

IEEE Recommended Practice for the Characterization and Evaluation of Energy Storage Technologies in Stationary Applications

IEEE Power and Energy Society

Developed by the
Energy Storage and Stationary Battery Committee

IEEE Std 1679™-2020
(Revision of IEEE Std 1679-2010)

IEEE Recommended Practice for the Characterization and Evaluation of Energy Storage Technologies in Stationary Applications

Developed by the

Energy Storage and Stationary Battery Committee
of the
IEEE Power and Energy Society

Approved 5 March 2020

IEEE SA Standards Board

Abstract: Recommended information for an objective evaluation of an emerging or alternative energy storage device or system by a potential user for any stationary application is covered in this document. Energy storage technologies are those that provide a means for the reversible storage of electrical energy, i.e., the device receives electrical energy and is able to discharge electrical energy at a later time. The storage medium may be electrochemical (e.g., batteries), kinetic (e.g., flywheels), electrostatic (e.g., electric double-layer capacitors), thermal, compressed air, or some other medium. Devices recharged by non-electrical means, such as fuel cells, are beyond the scope of this document. The document provides a common basis for the expression of performance characteristics and the treatment of life-testing data. A standard approach for analysis of failure modes is also provided, including assessment of safety attributes. The intent of this document is to ensure that characterization information, including test conditions and limits of applicability, is sufficiently complete to allow valid comparisons to be made.

Keywords: battery, cycling service, electric double-layer capacitor, energy storage, flywheel, IEEE 1679™, standby service, stationary application

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

Copyright © 2020 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 10 April 2020. 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 978-1-5044-6530-4 STD24102
Print: ISBN 978-1-5044-6531-1 STDPD24102

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/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 documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

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

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed through scientific, academic, and industry-based technical working groups. Volunteers in IEEE working groups are not necessarily members of the Institute 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 Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. 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.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. 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: PROCUREMENT OF 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 should be considered 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, or 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 his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide 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 revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

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 imply 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.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. 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 fee, 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. 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. A current 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 at <http://ieeexplore.ieee.org/> or contact IEEE at the address listed previously. For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website at <http://standards.ieee.org>.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE SA Website at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Patents

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 <http://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.

Participants

At the time this IEEE recommended practice was completed, the Emerging Technologies Working Group had the following membership:

Jim McDowall, *Chair*
Mike Nispel, *Vice Chair*

Curtis Ashton	Richard Hutchins	Robert Rallo
Stephen Barber	Thomas Keels	David Rosewater
Brandon Bartling	Dennis Kountz	Benjamin Schenkman
Shoham Bhadra	Daniel Lambert	David Schoenwald
Sharon Bonesteel	Jody Leber	Christopher Searles
Raymond Byrne	Jose Marrero	Yogesh Singh
Babu Chalamala	Andrew Miraldi	Jeff van Aaken
Kevin DiGenova	Sepehr Mogharei	Charlie Vartanian
Jeffrey Donato	Volney Naranjo	Vilayanur Viswanathan
Kevin Fellhoelter	Tu Nguyen	Steve Willard
Brian Hanking		Rachel Wood

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

Curtis Ashton	Mariana Hentea	Marc Patterson
Ali Al Awazi	Werner Hoelzl	Christopher Petrola
Gary Balash	Anderson Hoke	Robert Rallo
Daniel Barsell	James Houston	Charles Rogers
Thomas Basso	Anthony Johnson	Chester Sandberg
Brian Baumgart	Gerald Johnson	Janette Sandberg
Robert Beavers	Geza Joos	Kenneth Sanders
Shoham Bhadra	Yuri Khersonsky	Bartien Sayogo
William Bloethe	Jim Kulchisky	Kenneth Sedziol
Daniel Boyer	Chung-Yiu Lam	Daniel Seidel
Demetrio Bucaneg Jr.	Daniel Lambert	Robert Seitz
Paul Cardinal	Raluca Lascu	Nikunj Shah
Thomas Carpenter	Jon Loeliger	Hyeong Sim
Ke Chen	Jose Marrero	Gary Smullin
Randall Crellin	Hugo Marroquin	Wayne Stec
Jesus DeLeon Diaz	Walter McCannon	Joseph Stevens
Mamadou Diong	Hank McGlynn	Gary Stoedter
Dieter Dohnal	Larry Meisner	David Tepen
Neal Dowling	James Midolo	James Timperley
Paul Duncan	Andrew Miraldi	Philip Undercuffler
Donald Dunn	Sepehr Mogharei	James Van De Ligt
Kevin Fellhoelter	Daleep Mohla	Charlie Vartanian
Rostyslaw Fostiak	David Mueller	John Vergis
John Gagge Jr	Alexandre Nassif	Jane Verner
Jalal Gohari	Chenhui Niu	Keith Waters
Stephen Grier	Lorraine Padden	Kenneth White
Randall Groves	James Parello	Kevin Whitener
Joel Hayes	Bansi Patel	Jian Yu

When the IEEE SA Standards Board approved this recommended practice on 5 March 2020, it had the following membership:

Gary Hoffman, *Chair*
Jon Walter Rosdahl, *Vice Chair*
Jean-Philippe Faure, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
J. Travis Griffith
Grace Gu
Guido R. Hiertz
Joseph L. Koepfinger*
John D. Kulick

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 1679-2020, IEEE Recommended Practice for the Characterization and Evaluation of Energy Storage Technologies in Stationary Applications.

