pattern and time-domain display in parallel multi-channel configuration.](#)

4.4.4 Basic sensitivity

The basic sensitivity should be determined by means of calibrating pulses specified in 4. [5 6](#), which are injected into the input of the measuring impedance connected to the PD measuring instrument via the associated measuring cable. A calibrating charge of 50 pC should cause a minimum deflection of 50% of the full reading of the indicating instrument or of the optional display unit.

4.4.5 Linearity

The linearity should be determined by means of calibrating pulses specified in 4.5.6, which should be injected in the measuring impedance connected via the associated measuring cable to the PD measuring instrument. The measuring sensitivity should be adjusted such that the full reading (100%) is obtained for an injected calibrating charge of 500 pC. After that the magnitude of the calibrating charge should be reduced stepwise by 100 pC. Under this condition the values indicated by the PD measuring instrument should not deviate by more than $\pm 10\%$ from the true magnitudes of the injected pulse charges.

NOTE—Injecting calibration signals with magnitudes close to the noise floor produces an apparent non-linearity due to the so-called noise modulation—the calibration pulse “rides” on the noise and appears larger.

4.5 PD calibrator

The PD calibrator is intended for the simulation of the charge transfer from the PD source to the terminals of the test object; see Annex C. To generate artificial PD pulses required for this purpose, the calibrator is generally equipped with a pulse generator connected in series with a calibrating capacitor, C_0 ; see Figure 1. The pulse generator produces fast rising step voltages of known magnitudes, V_0 . Therefore, the calibrating charge is given by Equation (2):

$$q_0 = V_0 \times C_0 \quad (2)$$

The PD calibrator should meet the requirements of IEC 60270. To adjust the desired magnitude of the calibrating charge, q_0 , the magnitude of the voltage step, V_0 , and the capacitance of the calibrating capacitor, C_0 , can be tuned accordingly. Current calibrators use a fixed C_0 and an adjustable V_0 instead. The calibrating charge should be adjustable between 50 pC and 1000 pC. These magnitudes should not differ by more than $\pm 10\%$ from the rated values.

To ~~reduce~~ ~~minimize~~ the measuring error caused by non-controlled distortions of the pulse shape, care has to be taken that the conditions $C_0 < 200 \text{ pF}$ and $C_0 < 0.1 C_a$ are satisfied. A simplified approach for the evaluation of C_a is presented in Annex D. To avoid any superposition errors and thus to ~~reduce~~ ~~minimize~~ the impact of the pulse train response on the reading of the PD measuring instrument, the repetition frequency of the calibrating pulses should be in the range of ~~50~~ ~~100~~ Hz to 1000 Hz, inclusive.

The output impedance of the step pulse generator should not exceed 100Ω . The rise time of the step pulse, which refers to the 10% and 90% values of the maximum pulse magnitude, should be less than 100 ns. After the peak is obtained the voltage magnitude should not differ more than $\pm 5\%$ from the mean value for a time span not shorter than $50 \mu\text{s}$. The decay time, which refers to the 90% and 10% values of the pulse magnitude, should either be the same as the rise time, if bipolar calibrating pulses are created, or it should exceed $200 \mu\text{s}$ if pulses of only positive or negative polarity are created.

To display the calibrating pulses when the actual PD test under high voltage is running, the calibrating capacitor, C_0 , which is usually designed only for low voltages, should be substituted by an HV calibrating capacitor; this should be PD-free up the maximum ac test voltage level. The measuring cable between the step pulse generator and the terminating box connected to the input of the HV calibrating capacitor should be matched with the characteristic cable impedance in order to avoid disturbing pulse reflections. Generally, the HV calibrating capacitor should be located as close as possible to the HV terminal of the test object.

The objective of the calibration procedure is to determine the scale factor, S_f , which represents the ratio between the calibrating charge, q_0 , injected between the terminals of the test object, and the reading, R_0 , of the PD measuring instrument With current instruments, this scale factor is typically calculated automatically and often not user accessible [see Equation (3)]

$$S_f = q_0 / R_0 \quad (3)$$