IEEE 3000
STANDARDS COLLECTION®

IEEE 3001 STANDARDS:
POWER SYSTEMS DESIGN

IEEE Std 3001.9™-2023

Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commercial and Industrial Facilities



IEEE STANDARDS ASSOCIATION

IEEE Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commercial and Industrial Facilities

Developed by the

Industrial & Commercial Power Systems Standards Development Committee (IAS/ICPS/SDC)
of the
IEEE Industry Applications Society

and the

Illuminating Engineering Society

Approved 15 February 2023

IEEE SA Standards Board

Recognized as an American National Standard

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Abstract: The design of power systems supplying lighting loads of industrial and commercial facilities are covered in this recommended practice. Common power system considerations specifically related to lighting loads are discussed, including voltage drop, transients, flicker, and circuiting recommendations for various applications. General fundamental concepts of lighting design, including common light sources, control methods, and application techniques, are discussed. Industry-recognized lighting design organizations and applicable lighting codes are discussed and identified as further resources for the lighting designer.

Keywords: IEEE 3001.9™, IES RP-48-23, lighting controls, luminaire, power system design

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

Copyright © 2023 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 25 May 2023. 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.

National Electrical Code and NEC are both registered trademarks of the National Fire Protection Association, Inc.

National Electrical Safety Code and NESC are both registered trademarks and service marks of the Institute of Electrical and Electronics Engineers, Inc.

The IES Lighting Library is a registered trademark of the Illuminating Engineering Society.

PDF: ISBN 978-1-5044-9459-5 STD25981
Print: ISBN 978-1-5044-9460-1 STDPD25981

IEEE prohibits discrimination, harassment, and bullying.
For more information, visit https://www.ieee.org/about/corporate/governance/p9-26.html.
No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

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.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

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 & 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.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

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.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

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.

IES DISCLAIMER

IES publications are developed through the consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on lighting recommendations. While the IES administers the process and establishes policies and procedures to promote fairness in the development of consensus, it makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

The IES disclaims liability for any injury to persons or property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document.

In issuing and making this document available, the IES is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the IES undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The IES has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the IES list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or statement of compliance with the requirements of this document shall not be attributable to the IES and is solely the responsibility of the certifier or maker of the statement.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Participants

At the time this IEEE recommended practice was completed, the Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commercial and Industrial Facilities Working Group had the following membership:

Gary H. Fox, *Chair*
Bill Busch, *Vice Chair*
James Harvey, *Vice Chair*
Ahmed Elsayed, *Secretary*

Michael Anthony
Cody Bargholz
Koti Reddy Butukuri
Preston Cobb
Joseph Damm
Behzad Eghtesady
James Gaines
Shubhanker Garg
John Kay
Mark Lien
Christophe Martinsons
Kimberly Molloy
Sivaraman P
Lorraine Padden
Giuseppe Parise
Dev Paul
Derrick Robey
Emily Royal
Amit Singh
Wayne Stoppelmoor
Marcelo Valdes
Matthew Wakeham
Stephen Williams
Howard Wolfman
Georges Zissis

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

Robert Arno
Frederick Brockhurst
Bill Brown
Gustavo Brunello
Bill Busch
Koti Reddy Butukuri
Paul Cardinal
Sean Carr
Timothy Coyle
Joseph Damm
Neal Dowling
Donald Dunn
Behzad Eghtesady
Gary H. Fox
Carl Fredericks
James Gaines
Shubhanker Garg
James Harvey
Chris Heron
Werner Hoelzl
Robert Hoerauf
Richard Holub
John Houdek
Christel Hunter
Matthew Hussey
John Kay
Thomas Keels
Yuri Khersonsky
Edwin Kramer
Mikhail Lagoda
Chung-Yiu Lam
Wei-Jen Lee
Duane Leschert
Mark Lien
Christophe Martinsons
Jeffrey McElray
Daleep Mohla
Daniel Neeser
Arthur Neubauer
Noor Mohd Fadzli Othman
Sivaraman P
Lorraine Padden
Pathik Patel
Dev Paul
Howard Penrose
Jim Phillips
Derrick Robey
Charles Rogers
Emily Royal
Ryandi Ryandi
Ahmed Saied
Mervin Savostianik
Bartien Sayogo
Robert Seitz
Nikunj Shah
Jeremy Smith
Jerry Smith
Gary Smullin
Kris Sommerstad
Wayne Stec
Wayne Stoppelmoor
Divyapradeepa T
David Tepen
Prabhat Tripathi
Marcelo Valdes
James Van De Ligt
John Vergis
Matthew Wakeham
Keith Waters
Kenneth White
Kenneth White
Stephen Williams
Howard Wolfman
Oren Yuen
Nicholas Zagrodnik
Georges Zissis

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

When the IEEE SA Standards Board approved this recommended practice on 15 February 2023, it had the following membership:

David J. Law, *Chair*
Vacant Position, *Vice Chair*
Gary Hoffman, *Past Chair*
Konstantinos Karachalios, *Secretary*

Sara R. Biyabani
Ted Burse
Doug Edwards
Ramy Ahmed Fathy
Guido R. Hiertz
Yousef Kimiagar
Joseph L. Koepfinger*
Thomas Koshy
John D. Kulick
Joseph S. Levy
Howard Li
Johnny Daozhuang Lin
Gui Lin
Xiaohui Liu
Kevin W. Lu
Daleep C. Mohla
Andrew Myles
Paul Nikolich
Annette D. Reilly
Robby Robson
Lei Wang
F. Keith Waters
Karl Weber
Philip B. Winston
Don Wright

*Member Emeritus

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Introduction

This introduction is not part of IEEE Std 3001.9-2023/IES RP-48-23, IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commercial and Industrial Facilities.

IEEE 3000 Series®

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 IEEE's popular series of "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 thirteen "color books" will be included in a series of new standards—the most significant of which will be a new book, IEEE Standard 3000, "Recommended Practice for the Engineering of Industrial and Commercial Power Systems." The new book will cover the fundamentals of planning, design, analysis, construction, installation, start-up, 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 Standard 3000:

— Power Systems Design (3001 series)

— Power Systems Analysis (3002 series)

— Power Systems Grounding (3003 series)

— Protection and Coordination (3004 series)

— Emergency, Stand-By 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 color book. In other cases, material from several color books has been combined into a new "dot" standard.

The material in this recommended practice replaces Chapter 10 of IEEE Std 241™-1990, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*™).

IEEE Std 3001.9™/IES RP-48-23

This publication provides a recommended practice for the electrical design of 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 electrical design for commercial and industrial facilities.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Acknowledgments

Figure 10 is reprinted with permission from the Centre Scientifique et Technique du Bâtiment (CSTB). The figure was first published on page 150 in Technical Report ED-712-150021-712-ECE “Caractérisation de lampes à usage domestique” © CSTB, 2016.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Contents

1. Overview 13
1.1 Scope 13
1.2 Word usage 13

2. Normative references 14

3. Definitions, acronyms, and abbreviations 14

4. Local, state, federal, and regional codes, and regulations 14

5. Power systems for lighting 15
5.1 Power system components 15
5.2 Design considerations 25

6. Temporal light modulation 38
6.1 Definitions of TLM, TLA, and “flicker” 38
6.2 Temporal light modulation and the light waveform 38
6.5 Different types of temporal light artifacts perceived by the human visual system 42
6.6 Neurophysiological and health effects of temporal light modulation 45
6.7 Metrics describing temporal light artifacts 47
6.7.6 Comparison of the existing metrics 50
6.8 Measurement methods 50
6.8.1 Laboratory measurements 50
6.8.2 On-site measurements 51
6.9 Published limits concerning temporal light modulation and temporal light artifacts 52
6.9.1 Modulating current in high-brightness LEDs for mitigating health risks to viewers 52
6.9.2 NEMA 77 53
6.9.3 California Energy Commission (CEC) 53
6.9.4 ENERGY STAR® Specifications 54
6.9.5 European Commission Regulation EU 2019/2020 54

7. Lighting installation, safety and energy codes, and safety standards 55
7.1 NFPA 70, National Electrical Code (NEC) 55
7.2 California Energy Code 137
7.3 Seismic requirements 141
7.4 International Building Code (IBC) 143
7.5 NFPA 101 Life Safety Code 146
7.6 National Electrical Safety Code—Locations where applicable 150
7.7 UL safety standards, listing, NRTL, and CE marking 151
7.8 National Electrical Manufacturers Association 152

8. Damp, wet locations 156
8.1 General 156
8.2 Luminaire 157
8.3 Lampholders 158
8.4 Signs and outline lighting systems 158
8.5 Class 2 power supplies and transformers 159
8.6 Wiring methods and materials 159
8.7 Corrosion protection 161

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

9. Lighting systems in industrial and commercial facilities 163
9.1 References to existing lighting standards and recommended practices 163
9.2 Minimum and recommended luminaire information requirements 165
9.3 Installation instructions for luminaires 165
9.4 Luminaire mounting options....166
9.5 Isolation transformers and voltage drop 166
9.6 Lighting nomenclature and definitions 166
9.7 Multiwire systems (sharing a neutral in the system)....166
9.8 Retrofit considerations (energy compliance, third party listing, controls, etc.) 167
9.9 IES Lighting Library 168

10. Campus lighting systems 168
10.1 Overview 168
10.2 EPLS complexity 173
10.3 Basic terminology 175
10.4 General considerations....177
10.5 Best practices....182

11. Roadway tunnel lighting....186
11.1 General 186
11.2 LED light sources 187
11.3 Emergency lighting....187
11.4 Electrical considerations 187
11.5 Roadway tunnel cleaning and maintenance 187

12. Lighting control strategies 188
12.2 Commercial interior lighting control 189
12.3 Industrial and commercial exterior lighting control 191
12.4 Lighting control systems by space....191
12.5 Lighting control equipment 195

Annex A (informative) Bibliography 200
A.1 General references 200
A.2 Illuminating Engineering Society standards 205

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commercial and Industrial Facilities

1. Overview

1.1 Scope

This recommended practice covers the design of power systems supplying lighting loads of industrial and commercial facilities. Common power system considerations specifically related to lighting loads are covered, including voltage drop, transients, flicker, and circuiting recommendations for various applications. General fundamental concepts of lighting design, including common light sources, control methods, and application techniques, are discussed. Industry-recognized lighting design organizations and applicable lighting codes are discussed and identified as further resources for the lighting designer.

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*).[1, 2]

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

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

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

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

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

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.

NEMA LSD 2, Wiring Requirements for T8 and Twin T5 Fluorescent Lamps with Instant-Start Ballasts.[3]

NEMA LL 9, Dimming of T8 Fluorescent Lighting Systems.

NEMA LSD 14, Guidelines on the Application of Dimming to High-Intensity Discharge Lamps.

NEMA LSD 18, Selection of Electronic Ballasts for Fluorescent Lamps in Frequently Switched Applications.

NEMA LSD 21, End-of-life Operation of Small Diameter (5/8-inch Diameter or Less) Pin-Based Fluorescent Lamps.

NEMA LSD 23, Recommended Practice—Lamp Seasoning for Fluorescent Dimming Systems.

NEMA LSD 34, Recommended Practices for T8 Rapid Start Fluorescent Lamp Dimming (17W, 25W, 32W, and 40W Lamps).

NEMA LSD 55, Outdoor Lighting and Human/Animal Factors: An Industry Evaluation.

