IEEE SA
STANDARDS ASSOCIATION

IEEE Recommended Practice for Partial Discharge Measurements under AC Voltage with VHF/UHF Sensors during Routine Tests on Factory and Pre-Molded Joints of HVDC Extruded Cable Systems up to 800 kV

IEEE Dielectrics and Electrical Insulation Society

Developed by the
IEEE Standards Committee

IEEE Std 2862™-2020

IEEE

STANDARDS

IEEE Recommended Practice for Partial Discharge Measurements under AC Voltage with VHF/UHF Sensors during Routine Tests on Factory and Pre-Molded Joints of HVDC Extruded Cable Systems up to 800 kV

Developed by the

IEEE Standards Committee
of the
IEEE Dielectrics and Electrical Insulation Society

Approved 3 December 2020

IEEE SA Standards Board

Abstract: The aim of this recommended practice is to establish a protocol for the measurement of partial discharges using ac voltages and VHF/UHF electromagnetic sensors, for quality control during routine tests on factory and pre-molded joints of high-voltage direct-current (HVDC) extruded cable systems having voltage ratings up to 800 kV. The various steps of the protocol for the measurement of partial discharges in such cables are carefully described. Details are given about the procedure for a sensor performance check, test setup preparation, and success criteria. The ultimate goal of this recommended practice is not verifying the compliance with any maximum acceptable limit of partial discharge amplitude, but rather focusing on the whole phenomenon of partial discharges, in order to assess whether critical partial discharges are present in the tested object (either a factory joint or a pre-molded joint of a HVDC extruded cable system). “Critical partial discharge” is used here to mean a discharge within the insulation of the object under test, excluding all external discharges that can be present during the ac voltage test, (e.g., corona discharges due to HV electrodes, conducting leads related to the test setup).

Keywords: HVDC extruded insulation, IEEE 2862™, partial discharge measurements, power cables, power cable joints, power cable testing

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

PDF: ISBN 978-1-5044-7257-9 STD24535
Print: ISBN 978-1-5044-7258-6 STDPD24535

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.html), 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 the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. 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. 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 his or her 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 development 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.

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 Standards Coordinating Committees 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. An IEEE Account is needed to access the application.

Comments on standards should be submitted using the Contact Us form.

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.

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, IEEE does not 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. 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. 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.

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 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.html. 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

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. 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 IEEE recommended practice was completed, the HVDC Cable Systems Working Group had the following membership:

Giovanni Mazzanti, *Chair*
Ivan Troia, *Vice Chair*

Jerome Castellon
George Chen
Bassel Diban
John Fothergill
June-Ho Lee
Frank Mauseth
Peter Morshuis
Clive Reed
Antonios Tzimas
Kai Wu

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

Saleman Alibhay
Earle Bascom III
Martin Baur
William Byrd
Jerome Castellon
Yunxiang Chen
Robert Christman
Bassel Diban
Gary Donner
Namal Fernando
John Fothergill
Nancy Frost
Paul Gaberson
Craig Goodwin
Werner Hoelzl
Wu Kai
Boris Kogan
Jim Kulchisky
Chung-Yiu Lam
William Larzelere
Arturo Maldonado
Frank Mauseth
Giovanni Mazzanti
Peter Morshuis
Rachel Mosier
Gearold O.H. Eidhin
Bansi Patel
Howard Penrose
Branimir Petosic
Benjamin Quak
Ion Radu
Lakshman Raut
Bartien Sayogo
John Smith III
Gary Smullin
Peter Tirinzoni
Ivan Troia
Antonios Tzimas
John Vergis
Lanyi Wang

When the IEEE SA Standards Board approved this recommended practice on 3 December 2020, it had the following membership:

Gary Hoffman, *Chair*
Jon Walter Rosdahl, *Vice Chair*
John D. Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
Doug Edwards
J.Travis Griffith
Grace Gu
Guido R. Hiertz
Joseph L. Koepfinger*
David J. Law
Howard Li
Dong Liu
Kevin Lu
Paul Nikolich
Damir Novosel
Dorothy Stanley
Mehmet Ulema
Lei Wang
Sha Wei
Philip B. Winston
Daidi Zhong
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 2862-2020, IEEE Recommended Practice for Partial Discharge Measurements under AC Voltage with VHF/UHF Sensors during Routine Tests on Factory and Pre-Molded Joints of HVDC Extruded Cable Systems up to 800 kV.

High-voltage direct-current (HVDC) cable systems with extruded insulation are becoming a more appealing option compared with Mass Impregnated Non-Draining (MIND) HVDC cable systems (see [B15],[B12])[1], but still have issues to be addressed. One is the development of long-lasting and reliable accessories, namely joints and terminations. In fact, test and service experience shows that joints, whose number is huge in long HVDC links, are the components that mostly affect the reliability of the whole cable system, but so far only a few tests exist on joints for HVDC extruded cable systems and there is a lack of standardization (see [B13]). Aiming to fill this gap, the IEEE DEIS HVDC Cable Systems Technical Committee followed the suggestions by CIGRÉ Technical Brochure (TB) 496:2012[2] and [B18], thereby preparing two position papers published in 2019 (see [B13] and [B14]). In [B13] it is shown that today:

a) Among prospective methods to characterize joints using new qualification and routine tests the electrical techniques identified are:

   1) Space charge (SC) measurements, still very challenging when considering full-size accessories.