Recent years have seen a significant increase in the number of energy storage devices being proposed for use in traditional battery applications. In addition, the characteristics of an emerging or alternative technology may be an enabling factor for new energy storage applications. A problem may arise, however, in the provision and analysis of information regarding the new technology. For existing applications, the technology developer may not be aware of the conventions already in use for submittal of technical data. Furthermore, the prospective user may not request or receive sufficient information to enable a full comparison to be made between technologies.

This recommended practice describes a format for the characterization of emerging and alternative energy storage technologies in terms of performance, service life, and safety attributes. This format provides a framework for developers to describe their products. The resulting information assists users in evaluating the possible application of emerging and alternative energy storage technologies.

Additional guidance on the application of this document for specific groups of technologies is provided in accompanying guide documents, both published and under development. These documents cover emerging technologies and newer, alternative technologies that can be considered commercialized. This series of documents is not intended to cover traditional battery technologies, such as lead-acid and nickel-cadmium.

Contents

1. Overview	11
1.1 Scope	11
1.2 Purpose	11
1.3 Word usage	12
2. Definitions, acronyms, and abbreviations	12
2.1 Definitions	12
2.2 Acronyms and abbreviations	12
3. Characterization information	13
3.1 Submittal conventions	13
3.2 Aging mechanisms and failure modes	16
3.3 Safety	17
3.4 Independent verification	20
4. Qualification testing	20
4.1 Functional testing	20
4.2 Abuse tolerance	20
4.3 Fault tolerance	20
4.4 Field testing	21
4.5 Standards compliance testing	21
5. Technology description	21
5.1 General	21
5.2 Storage medium	21
5.3 Intended applications	21
5.4 Components and construction	22
5.5 Operating conditions	23
5.6 Power and energy characteristics	23
5.7 Charging characteristics	23
5.8 Active management requirements	24
5.9 Application interface	24
5.10 Maintenance requirements	25
6. Regulatory issues	26
6.1 Hazard classes	26
6.2 Transportation	26
6.3 Safety Data Sheet (SDS)	26
6.4 Permitting issues	26
6.5 Spill containment	26
6.6 Ventilation	27
6.7 Disposal/recycling	27
6.8 Interconnection	27
7. Evaluation techniques	27
7.1 General	27
7.2 Application considerations	27
7.3 Safety	28
7.4 Code compliance	28
7.5 Life-cycle costing	28
7.6 Performance assessment	29
Annex A (informative) Bibliography	31

Annex B (informative) Sample data for lead-acid batteries.....	32
Annex C (informative) Interpretation of application data involving variable cycling regimes.....	35

IEEE Recommended Practice for the Characterization and Evaluation of Energy Storage Technologies in Stationary Applications

1. Overview

1.1 Scope

This document covers recommended information for an objective evaluation of an emerging or alternative energy storage technology by a potential user for any stationary application. Energy storage technologies are those that provide a means for the reversible storage of electrical energy, i.e., the device receives electrical energy and is able to discharge electrical energy at a later time. The storage medium may be electrochemical (e.g., batteries), kinetic (e.g., flywheels), electrostatic (e.g., electric double-layer capacitors [EDLCs]), thermal, compressed air, or some other medium. While many of the principles outlined in this recommended practice can be applied to a wide range of energy storage technologies, the primary focus is on stationary batteries. Devices recharged by non-electrical means, such as fuel cells, are beyond the scope of this document.

For the purposes of this document, *emerging* technologies are defined as those technologies recently, or soon to be, made available for sale under customary commercial terms (e.g., defined scope-of-supply, warranted performance). *Alternative* technologies are those that are currently mature but are less well-known or as frequently deployed as traditional technologies such as lead-acid and nickel-cadmium batteries or pumped-storage hydro. Stationary applications include both standby service and cycling operation.

The document provides a common basis for the expression of performance characteristics and the treatment of life-testing data. A standard approach for analysis of failure modes is also provided, including assessment of safety attributes. The intent of this document is to ensure that characterization information, including test conditions and limits of applicability, is sufficiently complete to allow valid comparisons to be made. The document does not specify test methods, minimum requirements, or pass/fail criteria.

This recommended practice does not describe individual energy storage technologies, nor does it provide guidance on their suitability for a particular application. This document does not cover sizing, installation, maintenance, and testing techniques, except insofar as they may influence the evaluation of a technology for its intended application.

1.2 Purpose

This recommended practice describes a format for the characterization of emerging or alternative energy storage technologies in terms of performance, service life, and safety attributes. This format provides a