



# IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis

IEEE Power and Energy Society

Developed by the  
Electric Machinery Committee

**IEEE Std 115™-2019**  
(Revision of IEEE Std 115-2009)

**STANDARDS**

# **IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis**

Developed by the

**Electric Machinery Committee**  
of the  
**IEEE Power and Energy Society**

Approved 7 November 2019

**IEEE SA Standards Board**

**Abstract:** Instructions for conducting generally applicable and accepted tests to determine the performance characteristics of synchronous machines are contained in this guide. Although the tests described are applicable in general to synchronous generators, synchronous motors (larger than fractional horsepower), synchronous condensers, and synchronous frequency changers, the descriptions make reference primarily to synchronous generators and synchronous motors.

**Keywords:** acceptance and performance testing, dynamic analysis, IEEE 115™, parameter determination, synchronous machines

---

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 27 March 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 978-1-5044-6347-8      STD23999  
Print: ISBN 978-1-5044-6348-5      STDPD23999

*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 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 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. 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 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 IEEE standards can be accessed via <https://standards.ieee.org/standard/index.html>. 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: <https://ieeexplore.ieee.org/browse/standards/collection/ieee/>. Users are encouraged to periodically check for errata.

## 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 guide was completed, the Test Procedure for Synchronous Machines Working Group had the following membership:

**Haran C. Karmaker**, *Chair*  
**Innocent Kamwa**, *Vice Chair*  
**Robert F. Gray**, *Secretary*

Jemimah C. Akiror  
William Bloethe  
Abdelghafour Belqorchi  
Stefano Bomben  
Edson C. Bortoni  
Douglas J. Conley  
Mohammed El Kahel  
Ahmed El Serafi

Swarn S. Kalsi  
Travis Kittleson  
Jim F. Lau  
Leonardo Lima  
Kevin Mayor  
Arezki Merkhouf  
Robert Messel  
Ali Moeini  
Nils E. Nilsson

Edward L. Owen  
Roberto Siniscalchi  
Nick Stranges  
Ernest Tchuisse  
Robert Thornton-Jones  
Stephen Umans  
Rene Wamkeue  
John Yagielski

The working group recognizes the contributions made by Prof. Ahmed El Serafi to the standard since 1992. Prof. El Serafi passed away on 9 April 2018.

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

Thomas Bishop  
William Bloethe  
Stefano Bomben  
Demetrio Bucaneg Jr  
Paul Cardinal  
Luis Coronado  
Scott Cotner  
Edson da Costa Bortoni  
Roger Daugherty  
Gary Donner  
Donald Dunn  
Rostyslaw Fostiak  
Alexander Glaninger-Katschnig  
J. Travis Griffith  
Randall Groves  
Paul Hamer  
Werner Hoelzl

Geza Joos  
Innocent Kamwa  
Haran C. Karmaker  
John Kay  
Isidoro Kerszenbaum  
Chung-Yiu Lam  
Mario Lanaro  
Leonardo Lima  
William Lockley  
Lawrenc Long  
O. Malik  
Kevin Mayor  
James Michalec  
Ali Moeini  
William Newman  
Lorraine Padden  
Shawn Patterson

Iulian Profir  
Bartien Sayogo  
Gary Smullin  
Kris Sommerstad  
Gary Stoedter  
Nick Stranges  
K. Stump  
David Tepen  
Michael Thompson  
Wayne Timm  
John Vergis  
Lisa Ward  
Iain Wright  
Dean Yager  
John Yagielski  
Oren Yuen  
Hugh Zhu

When the IEEE SA Standards Board approved this guide on 7 November 2019, it had the following membership:

**Gary Hoffman, *Chair***  
**Ted Burse, *Vice Chair***  
**Jean-Philippe Faure, *Past Chair***  
**Konstantinos Karachalios, *Secretary***

Masayuki Ariyoshi  
Stephen D. Dukes  
J. Travis Griffith  
Guido Hiertz  
Christel Hunter  
Joseph L. Koepfinger\*  
Thomas Koshy  
John D. Kulick