   2) Partial discharge (PD) measurements, fostered in CIGRÉ TB 496:2012 and [B18].

b) Routine tests are the first practical target for the onset of new PD measurements on joints.

c) PD measurements under ac voltage are the readily-available measurements from manufacturers' practices for quality control of the insulation of accessories during routine tests. While the logical choice for HVDC extruded cable systems would be PD measurements using dc voltage, the reasons for choosing ac voltage are as follows:

   1) PD measurements under dc voltage may lead to insufficient data because of the low PD repetition rate, which can be many orders of magnitude lower than under ac voltage.

   2) Under dc voltage there are only very limited means of distinguishing PD from noise because of the lack of voltage phase relations.

   3) There is very little knowledge about the interpretation of PD signals obtained under dc voltage. Because the main purpose of PD measurements during routine tests is to detect defects in the insulation, it is, therefore, recommended to use ac voltage. AC voltage is generally more effective for the screening of production process defects, as voids, protrusions, adhesion problems between interfaces, etc. Furthermore, some issues may arise during successive dc energizations for other reasons, for example related to the dc design or to material behavior under dc voltage (space charge accumulation). This recommendation therefore focuses on screening for manufacturing defects for HVDC accessories. It has to be kept in mind that under dc voltage in a cable system under load, the electric field distribution in the insulation can be different from that under ac voltage. Therefore, there is a possibility that some defects that would give rise to PD activity in a loaded dc cable would remain undetected under ac voltage. In particular, this may be the case for defects close to the outer semicon sheath.

d) VHF/UHF electromagnetic (wireless) sensors are the best tool for performing such measurements on joints effectively in noisy environments like factories. In this respect, page 6 of IEC TS 62478:2016

[1]The numbers in brackets correspond to those of the bibliography in Annex C.
[2]Information on references can be found in Clause 2.

emphasizes the special need to give recommendations for the electromagnetic PD measurement methods[3], even though these do not accord with IEC 60270:2000.[4]

For this reason, in [B14] a protocol is proposed for PD measurements using ac voltages and VHF/UHF electromagnetic sensors during routine tests on factory and pre-molded joints of HVDC extruded cable systems. The protocol incorporates experience from manufacturers in similar measurements.

This recommended practice aims at improving this protocol and establishing it as a reference IEEE best practice for the measurement of partial discharges using ac voltages and VHF/UHF electromagnetic sensors on factory and pre-molded joints of HVDC extruded cable systems. At the time of writing, the maximum rated voltage of HVDC extruded cable systems commissioned worldwide is 400 kV [B7], but systems with rated voltage up to 640 kV are being qualified (see [B2] and [B8]) and higher voltages are expected. Aiming to account for these recent and/or ongoing developments, an upper limit of 800 kV has been selected for the rated voltage of HVDC extruded cables to which the present recommended practice is applicable [B16].

Acknowledgments

Grateful acknowledgment is made to CIGRÉ for permission to reprint the following source material:

— Technical Brochure N. 89, Accessories for HV Extruded Cables. CIGRÉ, February 1995.

— Technical Brochure N. 496, Recommendations for Testing DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 500kV. CIGRÉ, April 2012.

Grateful acknowledgment is made to the International Electrotechnical Commission (IEC) for permission to reproduce Information from its International Standards. All such extracts are copyright of IEC Geneva, Switzerland. All rights reserved. Further information on the IEC is available from www.iec.ch. IEC has no responsibility for the placement and context in which the extracts and contents are reproduced by the author, nor is IEC in any way responsible for the other content or accuracy therein.

[3] "*There is a special need to give recommendations for two used non-conventional methods, acoustic and electromagnetic ones, and this document is the first step in this direction.*" After IEC TS 62478:2016 ed. 1.0, Introduction, page 6, "Copyright © 2016 IEC Geneva, Switzerland. www.iec.ch. "

[4] "*Detection and measurement of effects of PD: activities that can be detected and measured using the following methods: electrical methods: conventional (according to IEC 60270) or electromagnetic (HF, VHF and UHF) methods.*" After IEC TS 62478:2016 ed. 1.0, clause 3.1.4, page 8, "Copyright © 2016 IEC Geneva, Switzerland. www.iec.ch."

Contents

IEEE Recommended Practice for Partial Discharge Measurements under AC Voltage with VHF/UHF Sensors during Routine Tests on Factory and Pre-Molded Joints of HVDC Extruded Cable Systems up to 800 kV

1. Overview

1.1 Scope

This document recommends best practices for the measurement of partial discharges using ac voltages and VHF/UHF electromagnetic sensors for quality control during routine tests on factory and pre-molded joints of HVDC extruded cable systems with rated voltage up to 800 kV. It must be emphasized that this recommended practice aims at focusing on the whole phenomenon of partial discharges, rather than solely on partial discharge pulse amplitude, in order to assess whether critical partial discharges are present in the tested object (either a factory joint or a pre-molded joint of a HVDC extruded cable system). By "critical partial discharge" it is meant here a discharge within the insulation of the object under test, excluding all external discharges that can be present during the ac voltage test, e.g., corona discharges due to HV electrodes, conducting leads related to the test setup.

1.2 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*).[5,6]

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*).

[5]The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.
[6]The use of *will* is deprecated and cannot be used when stating mandatory requirement; *will* is only used in statements of fact.