NFPA 70, National Electrical Code® (NEC®).[4, 5]

Status of State Energy Code Adoption—Commercial, U.S. Department of Energy Building Energy Codes Program (BECP).[6]

3. Definitions, acronyms, and abbreviations

The *IEEE Standards Dictionary Online* should be consulted for definition of terms used in this recommended practice.[7]

4. Local, state, federal, and regional codes, and regulations

The engineer should be cognizant of the codes and regulations that pertain to the facility for which they are designing an electrical distribution system. In the United States, the National Electrical Code® (NEC®) serves as an essential guideline, although it does not represent a design specification but instead identifies minimum requirements for the safe installation and utilization of electricity.[8] Other National Fire Protection Association (NFPA) standards may also be applicable. While most municipalities, counties, and states use the NEC (either with or without modifications), some have their own codes almost as extensive as the

[3] NEMA publications are available from the National Electrical Manufacturers Association (https://www.nema.org/).
[4] The NEC is published by the National Fire Protection Association (https://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers (https://standards.ieee.org/).
[5] National Electrical Code and NEC are both registered trademarks of the National Fire Protection Association, Inc.
[6] This document is available at http://www.energycodes.gov/status/commercial.
[7] *IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.
[8] Information on references can be found in Clause 2.

Copyright © 2023 IEEE. All rights reserved.
Documents Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

NEC. Only the code adopted by ordinance as of a certain date is official, and governmental bodies may delay adopting the latest code.

Versions of the NEC are also enforced in much of Latin America, while Canada has its own electrical code, CSA 22.1 [B29].[9] In Europe, International Electrotechnical Commission (IEC) standards have been adopted, although not universally by all countries. The countries of the United Kingdom share a common standard as do Australia and New Zealand. Elsewhere, individual countries typically have their own unique electrical code. It is beyond the scope of this recommended practice to cover all these variances; hence, the engineer is responsible for knowing which electrical code is being enforced and for becoming familiar with its requirements.

5. Power systems for lighting

5.1 Power system components

5.1.1 General

Power system components such as panels, cables, switchgear, conduits, automatic transfer switches (ATS), static transfer switches (STS), inverter systems, and generators are used for satisfactory operation of both normal and emergency lighting systems in commercial and industrial power systems, as explained in detail in this clause.

5.1.2 Lighting panels

Lighting panels are devices intended for the protection and control of branch circuits that supply lighting loads. Fuses or circuit breakers are typically used to provide overcurrent protection to the circuit. Switching devices and controllers are used for switching and controlling the lights and lighting circuits. Depending on the utilization voltage of the lighting load, a low-voltage transformer may or may not be necessary to transform the service voltage to that of the lighting load. Overcurrent devices are most often contained in branch-circuit panelboards separately enclosed from those that contain the control and automatic switching devices. The branch-circuit panels may be dedicated to lighting loads, or they might also supply other types of loads. Further information on panelboards used for power distribution is available in IEEE Std 3001.5™ [B63].

Modern lighting panels can generally control the lighting loads in smart and effective ways. An “intelligent” lighting panel or system can consist of sensors (e.g., motion sensors and light detection sensors) or timers to provide automatic operation of lighting loads. The primary benefit of automatic lighting controls is reducing energy consumption.

5.1.3 Relay control panels

Relay control panels can be free standing, floor mounting, or wall mounted. Cable entries can be from the top or bottom as needed to efficiently install the necessary wire raceways. Panels should be of NEMA 1 or ingress protection 31 (IP31) class or better for indoor and NEMA 3R/IP54 class or better for outdoor. Panel boxes may have conduit “knockouts” formed into the ends, or the ends may be blank and removable to make it easier to punch out holes. Panels should be painted or otherwise protected from corrosion. Fronts are commonly painted, while the boxes may be galvannealed. The color of paint for the exterior of the

[9] The numbers in brackets correspond to those of the bibliography in Annex A.

Copyright © 2023 IEEE. All rights reserved.
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

panels should match that of other panels in the facility. ANSI 61 [B3] gray is a common standard color in North America. Other colors may be available at a higher cost. Color should be discussed and mutually agreed to between supplier and client. Panels should have a hinged, lockable front door. Panels should facilitate direct access to any component mounted inside. Twenty percent free space is recommended for the possible addition of future devices. All equipment mounted on the panels should have individual name plates with engraved equipment designations. Internal wiring to be connected to external equipment should terminate on terminal blocks, which should provide a minimum of 20% spare terminals for the panel. However, the percentage of spares should be discussed and agreed to mutually between the client and the supplier. The terminal blocks for current transformers and voltage transformers should be provided with test links and isolating facilities. Current transformer terminal blocks should be provided with short-circuiting style terminals.

All auxiliary control relays and devices should be of latest version, manufactured by a reputable supplier and suitable for the application, subject to owner's or owner's representative approval. Relays and timers should have appropriate setting ranges, accuracy, resetting ratios, and other characteristics to provide required sensitivity to satisfaction of the customer. Relays should be provided with self-reset contacts except for the trip lockout relays, which should have manual reset facility. Current transformers should have suitable accuracy ratings and be rated for the expected load current. The pick-up range of binary inputs should be a minimum of 70 V dc/V ac. A timing accuracy of 1 ms should be achieved for all numerical relays. Relay control panels should have indicating lights and/or display screens mounted on the front cover for visual indication and display.

The panel enclosure and any integral ground bus provided should be grounded and bonded in compliance with local building codes and industry-recognized practices (refer to IEEE Std 3003.2™ [B65]). All the metallic cases of the mounted equipment should be separately connected to ground using copper wire with a minimum size of #14 AWG (2.5 mm^2) or greater if required by building codes or equipment listing standards.

Indicating instruments that are factory calibrated and adjusted should also be tested and calibrated at site before commissioning. Cover-mounted instruments should be flush or semiflush mounted.

5.1.4 Lighting dimmers and dimmer packs

Lighting dimmers and dimmer packs are used to adjust the light intensity from the luminaire through an external controller. They will decrease or increase the power or the control signal to the luminaire to adjust the light intensity. Dimmers allow a standard luminaire to be operated at a light output lower than the level at full voltage. Dimmer packs (or racks) will usually contain multiple dimmer controllers and are used primarily for stage lighting or other facilities where groups of people may congregate (e.g., school auditoriums or buildings used for religious worship). Individual dimmers may be combined with switching function and located as convenient access to the dimmer switch dictates. Multiple wired and wireless approaches could be used to modify the output of luminaires (both intensity and color); therefore, a phase-cut "dimmer" may not be required.

5.1.5 Photocells

A photocell is a light-dependent resistor whose resistance varies based on light intensity. Photocells are mainly used as light sensors for switching lighting circuits in response to sunlight. When sunlight intensity is very low at dusk, the photocell will switch the lighting circuit on and subsequently switch it off sometime before sunrise. Photocells may also be referred to using the terms *sun switch*, *automatic light switch*, or *nature switch*. They are typically simple in construction and easy to install on lighting control systems.

The control strategy for applying photocells in commercial and industrial lighting systems can vary from individual or integral controls to centralized control. In the case of integral systems, the photocell is a part

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

of an outdoor luminaire and controls only the individual luminaire. Conversely, group control systems use one photocell to control a group of luminaires in a room or hall, and in the case of a central control system, a photocell controls the entire lighting system of a building, an office, or a premise. Even though the cost of an integral or standalone control system is marginally higher, the extra cost may be offset by additional energy savings not obtainable in the central control system. The integral control system can have better reliability than a central control system since the central control can constitute a single point of failure for the operation of all the lighting under its control.

Exterior luminaires can be provided with a top-mounted receptacle designed to accept a photocell device, which saves the cost of wiring and mounting the photocell individually. The receptacles are designed with a proper ingress protection system (i.e., are weather resistant). Photocell receptacles complying with NEMA standards are a twist-lock style that has three, five or seven contacts (“pins”). Three-pin twist-lock receptacles are applied for photocell control only. The three pins are used for the incoming supply voltage, the outgoing controlled voltage, and a connection to the circuit neutral wire. Five-pin receptacles add two more contacts to the three twist-lock contacts for the purpose of connecting 0 V to 10 V dimming leads, or for connecting other sensors that may be installed in the luminaire housing. The seven-pin receptacle allows both 0 V to 10 V dimming circuits and other sensors to be connected simultaneously.

5.1.6 Conduit and wire

A conduit is one type of medium used to carry power, control, and communication cables from one location to another. It provides mechanical protection and helps to prevent cable damage due to external influences. These conduits are also called “electrical conduits” and are used in various applications (indoor, outdoor, and underground) in electrical systems. Electrical conduits are manufactured using materials such as polyvinyl chloride (PVC), high-density polyethylene (HDPE), metal, and fiber. IEEE Std 3001.5 [B63] should be referenced for general information regarding conduits and the wires and cables conveyed through them. The following provides information concerning conduit and wire practices and accessories specific to circuits that supply lighting.

5.1.7 Modular wiring

Modular wiring is a prefabricated, ready-to-use, or plug-and-play type of wiring system that connects lighting loads to branch panels in commercial and industrial systems. It could be used in residential applications; however, this is rare. It saves time, material, and cost compared with hardwired systems and increases the reliability of the wiring system. The cost of installation compared with other wiring methods can be reduced by approximately 30% due to a reduced installation labor cost of 70% to 75%. Modular wiring provides flexibility due to the availability of various types of connectors. The plug-in connectors allow circuits to be modified easily when lighting arrangements change over the course of a building’s lifetime. Luminaires can be easily replaced or swapped, and this can be done without shutting off power to the entire circuit. While modular wiring is typically encased in flexible metal conduit, the metal conduit should not be relied on to provide shielding from electromagnetic interference. The component cables can be reusable, which can result in less waste when modifying systems. This type of wiring reduces the requirement of a greater number of skilled workers, which was previously required for installation, as all the terminations are already made in the system.

5.1.8 Cord whips

Cord whips are lengths of cable used to connect a luminaire to an electrical source. It has a plug on one end that is connected by the installer to a wall outlet and on the other end are exposed insulated wires. Cord whips are also available with twist-lock style plugs that help to prevent accidental disconnection. The circuit can be extended to additional luminaires using lighting cables with push-in connectors at both ends. Multiple switching functions can be accommodated by these systems. Lighting cables and whips are

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

usually available in lengths ranging from 0.3 m to 5 m (1 ft to 16 ft) along with a three-pronged or a three-pin plug, which is provided with grounding conductors. Whips can be made with 13 mm (1/2 in) flexible conduit with insulated conductors.

5.1.9 Plugs and connectors

A plug is a movable connector used to receive power from a receptacle. Often the term “outlet” is used interchangeably with the term “receptacle”; however, distinctions can be made between these terms as defined in the NEC. The NEC regards an outlet as the location where a load receives its power from a branch circuit. The load connection to the branch circuit can be either hardwired or made via a plug connection into a receptacle installed in the outlet.

Electrical plugs and receptacles differ in voltage and current rating, shape, size, and type of connectors. When the attachment plug is inserted, the grounding contacts should connect first and then be the last to disconnect while pulling out the plug, to allow for better safety.

Plugs are available for single-phase and multiphase circuits with connectors included for neutral and ground conductors. Plug design varies with current ratings to reduce the risk of connecting a plug into a receptacle of a higher rating. Attachment plugs and connectors should be installed in accordance with the NEC, IEC 60309-1 [B36], IEC 60309-2 [B40], or other regionally applicable installation code.

The wiring devices standardized for lighting can have a current rating of 15 A to 60 A and a voltage rating of 125 V to 600 V. This standardization is done based on orientation, shapes, and blade widths. Generally, 15 A and 20 A plugs with both straight-blade and twist-lock varieties are used with luminaires.