David J. Law  
Joseph Levy  
Howard Li  
Xiaohui Liu  
Kevin Lu  
Daleep Mohla  
Andrew Myles

Annette Reilly  
Dorothy Stanley  
Sha Wei  
Phil Wennblom  
Philip Winston  
Howard Wolfman  
Feng Wu  
Jingyi Zhou

\*Member Emeritus

## Introduction

This introduction is not part of IEEE Std 115-2019, IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis

IEEE Std 115-2019 incorporates and updates the contents of the 2009 edition.

The first AIEE “Test Code” for Synchronous Machines (#503) was issued in 1945 and formed the basis for the subsequent IEEE Std 115, which was first published in 1965.

The Generator Subcommittee’s Working Group (WG) #7, which produced this guide, was formed in July 2015 at the IEEE PES General Meeting, and the Project Authorization Request (PAR) was approved by the IEEE SA Standards Board in December 2015. This PAR included a proposal by the WG to update the entire document to reflect the state-of-the-art practices and technology. All corrections sent by users of the standard to IEEE SA were reviewed by the WG and implemented as needed.

The WG decided to keep the format and titles of the guide the same as in the previous edition.

During editorial review, it was recommended that the working group discontinue the title in two parts and make one title including the previous separate titles.

## Contents

1. Overview .....	13
1.1 Scope .....	13
1.2 Organization of the guide .....	13
1.3 Miscellaneous notes.....	14
1.4 Instrumentation.....	14
2. Normative references.....	15
3. Definitions .....	17
4. Miscellaneous tests.....	19
4.1 Insulation resistance .....	19
4.2 Dielectric and partial discharge tests .....	19
4.3 Resistance measurements .....	21
4.4 Tests for short-circuited field turns.....	24
4.5 Polarity test for field poles.....	25
4.6 Shaft current and bearing insulation .....	25
4.7 Phase sequence .....	27
4.8 Stator terminal voltage—waveform deviation and distortion factors .....	29
4.9 Overspeed tests .....	34
4.10 Line-charging capacity .....	34
4.11 Acoustic noise.....	35
4.12 Vibration testing .....	36
5. Saturation curves, segregated losses, and efficiency .....	38
5.1 Saturation curves .....	38
5.2 General considerations in segregated loss measurements.....	40
5.3 Methods to measure losses .....	42
5.4 Efficiency .....	62
6. Load excitation .....	63
6.1 General .....	63
6.2 Test methods.....	64
6.3 Load excitation calculation methods for specified machine terminal conditions .....	67
6.4 Excitation calculation methods used in stability computer programs.....	74
7. Temperature tests.....	76
7.1 General .....	76
7.2 Methods of loading .....	77
7.3 Duration of test .....	83
7.4 Methods to measure temperature.....	83
7.5 Preparation for test.....	86
7.6 Determination of coolant temperature .....	87
7.7 Temperature readings .....	88
7.8 Shutdown temperatures .....	90
7.9 Temperature rise .....	91
8. Torque tests .....	91
8.1 General .....	91
8.2 Locked-rotor current and torque.....	92
8.3 Speed-torque tests.....	95

