

IEEE Recommended Practice for Conducting Harmonic Studies and Analysis of Industrial and Commercial Power Systems

Sponsor

Technical Books Coordinating Committee
of the
IEEE Industry Applications Society

Approved 27 September 2018

IEEE-SA Standards Board

Abstract: Harmonic studies and analysis of industrial and commercial power systems are described. The basic concepts involved in such studies are described first. This is followed by a discussion of how to determine the need for a harmonic study, how to assemble the required data, how to recognize potential problems, and how to implement corrective measures.

Keywords: commercial power system, harmonics, harmonic analysis, harmonic analysis methods, harmonic analysis tools, harmonic distortion, harmonic filters, harmonic frequency scan, harmonic impedance, harmonic limits, harmonic load flow, harmonic mitigation, harmonic power flow study, harmonic sources, harmonic studies, IEEE 3002.8™, industrial and commercial power systems, industrial power system, interharmonics, resonance, system modeling

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

Copyright © 2018 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 22 October 2018. 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 978-1-5044-5177-2 STD23311
Print: ISBN 978-1-5044-5178-9 STDPD23311

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. Volunteers 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 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, correctness, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: result 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, conferences, and 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 the IEEE-SA Website 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 Patent 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 Power Systems Analysis Working Group (IEEE 3002 Series) was chaired by Farrokh Shokooch with the following membership for the 3002.8 Working Group, harmonic studies and analysis:

J. J. Dai, Co-Chair
Farrokh Shokooch, Co-Chair

Alok Gupta
Tanuj Khandelwal
Wei-Jen Lee

Haijun Liu
Albert Marroquin

Louie Powell
Aparna Sinha
Peter Sutherland

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

William Ackerman
Steven Bezner
Wallace Binder
Thomas Bishop
Thomas Blair
William Bloethe
Mark Bowman
Frederick Brockhurst
Gustavo Brunello
William Bush
William Byrd
Paul Cardinal
Keith Chow
Larry Conrad
Stephen Conrad
Terry Conrad
Glenn Davis
Davide De Luca
Carlo Donati
Gary Donner
Neal Dowling
Keith Flowers
Gary Fox
Doaa Galal
Randall Groves

Ajit Gwal
Paul Hamer
Robert Hanna
Werner Hoelzl
Robert Hoerauf
John Houdek
Noriyuki Ikeuchi
Geza Joos
Laszlo Kadar
John Kay
Yuri Khersonsky
Jim Kulchisky
Theo Laughner
William Lockley
Omar Mezzoni
John McManey Jr.
William M. Bride
Jerry Murphy
Dennis Neitzel
Michael Newman
Nick S. A. Nikjoo
Joe Nims
Gearold O. H. Eidhin
Gregory Olson

Mirko Palazzo
Antony Parsek
Louie Powell
Jian Yu
Michael Roberts
Charles Rogers
Joseph Rostron
Daniel Sabin
Steven Sano
Bartien Sayogo
Kenneth Sedziol
Robert Seitz
Nikunj Shah
Michael Simon
David Singleton
Jerry Smith
Gary Smullin
Eugene Stoudenmire
K. Stump
David Tepen
Demetrios Tziouvaras
Marcelo Valdes
Kenneth White
Larry Young
Jian Yu

When the IEEE-SA Standards Board approved this recommended practice on 27 September 2018, it had the following membership:

Jean-Philippe Faure, *Chair*
Gary Hoffman, *Vice Chair*
John Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Ted Burse
Guido Hiertz
Christel Hunter
Thomas Koshy
Joseph L. Koepfinger*
Hung Ling

Dong Liu
Xiaohui Liu
Daleep Mohla
Andrew Myles
Paul Nikolich
Annette D. Reilly
Robby Robson

Dorothy Stanley
Mehmet Ulema
Phil Wennblom
Philip Winston
Howard Wolfman
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 3002.8™-2018, IEEE Recommended Practice for Conducting Harmonic Studies and Analysis of Industrial and Commercial Power Systems.