Straight-blade plugs do not have a locking feature. A straight-blade plug is a connector that can be simply pushed or pulled to connect or disconnect with a standard receptacle designed to accept it. Should heavy equipment, such as pumps, or compressors, obtain their power from a plug-in connection, vibrations resulting from the equipment operation could eventually cause the equipment to unplug itself.

Twist-lock receptacles can provide a more secure connection for these situations. Twist-lock male plugs have curved prongs that can be twisted to lock into place after insertion. It should not be possible to unplug the electrical devices without first twisting the plug in the opposite direction. The locking coupling provides a reliable connection because it cannot be easily unplugged.

A weather-proof plug is normally used in industrial and commercial buildings, and it is specially constructed so that exposure to weather will not interfere with its operation. It can also be used for outdoor applications, but flame-proof plugs are usually used in outdoor industrial applications like chemical plants and refineries where flammable gases are present and the atmosphere is dusty, marine, and/or corrosive. All wall plugs and sockets except those in offices should be of a metal-clad three-pin pattern.

The receptacles used in outdoor open locations should have a NEMA or IP enclosure rating appropriate for the degree of protection that should be provided. The plugs and sockets in Class I Division 2 or Zone 2 areas should be “Ex d” or “Ex e” type. The sockets for fixed installation should preferably be provided with an integral canopy. The separate canopy should be made of at least 14 SWG (2 mm) galvanized sheet steel, fiberglass reinforced plastic, or aluminum alloy. The canopy should be suitable for providing protection against rain on the top and sides. The plugs depend on the cable size, which should be supplied with a suitably sized cable entry for the specified cable size and complete with a double compression-type, nickel-plated brass flameproof cable gland.

IEC 60309 standardizes connectors with current ratings up to 800 A, system frequencies up to 500 Hz, and system voltages up to 1000 V dc or V ac. Standard current ratings include 16 A, 32 A, 63 A, 125 A, and 200 A.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

NEMA has standardized wiring devices for standard voltages of 125 V to 600 V and current ratings from 15 A to 60 A. Standard arrangements include both locking and nonlocking versions for each combination of ratings. Current standards require phase and neutral blades to have a polarized design to help prevent connecting load neutral wires to phase conductors. For additional information, refer to ANSI/NEMA WD-6 [B15].

5.1.10 Power over Ethernet

Power over Ethernet (PoE) is an electrical power transmission technique that enables the data cables to carry electrical power in addition to data. Most Ethernet cables will have four pairs of cables, in which two pairs are generally kept as spare. In a PoE system, these two spare pairs can be used for transmission of small amounts of electrical power (e.g., a maximum of 100 W). The basic schematic diagram is shown in Figure 1. Numerous devices can use PoE, including some luminaires.



Figure 1—Basic schematic diagram of PoE

5.1.11 Room controllers or area lighting controllers (0 V to 10 V dimming)

An efficient lighting system requires intelligent control techniques. These techniques will help in switching lights on and off, enabling color-changing lights, and controlling the light output [e.g., dimming (0 V to 10 V)], based on the actual requirement of illumination levels at a particular time and location (e.g., zoning). It can be manual or auto with preprogrammed control. Such a system can save time and energy in addition to providing comfortable lighting. It can be hooked up to sensors or to smart devices with IoT capability. One advanced type of lighting control is a networked lighting control system, which is part of a building automation system and can be programmed and controlled using computers and handheld devices. In addition, data can be stored in such systems to be used with more advanced artificial intelligence algorithms to make the system more efficient and easier to operate. The advantages of this system are energy conservation and flexibility—for example, to change a room's atmosphere according to the mood of the mood of the occupants by modifying the color of the light produced. The advantage of using a lighting controller is in the overall reduction in the use of electric light, which is further helpful in reduction of peak-demand charges.

5.1.12 Standby power equipment

5.1.12.1 General

Backup power equipment may provide external or internal power during failure of the normal power. The external power source may be a generator, battery system, inverter, and so on, while an internal power source equipment may be a battery typically referred to as "unit equipment." Except as permitted by the local authority having jurisdiction (AHJ), the emergency source, wiring system, and associated loads (e.g., lighting or fire alarm) are required to be independent and separated from normal or standby wiring systems. This requirement applies to all emergency equipment, regardless of being internally or externally powered. The internally powered equipment usually conform to these requirements through their listings by a recognized qualified testing agency.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Emergency lighting refers to lighting that provides illumination for egress when normal lighting is interrupted and must be supplied by a backup power source. NPFA 101 contains requirements for emergency lighting required for egress and lists the building occupancies where it must be provided. The NEC Article 700 has requirements concerning the installation of emergency systems. Codes applicable in other countries can have similar requirements. Emergency standby systems are required by the NEC in Article 700 to be completely separated from other wiring except as otherwise permitted. Where required, emergency standby system conductors are required to be installed as separate cable, cable raceways, and panels, and other types of loads may not be supplied. Lighting loads not required to be backed up by emergency standby systems can also have backup power, and these loads could be supplied via optional standby systems.

The standby power equipment source may use fuel or batteries as energy sources. Refer to IEEE Std 3005.4 [B66] and IEEE Std 446 [B59] for information regarding emergency and other standby systems for industrial and commercial facilities.

5.1.12.2 Central battery and inverter systems

Central battery and inverter systems are normally used on larger projects where the quantity of emergency luminaires may rise into the hundreds. For a large multistory office block, a central battery would be the best option to keep the ongoing operational costs at a minimum. An ac/ac static inverter system can be connected directly to a suitably designed mains supplying luminaires without having to make any modification to the luminaires. The luminaires would operate at full light output under both “mains healthy” and “mains failed” conditions. The control of maintained lights or signs under a central battery system is by circuit monitors that will energize the system when a circuit fails. Another major advantage of central battery systems is the maximization of battery life, which can be expected to last at least 10 years. Battery replacement is a quick and simple operation that avoids the disruption caused by having to access and dismantle numerous fittings in public areas. Central battery systems are simple to test and simple to maintain, provide completely unobtrusive emergency lighting, and offer long-term life-cycle cost advantages.

5.1.12.3 Emergency lights identification

Emergency lighting is classified as follows, based on its functional requirement:

a) Escape lighting: Provided to aid in the escape of occupants by clearly identifying the escape route during emergency situations. It should also provide sufficient light for the safe movement of people.

   Color code: Escape routes are identified by a universally used green background with white symbol. These should always be illuminated.

b) Safety lighting: Provided for the safety of people working in various hazardous and high-risk processes. It should operate within 0.5 s of normal supply interruption.

   Color code: The exterior of safety lighting luminaires should be painted with a red circle 10 mm in diameter.

c) Standby lighting: Provided to allow operations to continue after the failure of normal lighting. Should operate within 15 s of normal supply interruption.

   Color code: The exterior of the luminaire should be painted with a blue circle 10 mm in diameter.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

d) Maintained emergency lighting: This lighting operates whether normal supply is available or not.

   Color code: The luminaire exterior should be painted with a yellow circle 10 mm in diameter.

e) Nonmaintained emergency lighting: This lighting operates when supply to normal lighting is interrupted.

   Color code: The luminaire exterior should be painted with a black circle 10 mm in diameter.

5.1.12.4 Emergency generators

Emergency lighting is installed to satisfy essential illumination requirements during normal power supply interruption. The power source for emergency lighting should be from an independent source such as engine-driven generators. In the absence of normal supply failure, the generators should be able to supply the emergency lighting system for a period specified for the particular area of use. Refer to NFPA 110 [B77], IEEE Std 3005.4 [B66], and IEEE Std 446 [B59] for information regarding emergency and standby systems for industrial and commercial facilities.

Critical locations may require a power source with battery backup [e.g., an uninterruptible power system (UPS)] to operate the lighting system in hazardous areas for a minimum period of 4 h or as specified for a particular location based on its purpose and the hazard involved.

5.1.12.5 Emergency battery pack units

Emergency battery back units are widely used for powering emergency lighting devices or luminaires. During an ac input power failure event, all luminaires connected to it will turn off while the emergency battery packs supply power to emergency lighting located in critical rooms, and areas.

5.1.12.6 Automatic transfer switches

An ATS provides power supply redundancy with or without interruption. Automatic transfer switching is applied where building codes require emergency power availability within a certain time. Transfer switches can also come in a form that is manually switched. As these switches are not automatic, they could supplement an automatic transfer switch (for connecting temporary standby sources) or applied in optional standby systems.

The ATS usually contains all controls necessary to sense loss of the normal power supply, initiate the start of an emergency or standby generator, and transfer the load from one source to the other, including all necessary time delays. It has two incoming power supply terminals and a single output terminal, as shown in Figure 2. The normal input power supply originates from an electric utility service connection: Emergency input power supply can be powered by either another separate utility source or an emergency diesel generator.

Copyright © 2023 IEEE. All rights reserved.

Documents
Document Sharing Hub

Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.

Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

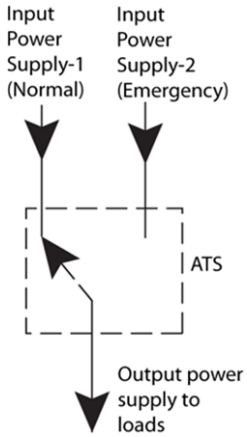


Figure 2—Switching arrangement of ATS

The ATS will transfer the load from the normal input power supply to the standby power supply whenever the normal input power supply fails and will transfer the load back to the normal input power supply when the input power supply has returned. Three-phase ATS designs can be either three pole or four pole. Four-pole designs provide a switching device for system neutral conductors. For further information concerning the application of ATS, refer to IEEE Std 3001.5 [B63].

Emergency systems are usually installed in places of assembly where artificial illumination is required for safe exiting and for panic control in buildings subject to occupancy by large numbers of persons, such as hotels, theaters, sports arenas, health-care facilities, and similar institutions. With respect to emergency lighting design, the automatic transfer switch monitors the primary source voltage, senses the power failure or power outage in the primary source, and automatically connects the emergency power source to its lighting load. It enables the general-illumination luminaires to act as emergency luminaires automatically when an emergency power source is available. Then when the primary source has been restored, the load is automatically transferred back to the primary source. As a switching device, the transfer switch should be capable of repetitively closing, carrying, and interrupting normal load currents.