8.4 Pull-out torque .....	101
9. Applications of machine electrical parameters .....	102
9.1 General .....	102
9.2 Per unit (p.u.) quantities.....	103
10. Tests for determining parameter values for steady-state conditions.....	111
10.1 Purpose .....	111
10.2 Instrumentation.....	111
10.3 Direct-axis synchronous reactance, $X_d$ .....	112
10.4 Quadrature-axis synchronous reactance, $X_q$ .....	113
10.5 Negative-sequence quantities (steady state) .....	117
10.6 Zero-sequence quantities .....	124
10.7 Testing procedures and parameter determination for positive-sequence resistance for a synchronous machine.....	130
10.8 Additional miscellaneous steady-state tests for synchronous machines .....	131
11. Tests for evaluating transient or subtransient characteristic values .....	134
11.1 Introduction .....	134
11.2 Instrumentation.....	135
11.3 Caution .....	135
11.4 Test procedures.....	136
11.5 Models and methods to extract parameters from tests .....	144
12. Standstill frequency response (SSFR) testing.....	179
12.1 General considerations and basic theory.....	179
12.2 Testing conditions for SSFR procedures and instrumentation requirements.....	183
12.3 Test procedures.....	189
12.4 Interpretation of test data .....	197
12.5 Suggested procedure for development of a third-order model.....	200
Annex A (informative) Bibliography .....	212
Annex B (normative) Nomenclature .....	215
B.1 Overview.....	215
B.2 Parameters used in Clause 4.....	215
B.3 Parameters used in Clause 5.....	215
B.4 Parameters used in Clause 6.....	216
B.5 Parameters used in Clause 7.....	217
B.6 Parameters used in Clause 8.....	218
B.7 Parameters used in Clause 9.....	219
B.8 Parameters used in Clause 10.....	219
B.9 Parameters used in Clause 11.....	221
B.10 Parameters used in Clause 12.....	223
Annex C (informative) Telephone-influence factor (TIF).....	225
C.1 General.....	225
C.2 Balanced TIF.....	226
C.3 Residual-component TIF.....	226
C.4 Line-to-neutral TIF .....	228
Annex D (informative) Discussion on leakage and Potier reactances .....	229
Annex E (informative) Example of calculation of field current $I_{fd}$ in per unit.....	231

Annex F (informative) Details on the mathematical background for Clause 11 .....	233
F.1 General .....	233
F.2 Theoretical background for ac and dc components of short-circuit current .....	234
F.3 Polynomial fitting of upper and lower short-circuit current envelopes .....	235
F.4 Theoretical background for load rejection test .....	235
Annex G (informative) Magnetic nonlinearity .....	237
Annex H (informative) Example of SSFR test data analysis for a large turbogenerator .....	240
H.1 Introduction .....	240
H.2 Machine technical details.....	240
H.3 Establishing field-to-armature-turns ratio .....	241
H.4 Approach to model development .....	241
H.5 Method I: Single-step full data fitting.....	241
H.6 Method II: Fitting with unknown values of $R_{fd}$ and $N_{afd}$ .....	242
H.7 Method III: Fixed $N_{af}$ .....	242
H.8 Presentation of data for stability studies .....	242

# IEEE Guide for Test Procedures for Synchronous Machines Including Acceptance and Performance Testing and Parameter Determination for Dynamic Analysis

## 1. Overview

### 1.1 Scope

This guide contains instructions for conducting generally applicable and accepted tests to determine the performance characteristics of synchronous machines. Although the tests described are applicable in general to synchronous generators, synchronous motors (larger than fractional horsepower), synchronous condensers, and synchronous frequency changers, the descriptions make reference primarily to synchronous generators and synchronous motors. The tests described may be applied to motors and generators, as needed, and no attempt is made to partition this guide into clauses applying to motors and clauses applying to generators. It is not intended that this guide shall cover all possible tests or tests of a research nature, but only general methods that may be used to obtain performance data. The schedule of factory and field tests, which may be required on new equipment, is normally specified by applicable standards or by contract specifications. This guide should not be interpreted as requiring any specific test in a given transaction or implying any guarantee about specific performance indices or operating conditions.

The term *specified conditions* for tests as used in this guide will be considered as rated conditions unless otherwise agreed upon. Rated conditions apply usually to the quantities listed on the machine nameplate.

### 1.2 Organization of the guide

The guide consists of 12 clauses. Each clause is organized into subclauses.

Alternative methods of making many of the tests covered in this guide are described and are suitable for different sizes and types of machines and different conditions. In some cases, the preferred method is indicated. The manufacturer's choice of method for factory or field tests on new equipment will govern in the absence of prior agreement or contract specification.