IEEE 3000 Standards Collection™

This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society, as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material included in the 13 IEEE Color Books will be included in a series of new standards—the most significant of which will be a new standard, IEEE Std 3000™, IEEE Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000™:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

IEEE Std 3002.8™

The material in this recommended practice originally comes from Chapter 10 of the *IEEE Brown Book™*, IEEE Std 399™-1997 Recommended Practice for Industrial and Commercial Power Systems Analysis but includes major modifications based on the latest technological advancements.

This publication provides a recommended practice for conducting harmonic studies and analysis of power systems in commercial and industrial facilities. It is likely to be of greatest value to the power-oriented engineer with limited commercial or industrial plant experience. It can also be an aid to all engineers responsible for the electrical design of commercial and industrial facilities. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and general reference on analysis of commercial and industrial facilities.

Topics of this standard are organized in the following sequence:

- a) Harmonic-analysis objectives

- b) Harmonic-analysis methodologies and applicable standards
- c) System and component models for use in computer simulations for harmonic analysis
- d) Data required for computer simulations
- e) Common data collection and preparation procedures
- f) Importance of model and data validation
- g) Typical harmonic-analysis study scenarios, solution parameters, and results and reports interpretation
- h) Preferred features for harmonic-analysis tools
- i) Illustration examples

Currently in preview, click buy full version

Contents

1. Overview.....	15
1.1 Scope.....	15
2. Normative references	15
3. Definitions.....	16
4. Introduction.....	17
5. Background.....	18
6. Analysis objectives.....	19
7. Methodology and standards.....	21
7.1 General harmonic-analysis methodology	21
7.2 Harmonic sources	21
7.3 Effects of harmonics	22
7.4 Resonance	23
7.5 Harmonic-analysis-related standards.....	29
8. System simulation and modeling.....	29
8.1 General harmonic response study techniques	29
8.2 General power system element modeling for harmonic analysis	30
8.3 Rotating machine model.....	30
8.4 Transformer model	32
8.5 Passive load model	33
8.6 Transmission line and cable models	33
8.7 Filter models.....	34
8.8 PF correction capacitor model and its effect	36
8.9 Representation of the utility system.....	37
8.10 Computer simulation methods.....	38
8.11 Common harmonic distortion indices.....	39
8.12 Harmonic generation	41
8.13 Interharmonics.....	44
8.14 Harmonic analysis for industrial and commercial systems	45
9. Required data	47
9.1 Data for analysis	47
10. Data collection and preparation.....	49
11. Model and data validation	49
12. Study scenarios.....	50
13. Solution parameters.....	50
14. Results and report.....	50
14.1 Introduction.....	50
14.2 Study report.....	51
14.3 Study plot	51
14.4 Study display	53
14.5 Harmonic study distortion limits	54
14.6 Harmonic study result analyzer	56

15. Features of analysis tools.....	56
16. Illustration examples.....	58
16.1 Introduction.....	58
16.2 Example 1: A simplified industrial system.....	58
16.3 Example 2: A 13-bus balanced industrial distribution system.....	63
16.4 Example 3: A composite industrial power system.....	65
Annex A (informative) Bibliography.....	73