For maximum reliability, multiple transfer switches of lower current rating, each supplying a part of the load, may be used rather than one transfer switch for the entire load (see Figure 3). Regardless of the location and number of transfer switches, caution should be exercised to ensure that transfer control and operation do not in any way detract from overcurrent protection and vice versa.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

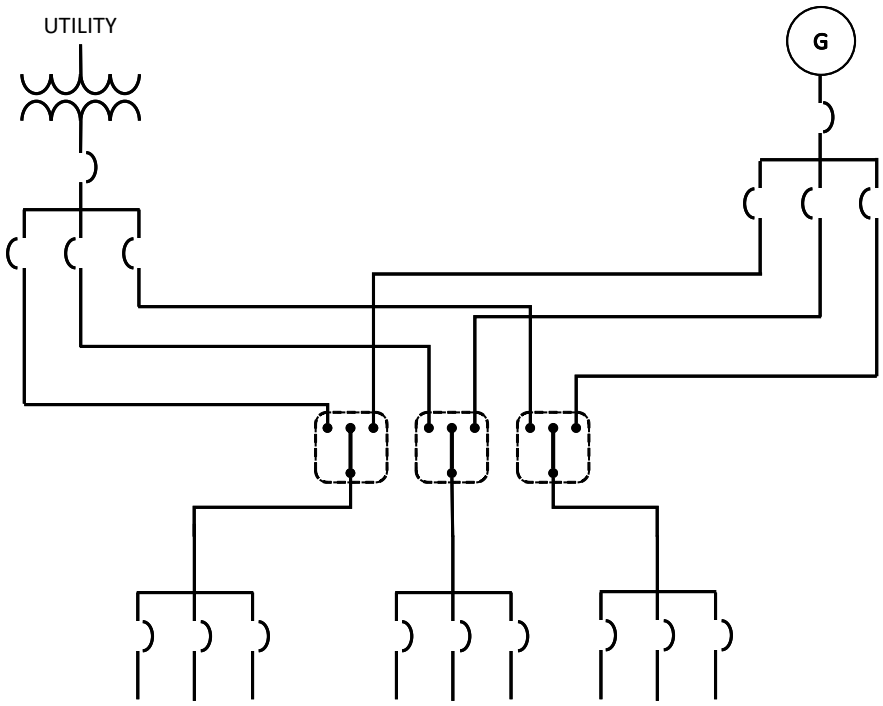


Figure 3—Lighting distribution board powered through ATS

5.1.12.7 Static transfer switches

Static transfer switches (STS) are used to transfer critical loads between two independent ac power sources without interruption or with a transfer time of less than 0.25 of a cycle (4 ms at 60 Hz). It has no moving parts like ATS; instead it uses a semiconductor technology. The STS may be used for the switching of an optional standby system; however, STS do not have the features of a transfer switch as described in Article 700 and Article 701 of the NEC and cannot be used as part of emergency or legally required systems unless incorporated as part of a listed and approved emergency or legally required automatic transfer switch.

The use of an STS within an electrical distribution system provides a means of secure protection against any potential disruption of the power supply due to interruptions of the supply source or failure of the distribution lines caused by environmental phenomena or human error. The STS provides a means of switching between two alternative and independent power sources, which provides a continued supply of power to any critical load.

The STS consists of semiconductor devices such as silicon-controlled rectifiers (SCRs), as well as control and sensing circuits to monitor the incoming sources and transfer the critical loads to the secondary source when the primary source fails. It is used for sensitive and critical applications within an electrical distribution system such as a single-phase two-wire and three-wire or four-wire applications. It enables automatic or manual changeover between two power supply sources within a transfer time of 1/8 to 1/4 of a cycle. When any power supply source failure occurs due to any disturbance in the power supply or any interruption due to environmental or human error, the static transfer switch promptly switches the load to the designated emergency power source.

The two selected power sources should be independent power sources of the same voltage, phase rotation, and frequency. Inputs are generally from uninterruptible power supplies (UPS), but they may be utility power sources, lighting transformer outputs, or power distribution unit outputs and a single ac output that supplies redundant power to the connected loads.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

In Figure 4, two pairs of SCRs connect the ac load to the Source Input 1, and it is Source Input 1 that will normally carry the load when both sources are available. It is selectable by the user from the operator control panel. A second set of SCRs stands ready to transfer the ac load to the alternate Source Input 2 should the preferred source fail or if a manual transfer is initiated (Figure 5). During static switch transfers and retransfers, the conduction state of the SCRs is carefully monitored and controlled to help prevent a current path from one source to the other. This technique reduces the risk of a good source feeding into a faulted source.

In normal mode, CB1 and CB2 are both closed, allowing a power path from either source, which in turn allows for the load to be automatically transferred from one source to the other. Sensor logic opens or closes STS 1 or STS 2 to transfer the load rapidly from one source to the other. A sensor continuously monitors the two power sources and controls transfers using its sensing algorithms.

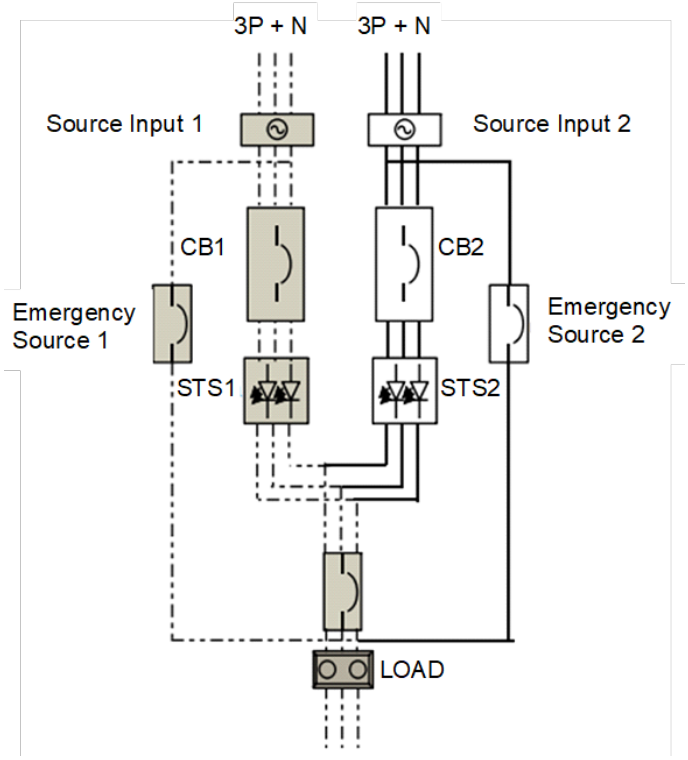


Figure 4—Normal mode—loads are powered by Source Input 1

Copyright © 2023 IEEE. All rights reserved.
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

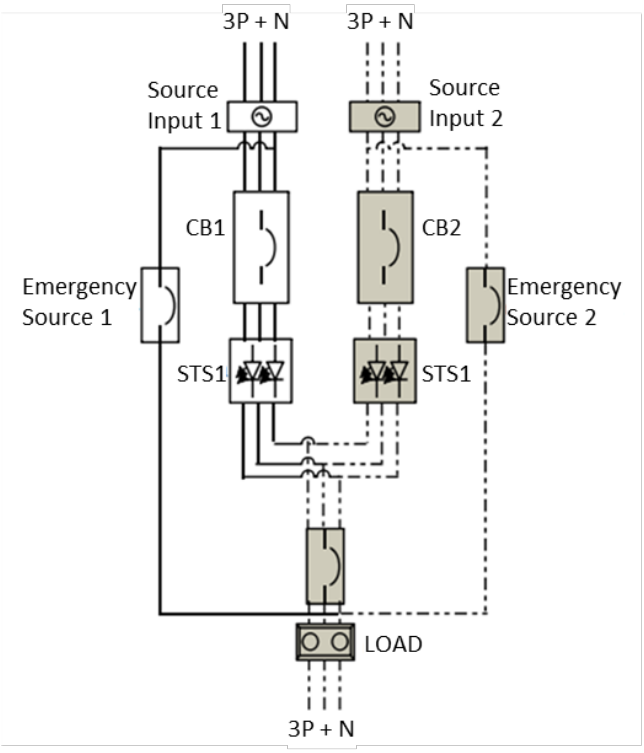


Figure 5—Alternate source mode—loads are powered by Source Input 2

5.2 Design considerations

5.2.1 Workspace for lighting panelboards

In commercial and industrial power systems, wall-mounted panelboards are widely used to control the connected luminaires. These panelboards are smaller in size and installed closer to the luminaires. In panelboards, all components are installed in a way that will provide for easy accessibility from the front. Hence, spacing and working clearances are required only in front of the panelboard as per applicable codes and regulations.

5.2.2 Voltage regulation

Poor voltage regulation is detrimental to the life and operation of electrical equipment. The goal of good voltage regulation is to control the voltage of the system so that it will stay within a practical and safe range of voltage tolerances under all design loads. Voltage at any utilization equipment should be within the ensured operative range of the equipment. The type and size of wires or cables, types of raceways, reactance values of transformers and cables, selection of motor-starting means, circuit design, power factor correction, and the means and degree of loading will all affect voltage regulation.

Voltage regulation in any circuit, expressed as a percentage, is given in Equation (1).

Copyright © 2023 IEEE. All rights reserved.
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

$$\text{Voltage regulation (\%)} = \frac{\text{No load voltage} - \text{Full load voltage}}{\text{No load voltage}} \times 100\% \quad (1)$$

When it is not economical to control voltage drop through conductor sizing, circuit design, or other means, voltage regulators may be needed. Several types of voltage regulators, either automatic or manual, are available for all types and sizes of loads, from individual electronic devices to the equipment for an entire laboratory or department store. Voltage regulators are frequently used by electric utility companies in their distribution system feeders and are seldom needed within commercial buildings, except for use with electronic equipment. Normally, the power and light distribution system within a large commercial building can be designed economically and adequately without the use of voltage regulators. For more information on voltage considerations, refer to Chapter 3 of IEEE Std 141™ (*IEEE Red Book*™) [B56] and Chapter 3 of IEEE Std 241™ (*IEEE Gray Book*™) [B57].

5.2.3 Separation of lighting loads from other loads

The design of a building's electrical distribution system depends on factors such as the selection of system voltage and the power system configuration. It also depends on the types, the ratings, and characteristics of the connected loads. In modern commercial and industrial power systems, a combination of both linear and nonlinear loads is used. If these loads are connected in the same distribution circuit or feeder powered by a small kilovoltampere transformer, the normal operation of linear loads can have an impact on nonlinear loads and vice versa. For an example, the starting current (inrush current) of an induction motor can create a voltage sag that affects other equipment connected to the same feeder or circuit. Similarly, modern lighting loads using light-emitting diode or compact fluorescent light technology may inject current harmonics back into the power system, which can affect other loads connected in the same feeder or circuit. These issues may be reduced by using a dedicated feeder-supplied lighting panel(s) for lighting loads.

5.2.3.1 Lighting transformer and its requirements

In a large commercial or industrial power system, a separate distribution transformer may be used specifically for lighting loads. This is called a "lighting transformer." The voltage transformation of these lighting transformers is generally medium-to-low voltage, although in some cases it is low voltage to low voltage. In general, these lighting transformers are similar in function to distribution transformers.

5.2.4 Separate systems for metering [e.g., ANSI/ASHRAE/IES Std 90.1, International Energy Conservation Code (IECC), and LEED requirements]

Since 2013, ANSI/ASHRAE/IES Std 90.1 [B4] has required measurement devices be installed in new buildings 25 000 ft^2 or larger to monitor the electrical energy use for each of the following load types: total electrical energy; heating, venting, and air conditioning (HVAC) systems; interior lighting; exterior lighting; and receptacle circuits. ANSI/ASHRAE/IES Std 90.1 requires electrical energy usage for all those specified loads be recorded a minimum of every 15 min and reported at least hourly, daily, monthly, and annually. Additionally, all data collected must be maintained for a minimum of 36 months. Since 2021, the International Energy Conservation Code (IECC) has required new buildings 25 000 ft^2 or larger to be equipped to measure, monitor, record, and report energy consumption data for the following load types: total HVAC system, interior lighting, exterior lighting, plug loads, process loads, building operations, and other miscellaneous loads. The California Building Efficiency Standards [B22] requires the same load types described above to be grouped and separated from each other in the building electrical distribution system to allow the energy metering of each load type. Unlike ANSI/ASHRAE/IES Std 90.1, the California Standards do not require load meters to be installed and provisions for applying meters in the future must be accommodated. However, the standard may require metering on the service or other locations when certain conditions cannot be met.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Leadership in Energy and Environmental Design (LEED) certification of green buildings is intended for the design, construction, operation, and maintenance of buildings of both commercial and industrial establishments. This rating system is developed by the U.S. Green Buildings Council (USGBC) and makes the building owners responsible for effective use of energy resources, thus, protecting the environment. A LEED rating is given for new constructions, as well as for operation and maintenance of existing buildings. The main LEED certification requirements (LEED 2009-V3) are as follows:

— Minimization of light trespass from the buildings

— Automatic control of lighting

— Decentralization or zonal system

— Use of daylight with proper design of buildings

— Installation of a separate metering system, which aids in energy savings. Calibration of meters at regular intervals, with replacement if found defective.

— Automatic metering system with continuous displays at dashboards for real-time analysis and necessary controls.

— Separate meters (e.g., submeters) are preferred in every building of gross floor area of above 500 m^2.

— The separate metering system should have the capability to record the power factor in addition to the active power, or to record the apparent power or reactive power as well as the active power.

5.2.5 Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the supply frequency at which a system is designed for operation. Electronic equipment is a major source of harmonics in an electrical system. Modern LED drivers use such electronic components and will create nonlinear voltage-current characteristics (harmonics) during their normal operation. These harmonics can affect other equipment connected in the system, causing, for example, malfunctions, component failures, and overloading. More detailed information concerning harmonics can be found in Chapter 9 of IEEE Std 141™ (*IEEE Red Book*™) [B55] and in IEEE Std 1100™ (*IEEE Emerald Book*™) [B60].

5.2.6 Transient voltages

Surges on ac low-voltage power circuits may cause disruptions, degradation, and/or destruction of lighting system components. Transient overvoltage events may be generated by lightning or by a sudden change of system conditions (such as switching operations, faults, or load rejection), or both. Broadly, types of transient overvoltages are normally classified as lightning generated or switching generated. The magnitude of a transient overvoltage event can be greater than the maximum permissible level (e.g., basic insulation level) and, therefore, will need to be protected against if damage to equipment and possible undesirable system performance are to be avoided.

Direct lightning strikes to overhead outdoor wiring are rare because of the shielding effect of adjacent structures. However, direct strikes to objects 8 m to 15 m (25 ft to 50 ft) away can induce substantial transient overvoltage into an overhead line. Surge arresters should be installed at the end of an overhead line that connects to building wiring, to reduce the effects of such induced transients. In instances where a local industrial plant's electrical system is without lightning exposure, except from exposed high-voltage lines through step-down transformers effectively protected with surge arresters at the high-voltage side, lightning surges can be moderate. Likewise, surges due to switching phenomena, although more common, are generally not as severe.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Surges can be caused by myriad anomalies, including anomalies in lighting system switches, transfer switches, motor operators or controllers, solid-state controllers, or capacitor bank switching within the building. These surges can upset the operation of lighting equipment or can damage such equipment to the extent it is no longer operational. This equipment includes a broad scope of lighting technologies, such as integrally ballasted compact fluorescent lamps (CFLs), high-intensity discharge (HID) lamps, tungsten-halogen lamps, or light-emitting diodes (LEDs). The power supplies (also sometimes referred to as "ballasts" for fluorescent or HID lamps or "drivers for LEDs) for these lighting systems are especially susceptible to surges. However, surge protective devices (SPDs) provide effective protection as demonstrated by Fox and Whitehead [B34]. SPDs can be used to protect the equipment from transient overvoltage events. These SPDs are usually installed at low-voltage distribution panels or distribution boards. A multiple SPD approach may be needed to provide comprehensive protection against all surge sources. Surges can enter a building using a path other than the utility service entrance. Surges can enter using any conductor that penetrates the building, such as those that supply equipment mounted on the building rooftop. SPDs applied at the building perimeter reduce the severity of a surge but do not eliminate it completely. Furthermore, switching of electromagnetic loads within the facility system can cause low-level damaging surges. SPDs should be located where they can protect conductors that enter the building. SPDs for treating internally generated transients should be located close to the source of the transients if practical. SPDs applied close to the load that requires protection can protect from internally generated transients and from the pass-through surges that continue beyond SPDs located at the building perimeter. Refer to IEEE Std 1100 [B60] for more information regarding the selection and application of SPDs.

General information concerning surge voltage is available in IEEE Std 141 (*IEEE Red Book)* [B56]. ANSI C82.77-5 [B11] prescribes surge limits and testing methods for lighting equipment. The IEEE C62™ series of standards should also be referred to for further details on voltage surges, testing methods, and surge protection (IEEE Std C62.41.1™ [B48], IEEE Std C62.41.2™ [B49], IEEE Std C62.41.3™ [B50], IEEE Std C62.42™ [B51], IEEE Std C62.44™ [B52], IEEE Std C62.45™ [B53], IEEE Std C62.62™-2010 [B54], IEEE Std C62.72™ [B55]).

5.2.7 Influence of lighting controls on power system design strategy

A lighting controls system is used to switch lights on or off, to adjust the light output with respect to quantity and color characteristics, or to do both. The control can be either automatic, with predefined conditions, or manual and may be used for a building's interior space and its exteriors. The benefits of lighting control include the following:

- Reduced energy consumption, (between 24% and 38% energy savings as per Williams et al. [B109]
- Reduced electrical power expenditure for commercial and industrial establishments
- Adjustable color and correlated color temperature (CCT) to suit to the area users
- Increased life of luminaires due to systematic control with optimum operation

The lighting control system should include one or more of the following:

- Automatic and manual control
- Color and shade control
- Dimming capability
- Light adjustment based on weather conditions for outdoor lighting
- Timer-enabled and photocell-enabled controls with integral and central strategies
- Occupancy and motion sensors

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

A networked control system, which is generally set up as a standalone system, enables the user to operate the lighting system from digital devices with software designed for such operations. More advanced software can also store the data, which can then be used for many other purposes, such as energy management and monitoring of efficiency.

5.2.8 Protection requirements for normal and emergency lighting

North American practices for protection of lighting circuits are similar to those for other nonmotor loads. Overcurrent protection is required by code, and the rating of the overcurrent device is generally the same as or lower than the ampacity of the lowest-rated conductor or device in the circuit. Molded-case circuit breakers (MCCBs) or fuses can be applied in branch panels. MCCBs typically have an inverse-time overcurrent function for action in overload conditions. The inverse-time characteristic is usually accompanied by an instantaneous overcurrent function that has a minimum pickup of eight times the device rating or higher and is intended to act on short circuits. Fuses can be “fast-acting” type or include a time delay characteristic. Besides applying a device with a suitable short-circuit current rating, the designer should also make sure that the load characteristic does not have an inrush current that might cause a nuisance operation of the breaker or fuse when the circuit is switched on.

Emergency lighting circuits involve an additional concern for compliance with the NEC, which is the overcurrent devices in those circuits must be selectively coordinated with all supply-side overcurrent devices. The selective coordination must occur for the full range of currents that the device may operate on, up to and including the available fault current. Fuse manufacturers provide tables showing the current rating ratios of one fuse type to another that allows selective coordination. As time current curve analysis cannot indicate whether circuit breaker instantaneous trips are selective, circuit breaker manufacturers provide tables showing the combination of supply-side and load-side circuit breakers that are selective. These tables address the instantaneous tripping only, and time current curve analysis is needed to evaluate the coordination of the overload trips and instantaneous pickup settings. These selective combinations may be limited to specific trip types, breaker models, breaker ratings, and the maximum available fault current for which they can be applied. Using a combination of fuses and circuit breakers in the same system is not generally practical. Circuit breaker selectivity tables do not typically include fuses as supply-side devices. A circuit breaker instantaneous trip could be selective with a load-side fuse when the available fault current allows for the fuse to operate in its current-limiting range and the setting of the circuit breaker instantaneous trip allows for the breaker to remain closed for the peak let-through current of the fuse. However, this situation is not practical in most circumstances. Selectivity tables are manufacturer specific and combining devices made of different manufacturers in these situations is not practical. IEEE Std 3004.5™ [B66] should be referred to for further information.

For protection of lighting systems compliant with IEC standards, overload protection is not mandatory and miniature circuit breakers (MCBs) are widely used. The early practice of using fuses is outdated, and the MCB is preferred for protection against overloads and short-circuit faults. It is a singe pole (for one phase of the single-phase circuit, when permissible), two pole (for two phases/phase-neutral of the single-phase circuit) triple pole (for the three-phase circuit), and tetra pole (for the three-phase neutral circuit). MCBs are classified based on the magnitude of the tripping current and the clearing time with their application area as shown in Table 1.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Table 1—Miniature circuit breaker types, application, and clearance time

Type	Tripping current (multiples of rated current)	Trip time (s)	Application	Remarks
B	3 to 5	0.04 to 13	Resistive lighting (e.g., incandescent lamps) Heaters	Quick reaction for overloads and minimum short-circuit values
C	5 to 10	0.04 to 5	Commercial and industrial area Fluorescent lamps with ballast Fans Air Conditioners Household appliances	Slow reaction Used for protection of cables against overloads
D	10 to 20	0.04 to 3	Heavy duty commercial and industrial loads UPS systems Welding and X-ray machines	Reacts more slowly for faults (equipment—motor inrush)
K	8 to 12	<0.1	Highly inductive loads like transformers	Slower operation
Z	2 to 3	0.4 to 3	Low short-circuit category of loads	Fast response

For commercial and industrial lighting, Type C and Type D MCBs are most widely used. The clearance time is supposed to be less than that of the fault-bearing capacity of circuits, mainly power cables.

Additional information on electric power system protection may be found in the IEEE 3004 series of standards and in IEEE Std 242™-2001 (*IEEE Buff Book*™) [B58], as summarized below.

The main objectives of a protection system are to provide reliable protection with reasonable cost, adequate sensitivity and selectivity, and high speed of operation. The protection system should detect and isolate the faults quickly so that the extent of damage is reduced.

Protection against electric shock by direct contact is provided by insulation and barriers or covers (either insulated or conductive) that guard against such contact. However, leakage currents caused by ground faults can flow on exposed covers and cause an electric shock injury if the cover is touched. Such ground faults can be protected by circuit breakers that combine ground-fault sensing technology with the thermal magnetic trips provided for phase protection. These specialty breakers are known as ground-fault current interrupters (GFCIs) in North America, whereas countries that have adopted IEC standards know them as residual current circuit breakers (RCCBs) or residual current devices (RCDs). All of these breakers are designed to provide protection when a situation occurs that could result in electric current causing a shock injury to someone who either directly or indirectly comes in contact with the current. Sensitivities of 5 mA through 30 mA are available, with the more sensitive devices designed for personnel protection while the less sensitive devices are intended for equipment protection. The basic working principle of GFCIs and RCDs is a comparison between the current entering and leaving a summation current transformer as shown in Figure 6. The difference in current, if any, may be due to current leakage with some of the current returning to the source through the intended neutral conductor path and some of the current returning to the source through a ground path. The device detects the fault current and trips the circuit if the residual current is higher than the setting threshold. A test push button is provided to test the RCD function at regular intervals.

In North America, GFCIs are required primarily in residential occupancies on circuits supplying receptacles located in bathrooms, kitchens, or outdoors, as well as in other special applications such as swimming pools. The designer of high-density residential properties or mixed-use commercial/residential properties needs to be familiar with these requirements. They are not required for dedicated lighting circuits except in cases involving wet or damp locations (see 8.4 and 8.5). However, the design engineer could require these devices. If they are installed, then GFCIs are available for a limited range of ratings, typically 120 V/240 V maximum, up to 30 A, and in one- or two-pole arrangements only.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

The IEC standard RCD has different names, such as RCCB (residual current circuit breaker), RCBO (residual current circuit breaker with overload protection) or CBR (circuit breaker with built in RCD). They are available with a sensitivity range of 30 mA to 1A of leakage or residual current, with rated current ranging from 16 A to 125 A and time delays of 10 ms to 450 ms. Electric current up to 30 mA is generally not fatal, although the ability of muscles to counteract a current passing through them (e.g., to "let go") is at threshold of approximately 9 mA. However, the exposure to the current should not be prolonged as leakage or residual currents above 30 mA may be fatal. RCDs limit only the exposure time; they do not limit the magnitude of the current. In extended circuits with multiple loads, some amount of current leakage should be expected. For this reason, RCDs cannot pick up at a half-threshold value (e.g., 15 mA for the sensitivity of 30 mA). The basic schematic diagram of a single-phase RCCB is shown in Figure 6, and three-phase RCCBs are shown in Figure 7. RCDs are classified based on their sensitivity to various types of residual or leakage currents, as listed in Table 2 along with their application.