List of Figures

Figure 1—Example circuit for series resonance	24
Figure 2—Impedance magnitude versus frequency for series resonant circuit.....	25
Figure 3—Potential series resonant situation	26
Figure 4—Typical parallel resonant circuit	27
Figure 5—Impedance magnitude versus frequency for parallel circuits	27
Figure 6—Possible parallel resonant circuit: plant harmonics	28
Figure 7—Impedance characteristic of multiple tuned filters.....	28
Figure 8—Filters commonly used for harmonic mitigation	35
Figure 9—Example system for PF correction capacitor model	36
Figure 10—Variations in frequency response at the 33 kV bus as a function of capacitor bank size	37
Figure 11—Frequency response at the 33 kV bus as a function of utility fault MVA.....	38
Figure 12—Multipulse converter arrangements.....	43
Figure 13—Study results with consideration of interharmonics (voltage waveform at BUS B).....	44
Figure 14—Study results without consideration of interharmonics (voltage waveform at BUS B)	45
Figure 15—Harmonic current spectrum in percent of fundamental current (horizontal axis is harmonic order).....	52
Figure 16—Current waveform with harmonics in one cycle (vertical axis is in per unit and horizontal axis is in cycle)	52
Figure 17—Bus driving point impedance magnitude within a selected frequency range (horizontal axis is multiplier of the fundamental frequency 60 Hz).....	53
Figure 18—Bus driving point impedance phase angle within a selected frequency range (horizontal axis is multiplier of the fundamental frequency 60 Hz).....	53
Figure 19—Sample one-line display of results for harmonic power flow calculation	54
Figure 20—Example system for harmonic studies	59
Figure 21—Driving point impedance at the 33 kV bus.....	60
Figure 22—Harmonic magnitude spectrum at the 33 kV bus	61
Figure 23—Harmonic magnitude spectrum at the 220 kV bus	61
Figure 24—Driving point Impedance at the 33 kV bus	62
Figure 25—Driving point impedance at the 6.6 kV bus.....	63
Figure 26—One-line diagram of Example 2 system.....	63
Figure 27—One-line diagram of illustration Example 3	66

Figure 28—Arc furnace voltage harmonic spectrum (typical)	67
Figure 29—ASD current harmonic spectrum (IEEE typical 6-pulse)	67
Figure 30—Arc furnace feeder current harmonic distortions (without filters)	68
Figure 31—Arc furnace feeder current harmonic distortions (comparison at 13.8 kV).....	68
Figure 32—Reduced harmonic current distortions.....	69
Figure 33—Harmonic currents from ASD and cancellation by phase-shift transformers.....	70
Figure 34—Current harmonic cancellation from parallel phase-shifting transformers	71
Figure 35—Bus 1A driving point impedance frequency characteristics.....	72

List of Tables

Table 1—Power system component models for harmonic analysis	31
Table 2—Characteristic ac line harmonic currents in multipulse systems	42
Table 3—Fundamental voltage across a single-tuned filter capacitor	47
Table 4—Maximum odd harmonic current distortion limit in percent of load current (I_L)	54
Table 5—Harmonic voltage distortion limit	55
Table 6—Harmonic result analyzer indicating VTHD results of multiple studies	56
Table 7—Utility supply data	59
Table 8—Transformer data	59
Table 9—Load and capacitor data	59
Table 10—Harmonic content of diode rectifier current (ac side) at the 33 kV bus	60
Table 11—Harmonic content of bus voltages including the effects of ASD at the 6.6 kV bus	62
Table 12—Harmonic source data for ASD	64
Table 13—Plant harmonic voltage distortion summary	64

IEEE Recommended Practice for Conducting Harmonic Studies and Analysis of Industrial and Commercial Power Systems

1. Overview

1.1 Scope

This recommended practice describes how to conduct harmonic studies and analysis of industrial and commercial power systems. The basic concepts are described first. This is followed by a discussion of how to determine the need for a harmonic-analysis study, how to assemble the required data, how to recognize potential problems, and how to implement corrective measures.

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.

CIGRE Working Group 36, 05, “Harmonics—characteristic parameters, methods of study, estimates of existing values in the network,” *Electra*, no. 77, pp. 35-54, 1981.¹

IEC/TR 61000-3-6, Electromagnetic compatibility (EMC)—Part 3-6: Limits—Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.²

IEEE Power Engineering Society, “Tutorial on harmonics modeling and simulation,” Publication No. 98TP125-0. Piscataway, NJ: Institute of Electrical and Electronics Engineers, 1998.^{3,4}

IEEE Power Engineering Society Transmission and Distribution Committee Task Force on Harmonics Modeling and Simulation, “Test systems for harmonic modeling and simulation,” *IEEE Transactions on Power Delivery*, vol. 14, no. 2, pp. 579-587, April 1999, <http://dx.doi.org/10.1109/61.754106>.

¹CIGRE publications are available from the Council on Large Electric Systems (<http://www.e-cigre.org/>).

²IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>) and the American National Standards Institute (<http://www.ansi.org/>).

³The IEEE standards or products referred to in [Clause 2](#) are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

⁴IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).