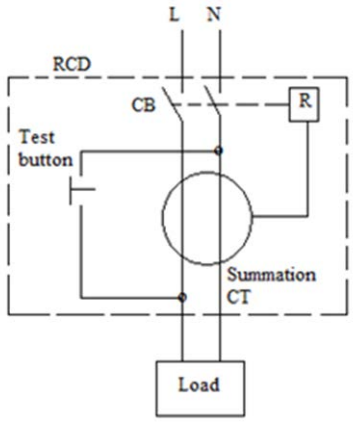


Figure 6—Schematic diagram of a single-phase RCD

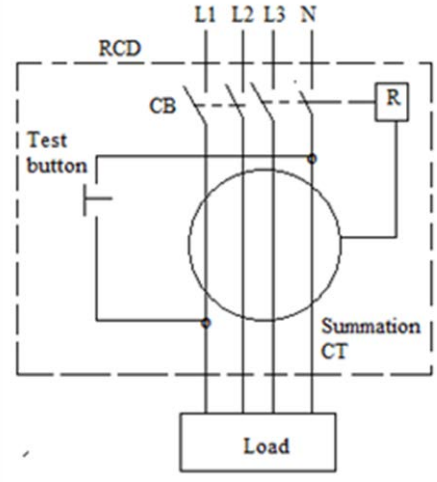


Figure 7—Schematic diagram of a three-phase RCD

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Table 2—Types of RCDs

Type of RCD	Sensitive to residual current	Application	Reference standard
AC	Sinusoidal ac with rated frequency	For sinusoidal currents Single phase rectifiers and household installations, up to 6 mA. This should not be used for frequency inverters.	IEC 61008 and IEC 61009
A	Sinusoidal ac and pulsating dc currents above 6 mA	New household installations and dc rectifiers (arcing ground fault).	IEC 61008 and IEC 61009
F or C	Type A and residual currents with mixed frequencies up to 1 kHz and above 10 mA	Frequency inverters with a maximum dc component of 10 mA and single-phase rectifiers.	IEC 62423
B	Type F plus and smooth dc, both pulsating and flat and up to 2 kHz	For inverters with six-pulse rectifier circuits. For most of the electronic appliances in industries, frequency inverters, solar photovoltaic (PV) circuits, electric vehicle charging stations, medium size UPS, medium size welding machines and general circuits up to 1 kHz.	IEC 60755 and IEC 62423
Bfq	All types up to 1 kHz	Special type of inverters up to 20 kHz and sensitivity up to 300 mA and three-phase fed inverters and UPS.	IEC 62423
B+	Type B plus with frequency up to 20 kHz	Special application of protection against fire up to 420 mA and three-phase fed inverters and UPS.	VDE 0604-440

The setting sensitivity of RCD depends on the type of earthing system (e.g., TN, TT, and IT) with clearing time shown in Table 3.

Table 3—Type of network and protection clearing times

Network	Clearing time and remarks
TN	Rated current of up to 32 A: 0.8 s for supply voltage <120 V, 0.4 s for 120 V ≤ supply voltage ≤ 230 V 0.2 s for 230 V < supply voltage ≤ 400 V 0.1 s for supply voltage >400 V
TN-C	No RCD is possible at supply side
TN-S	Suitable for buildings with separate conductors for neutral and protection are available
TT	Two RCDs in series with 30 mA setting

All load-carrying conductors of power circuits that require RCD (phase and neutral) should pass through the summation CT of the RCD. All metal frames/bodies of appliances or equipment should be effectively grounded. Protective earth conductors are not connected through the summation CT as subtraction of the return of ground-fault currents through these conductors would reduce the sensitivity of the RCD. PE and N conductors should not be connected together after the RCD; hence, RCD cannot be used in the TN-C system. SPDs should be connected on the supply side of RCDs. Leakage current settings of 30 mA should be selected for smaller appliances and mobile connected devices for the primary purpose of personnel shock protection. Leakage current settings of 300 mA should be applied for Class I fixed equipment. This is the maximum permissible value for fire protection. In selecting leakage or residual current settings, discrimination between RCD at mains and RCD at submains should be considered. The rated residual current of mains or upstream RCD should be a minimum of three times the residual current of subcircuits at downstream of mains RCD.

The following guidelines can be used for selection of RCDs based on sensitivity current:

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

— ≤30 mA: Receptacles with ratings up to 20 A and outdoor receptacles up to 32 A. Type A RCDs high immunity should be used to avoid nuisance tripping. Type B RCDs should be used for plants and classrooms with experimental equipment with circuit in TT or TN systems, and for electric vehicle charging stations.

— ≤100 mA: For receptacle circuits.

— ≤300 mA: For TN and TT circuits and temporary power supply connections.

— ≤500 mA: For receptacle circuits >32 A applied primarily on construction sites.

Other classifications of RCD are the fixed type (installed in the mains switch board to protect the downstream circuit area), the socket outlet type (RCD built into socket), and portable type (for socket outlets).

RCDs should not be installed on feeder circuits if the normal leakage current is expected to be greater than 30 mA. The feeder circuit should be separated into a smaller feeder or branch circuits and RCDs installed on the smaller circuits. This is especially needed when the feeders supply electronic devices such as computers, photocopiers, and printers. For example, for a quantity of 10 computers, each having an expected leakage current of 2 mA, the total leakage current is $10 \times 2 = 20$ mA. The main RCD rating should be three times 20 mA, or 60 mA.

Arc fault circuit interrupters (AFCIs) are protective devices used to detect arc faults in the distribution system and to de-energize the electrical power circuit to avoid electrical fire accidents. While more commonly applied in residential properties, commercial building designers need to specify their use when designing dormitories, guest rooms and suites in hotels and motels, and patient sleeping rooms in nursing homes and limited-care facilities where the NEC applies. Article 100 of the NEC defines an AFCI as “a device intended to provide protection from the effects of arc faults by recognizing characteristics unique to arcing and by functioning to de-energize the circuit when an arc fault is detected.”

AFCIs are used in distribution circuits as follows:

— Detect the nonperiodic waveform of an arc from its normal sinusoidal shape

— Isolate the faulted area from the power source

The function of an AFCI should not be confused with that of a GFCI. The function of a GFCI is to detect line-to-ground faults. Most GFCI devices do this by sensing the combined magnetic fields of the phase and neutral currents associated with the circuit being protected. Ideally, under normal operating load conditions, the resultant magnetic field will have zero field strength. A ground-fault current produces an imbalance in these fields because the ground-fault current takes a path back to the source other than through the power system conductors. Ground-fault currents are easily detected at very low levels.

Electrical arcs are of two types, parallel and series arcs. Parallel arcs are developed in the gap between the line conductors of different phases or from one phase to neutral as shown in Figure 8. This commonly occurs from wire insulation failure. The resulting current is dependent on the applied voltage, system impedance, and arc impedance, and it ranges from less than load current levels to the maximum available short-circuit current.

Series arcs occur due to gaps that develop in series with a conductor or wire. This may be a loose contact within the wire, as shown in part (b) of Figure 8 or between a wire and its connecting terminal, as shown in part (c) of Figure 8. In these cases, the arc current will not be more than the load current.

The earliest AFCI types were designed to detect only series arcs. The ability to detect parallel arcs was developed later, and AFCIs that detected both were referred to as “combination-type” AFCIs to distinguish them from the earlier types. The NEC requires that combination-type AFCIs must be used to satisfy AFCI requirements. GFCIs and AFCI functions may be combined into a single device. Such a device is referred

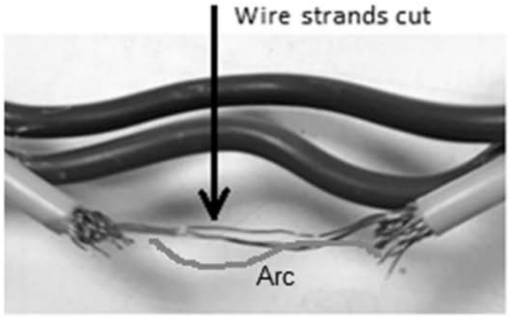
Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

to as a “dual-function GFCI/AFCI.” Furthermore, branch circuit breakers may be provided with the functions of an AFCI, a GFCI, or both. AFCI and GFCI protection are then combined with overload and short-circuit overcurrent protection in one device.

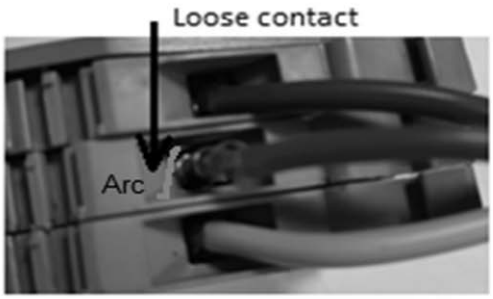
Clause 210.12 of the NEC requires AFCIs to be applied on 120 V ac, single-phase 15 A and 20 A branch circuits. In general, the requirements apply to residential applications (“dwelling units” as defined by the NEC). These requirements also apply to commercial applications when those applications include living, sleeping, sanitary, and storage facilities (e.g., “guest rooms,” “guest suites,” and “dormitory units”).



(a) Parallel arc



(b) Series arc-terminal area



(c) Series arc-terminal area

Figure 8—Types of arc faults

The listing standard for AFCIs is ANSI/UL 1699 [B16], which sets requirements for AFCIs “of the branch/feeder, outlet circuit, portable and cord type intended for use in dwelling units.” They are intended for use on 120 V ac, 60 Hz circuits. Cord-type AFCIs may be rated up to 30 A. Once tripped, AFCIs are required to be reset manually before power can be restored to the load. ANSI/UL 1699 [B16] requires AFCIs to be provided with a test circuit that will simulate an arc to test the arc detection circuitry of the device. It also requires that operation of the test circuit must cause the device contacts to open and tripping to be confirmed by a positive visual indicator. The test circuit should be operated periodically to ensure proper operation, preferably every 3 months.

AFCIs are installed at outlet circuits, to protect the extension cord and the appliances, and at branch circuits to protect the feeder and branch wiring. They may also be installed as combination units for outlet and branch circuits. The schematic diagram of AFCI is shown in Figure 9, with examples of feeder and branch AFCIs. North American practice is to apply AFCIs only on branch circuits. They are not available in the ratings commonly used for feeder protection devices.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

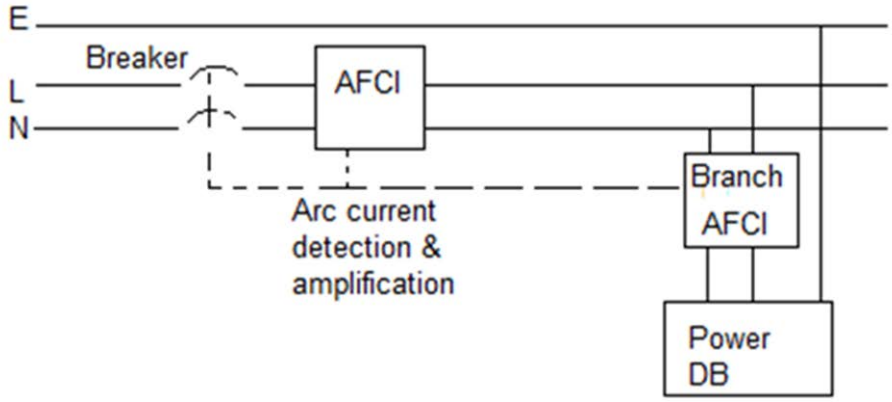


Figure 9—AFCI schematic diagram

5.2.9 Grounding of lighting power systems

The earthing, or grounding, of a power distribution system is applied to satisfy important goals of operating an electrical power system, which are to reduce the risk of a shock hazard for people coming in contact with conductive electrical enclosures, to control transient overvoltage events that can occur, and to create a condition where an overcurrent device will likely provide protection in a short-circuit condition, or make it unlikely to result in equipment damage or injury to personnel if the fault current is so small as to be undetectable. This is achieved through both proper system grounding, where the electrical source is connected in some fashion to ground, and by equipment grounding, where conductor enclosures and raceways are connected to each other and to ground via a low-impedance path. These two topics are covered extensively in IEEE Std 3003.1™ [B64] and IEEE Std 3003.2™ [B65]. NEC Article 250 contains the minimum requirements for grounding.

The following system grounding methods are employed in low-voltage ac systems:

— *Solidly grounded*, where a low-impedance connection is made from the system neutral to earth. Solidly grounded IEC methods are T-T and T-N (TN-S, TN-C, and TN-C-S).

— *Ungrounded*, where there is no connection made between the source and earth.

— *High resistance grounded*, where an impedance connected between the system neutral and earth will limit the current magnitude.

IEC designation IT is applied to both ungrounded and impedance grounded systems. The IEC designations are standardized in IEC 60364-1 [B41]. The first letter of these designations identifies the neutral point of the source with respect to ground, and the second letter identifies the grounding connection of the metallic enclosures of equipment.

AC electrical systems are generally not operated ungrounded because of the risk of temporary overvoltage (TOV) events. TOVs are overvoltages that can result from switching operations or from faults and have durations that are much longer than those of surge voltages. Building codes may not permit ungrounded systems except under limited conditions. High-resistance systems, where the ground-fault current is limited to only a few amperes (as practiced in North America) or a few milliamperes (as practiced where IEC standards are applied, such as in hospital operating rooms), can provide some of the same advantages of an ungrounded system (i.e., the ability to continue operation on the onset of a single ground fault and limitations of the degree to which a temporary overvoltage event can occur better than in an ungrounded system). However, a ground fault on an impedance-grounded system will raise the system line-to-neutral voltage with respect to ground, making it unsuitable for connection to most single-phase loads connected

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

line-to-neutral. Most single-phase, low-voltage lighting loads should be supplied from a solidly grounded source. If a facility contains a high-resistance grounded system, lighting loads could be supplied from it if the lighting loads are supplied via an isolation transformer with a grounded secondary.

The ability of an overcurrent device to trip on a ground fault is dependent to a great degree on the impedance of the return path. While conductive raceways and equipment enclosures may be able to provide a suitable low-impedance path, this path could degrade over time. The use of equipment grounding conductors installed with the phase and neutral conductors provides a more reliable return path that creates a lower fault impedance than there would be if the equipment grounding conductor was not there. An equipment grounding conductor is mandatory when conductors are routed through nonconductive raceways, which is often the case in underground conduit installations.

Equipment grounding conductors and bonding of electrical enclosures should be installed regardless of the source grounding method. However, the way equipment grounding conductors are connected can vary depending on local practices. In North America, solidly grounded systems will have a neutral-to-ground bond at the service entrance. The neutral should not be bonded anywhere else to help prevent returning load currents from flowing through ground conductors instead of neutral conductors. The neutral established by each power transformer (also referred to as a “separately derived source”) should be bonded. The IEC equivalent of this is the TN-S type system.

Special grounding practices may need to be applied when supplying sensitive electronic loads such as information technology equipment. While uninsulated bare equipment-grounding conductors can be used for most loads, it is sometimes necessary with electronic loads to use an insulated grounding conductor whose connection is made at the system bond. For more information on these practices, refer to IEEE Std 1100 [B60].

To summarize, the following grounding design considerations are recommended:

— Metal frames of equipment or appliances, and metal raceways and conduits, should be grounded to limit the ground voltage.

— Neutral points of sources should be solidly grounded.

— The grounding system’s resistance should not not be greater than that specified by relevant area standards applicable to specific appliances or equipment.

— For satisfactory operation of sensitive electrical, electronic, and information technology appliances, the grounding system should be designed such that the voltage between neutral and ground should not be significant, which may cause misoperation of low-voltage appliances and control systems.

5.2.10 Designing the capacity of the lighting system

As per ANSI/ASHRAE/IES Std 90.1 [B4], lighting power density (LPD) is lighting power per unit area of a building, space, or outdoor area, expressed in real power per square area (W/m^2 or W/ft^2). ANSI/ASHRAE/IES Std 90.1, and the IECC (International Energy Conservation Code) [B36] are the two most widely adopted in North America. Other energy codes are used outside North America, and local jurisdiction(s) should be contacted to identify the energy codes that are enforced.

Also, the lighting power allowance (LPA) is the maximum lighting power in watts allowed for either the exterior or the interior of a building. Building lighting power estimates should include light sources, drivers, ballasts, transformers, and controllers. The following methods are used to estimate the lighting requirements of building interiors and exteriors:

Simplified building method: This method can be used for interior and exterior lighting of buildings where a minimum of 80% of the floor area belongs to either office or retail applications and is illuminated

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

completely with electric lighting. This method can be applied for new buildings and for alterations. No additional lighting allowance is permitted for this method.

Building area method: Here the space in each building of the same type will have the same LPD. This method is appropriate for buildings where automatic lighting control is not applied and only manual lighting controls are used. Energy consumption from designs using this method may be greater than for facilities designed using other methods because the lighting control is manual rather than automatic.

Space-by-space method: Here it is permitted to use additional lighting, such as for wall displays and floor displays. It is not used where the simplified building method is used. This method should be used when automatic controls are applied. The lighting power calculations should result in lower values than with other methods.

The LPA values specified by ANSI/ASHRE/IES Std 90.1 [B4] are shown in Table 4.

Table 4—Recommended lighting power density allowances

Method	Location	LPA (W/ft^2)	ANSI/ASHRE/IES 90.1 table
Simplified building method	Retail building interiors		9.3.1-2
	All spaces in retail buildings except parking garages, stairwells, and corridors	1.00	
	Sales area, stock room, office spaces, conference rooms, training rooms, stairwells, and corridors	1.00	
	Parking garages	0.13	
	Building exteriors		9.3.2
	Base allowance (W)	200	
	Façade lighting, walkways	0.10	
	Landscape	0.04	
	Entry doors (W/lineal foot)	14.00	
	Stairs and ramps	0.70	
	Parking lots and drivers	0.05	
	All others not listed	0.20	
Building area method	Office interiors	0.64	9.5.1
	Fire station	0.56	
	Parking garage	0.18	
	Warehouse	0.45	
	Workshop	0.91	
	Retail	0.84	
	Convention center	0.64	
	Manufacturing facility	0.82	
	Automotive facility	0.75	
	Healthcare clinic	0.81	
	Warehouse	0.810	
Space-by-space method—interior	Atriums		9.61
	<20 ft in height	0.39	
	≥20 ft and ≤40 ft in height	0.48	
	>40 ft in height	0.60	
	Conference meeting	0.97	
	Corridor—hospital	0.71	
	All other corridors	0.41	
	Computer room	0.94	
	Electrical/mechanical room	0.43	
	Emergency vehicle garage	1.09	
	Lobby—elevator	0.65	
	Retail facilities	0.51-0.82	
	Transport facility	0.25–0.51	
	Warehouse or storage area	0.33–0.69	

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

6. Temporal light modulation

6.1 Definitions of TLM, TLA, and "flicker"

Temporal light modulation (TLM) is a change in the luminous quantity or spectral distribution of light with respect to time of either a light source or a lighting system. These changes arise because of the electrical design of the light source power supply, including ballasts, drivers, and control gears, and because of fluctuations in the electrical distribution network (CIE[10] TN 006 [B24]).

The term *temporal light artifact* (TLA) is used for the human visual perception of TLM (CIE TN 012 [B26]). The term "*flicker*" was formerly used as a generic term for both TLM and TLA. However, flicker is now defined as a type of TLA: the visual perception of light fluctuations in a static situation (no deliberate eye saccade, no object in motion). Other types of TLAs, distinct from flicker, may appear TLM. Of these other TLAs, the stroboscopic effect and the phantom array are the most reported TLAs in general lighting applications.

TLAs can be a cause of annoyance and distraction. They may have a detrimental influence in the judgment of electric lighting. Furthermore, exposure to temporal light modulation may cause undesired effects on visual performance and health (CIE TN 008 [B25]).

Although TLAs are generally undesirable, they can have desirable effects in certain circumstances, such as with candlelight or campfires, with moonlight or sunlight reflecting from rippling water, or with sunlight passing through tree leaves.

6.2 Temporal light modulation and the light waveform

6.2.1 General

In lighting products, TLM is the result of ac or transient currents flowing through the light source, creating fluctuations in the light output. In lighting devices connected to ac mains power sources, ripple currents (imperfect rectifying) at the output of the driver or ballast are the principal causes of TLM.

The light waveform is the time-domain variation of a luminous quantity (e.g., luminance, luminous intensity, illuminance, and luminous flux). TLM is associated with a nonuniform light waveform. The temporal variations of the waveform can be periodic with a single frequency or a superposition of several frequencies. They can also be transient or a combination of transient and periodic waveforms.

6.2.2 Common types of light waveforms of electric lighting

The common types of light waveforms of electric lighting are as follows:

— Periodic waveforms at twice the mains frequency (100 Hz or 120 Hz): This was the case of fluorescent lamps and HID lamps powered by magnetic ballasts, now largely obsolete. LED lamps and luminaires used with an ac/dc converter also exhibit TLM at 100 Hz or 120 Hz since there will generally be some residual of the mains fundamental frequency present. The amount of this residue depends on the exact electrical design. An example of a typical light waveform of an LED lamp is given in Figure 10.

[10] Commission Internationale de l'Eclairage or "International Commission on Illumination."

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

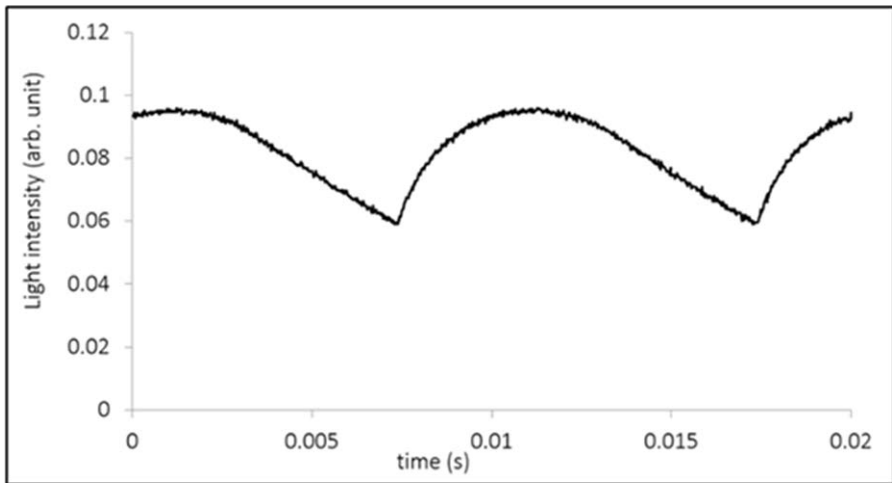
— Periodic waveforms at high frequencies: Light sources powered by high-frequency electronic ballasts or drivers usually operate in the 20 kHz to 100 kHz range, inducing TLM at the frequencies. A residual light modulation at the mains frequency may also be present.

— Periodic waveforms with variable duty cycle: This is the case of some systems, including dimmers. Dimming may be based on pulse-width modulation (PWM), usually leading to a light square-wave at frequencies of a few hundred Hertz, 100% modulation, and a variable duty cycle.

— Phase-cut dimmers (trailing edge or leading edge): These were originally developed for incandescent lamps and have been redesigned for use with CFL and LED lamps. They modify the 50 Hz or 60 Hz fundamental voltage waveform (removing an adjustable portion from each one-half cycle of the sine wave) supplied to the lamp or luminaire input. The electronics inside the lamp or luminaire determine how the input phase-cut waveform is translated into the output light waveform.

— Erratic waveforms: These occur with certain noncompatible associations of dimmers and luminaires.

— Transient waveforms: Those can be caused by electrical disturbances in the power supply (e.g., voltage sag/dip or random variation) or by radiated electromagnetic perturbations.



Graph reprinted with permission from Technical Report ED-712-150021-712-ECE “Caractérisation de lampes à usage domestique” © CSTB, 2016.

Figure 10—Examples of a light waveform of an LED lamp

Some lamps and luminaires are designed to produce TLM for specific purposes, different from general lighting, such as in emergency vehicles, fire alarms, strobe lights, flashing signs, entertainment lighting, and communications.

Lamps and luminaires are sometimes equipped with visible light communication (VLC) modules, such as Li-Fi. In this case, the emitted light is used for communication purposes through TLM. These types of TLM are not in the scope of this document because they have no known effect on visual performance, health, or other human responses. Similarly, Li-Fi and other modern digital optical communication techniques are not known to produce visible artifacts on image sensors and electronic displays.

6.2.3 Characteristics of the light waveform

Unless the light waveform is purely sinusoidal and stationary, it is not possible to identify a single frequency characterizing the waveform. In general, several relevant types of frequencies exist: for example,

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

dominant frequencies, fundamental frequencies, harmonic frequencies, subharmonic frequencies, and interharmonic frequencies. In the case of a periodic waveform, the dominant frequency corresponds to the Fourier component of highest magnitude in the power spectrum of the light waveform. The fundamental frequency is the lowest nonzero frequency among all the Fourier components. Harmonic frequencies are multiples of the fundamental frequency. In the presence of harmonic frequencies, the light waveform is not a pure sine wave and presents harmonic distortion.

Subharmonic and interharmonic frequencies may come from dysfunctional light sources or the associated electrical power circuit. They represent unwanted components in the light waveform. At a high level, they might be responsible for instabilities in the light output.

6.2.4 Metrics related to the light waveform

CIE TN-012 [B26] defines the two parameters commonly used to describe a periodic light waveform associated with TLM of ac-powered lamps and luminaires.

The modulation depth (Mod%), sometimes called “flicker percent” or simply “modulation,” is defined using the minimal and maximal values of the light waveform, as shown in Figure 11. The flicker index *FI* is defined as the area above the line of average light divided by the total area of the light output curve for a single cycle (Figure 11).

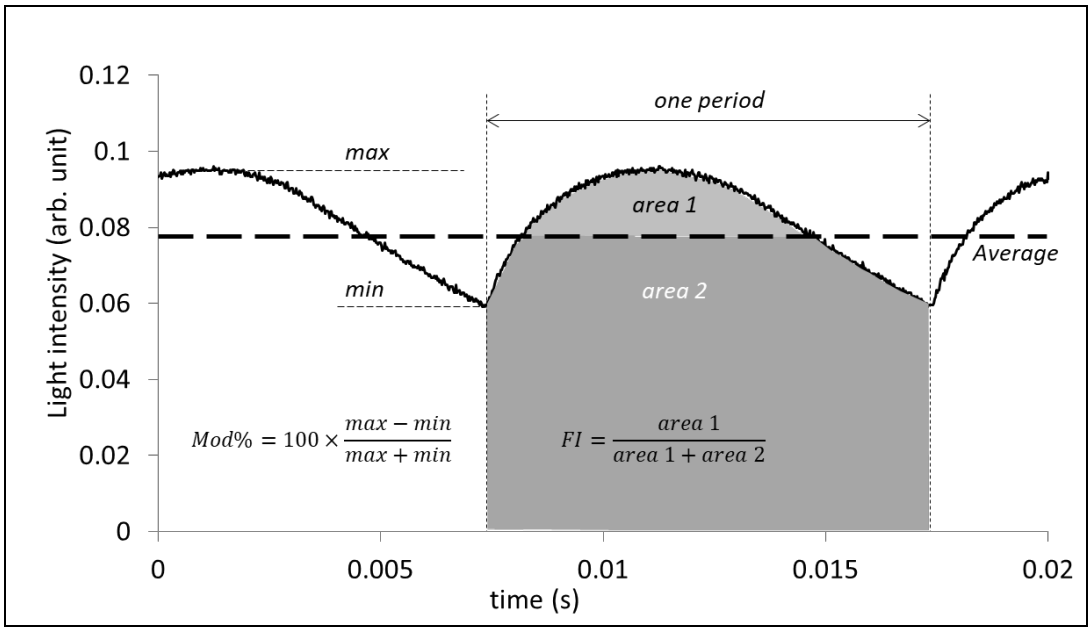


Figure 11—Definitions of the Mod% and FI

6.3 Temporal light modulation associated with voltage fluctuations

The mains voltage is ideally represented by a constant-frequency, constant-amplitude sine wave. However, mains voltage may be distorted and/or may fluctuate for several reasons, such as follows:

— Insufficient available instantaneous power for the load

— Sudden load changes with accompanying inrush current (e.g., the turning on of an air conditioner, refrigerator, coffee maker, or hair dryer)

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

— Powerline communications superimposed on the mains waveform

— Environmental effects (e.g., lightning and wind storms)

— Distributed power generation (e.g., wind or solar) may create fluctuations because of changes in wind or sunlight

Voltage fluctuations may be periodic or aperiodic. They may be transient or continuously present.

IEC 61000-4-15 [B45] describes an apparatus called a "voltage flicker meter," designed to characterize voltage fluctuations in terms of the visual flicker perception level that these fluctuations induce in a 60 W incandescent lamp. This lamp was chosen in the past as a reference to determine the visibility threshold level. This agreement serves as a "handshake" between nonlighting and lighting equipment. The IEC flicker meter provides two metrics to characterize the voltage fluctuations: the short-term flicker severity P_{st} and the long-term flicker severity P_{lt}.

Equipment connected to the mains may be adversely affected by the presence of voltage fluctuations if the equipment has insufficient immunity to those fluctuations (e.g., causing a reduction in product lifespan). In the case of lighting equipment, depending on their severity, voltage fluctuations can potentially increase TLM. IEC TR 61547-1-1:2020 [B46] provides a description of an objective light flicker meter and a method for measuring the intrinsic flicker of lighting equipment, as well as for testing the immunity of lighting equipment against mains voltage fluctuations. The light flicker meter is different from the voltage flicker meter of IEC 61000-4-15 [B45] because it does not rely on a reference lamp. Instead, the light flicker meter is based on the luminous waveform generated by the light source under test. The output of the light flicker meter is the short-term flicker metric P_{st}^{LM} of the light source.

IEC TR 61547-1-1:2020 [B46] describes two types of measurements applicable to light sources. One is performed with a stable mains and evaluates the intrinsic light flicker of the light source. It will reveal any flicker generated by the light source itself. The second is an immunity test performed with a deliberately distorted mains source. The result of the measurement when a voltage fluctuation is applied is referred to as $P_{st}^{LM}(I)$, according to IEC TR 61547-1-1:2020. Five sinusoidal voltage fluctuation waveforms are defined, which are individually superimposed on the stable mains waveform. The waveform parameters (frequency and voltage) depend on the mains frequency and voltage. The light output is measured with each voltage fluctuation applied separately, and the short-term flicker metric $P_{st}^{LM}(I)$ is measured for each. The measured values of $P_{st}^{LM}(I)$ provide an indication of the immunity of the light source. The flicker visibility threshold (Section 11 of IEC TR 61547-1-1:2020) is $P_{st}^{LM} = 1$.

Note that even if all equipment adhered to the IEC limit of $P_{st}^{LM} = 1$, it is still possible to have voltage fluctuations that exceed the limit if, for example, more than one piece of equipment is connected to the mains circuit or the mains circuit has insufficient capacity to handle the load without distortion.

IEC TR 61547-1-1:2020 [B46] also describes testing to determine compatibility with external light-regulation equipment (i.e., dimmers). A stable mains is used, and testing is done with the external equipment set to 100% and 50% light output levels.

IEEE Std 1453™ [B61] is used by utilities to determine emission limits on how much voltage flicker individual facilities may introduce in the utility system. This standard provides a flicker measurement method using the flicker meter described in IEC 61000-4-15. The short-term (P_{st}) and long-term (P_{lt}) voltage flicker metrics are also used, together with limits applicable to the entire facility, not to individual devices or equipment. An assessment procedure for evaluating voltage flicker compliance is described. The document provides ways to estimate voltage flicker levels at the point of common coupling (PCC), depending on the type of the load. IEEE Std 1453 does not provide flicker metrics based on the luminous output of a light source.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

NEMA 77 [B71] advises manufacturers to consider the immunity of their products to variations in mains voltage during the design process. Because the possible variations in the mains waveform are endless, as described above, NEMA 77 does not prescribe the waveforms to use but advises the manufacturer to choose representative distorted waveforms to evaluate product immunity.

ANSI C82.77-1 [B10] addresses electromagnetic compatibility (EMC) and is primarily used in the United States.

6.4 Temporal light modulation introduced by dimmers

Phase-cut dimmers are the most common type of equipment used to dim lamps. Phase-cut dimmers operate by interrupting the mains voltage to the light source twice each line cycle (i.e., 120 times each second).

The phase angle determines the root-mean square (RMS) voltage applied to the light source, which in turn determines the light output. The primary source of temporal light modulation that occurs from a lamp connected to a phase-cut dimmer does not occur at harmonics of the mains voltage because most LED lamps with integral drivers also include some degree of energy storage. Rather, the primary source of TLM that occurs from a lamp connected to a phase-cut dimmer is low frequency and broadband due to instabilities of the dimmer power supply.

Proper operation of the dimmer determines the phase angle. If the dimmer power supply is unstable, then the phase angle is unstable, so the RMS voltage applied to the lamp is not stable. Consequently, the light output modulates in a low-frequency, visible manner, resulting in visible flicker.

The power supplied to the phase-cut dimmer typically passes through the light source. Therefore, a design interface requirement exists between phase-cut dimmers and dimmable LED lamps with integral drivers. Such an interface requirement has been described in two IEC technical reports (IEC TR 63036 [B43] and IEC TR 63037 [B44]), and methods of measurement for compliance of the dimmer and light source exist in NEMA SSL 7A [B74] and NEMA 77 [B71] to ensure their proper mutual compatibility.

6.5 Different types of temporal light artifacts perceived by the human visual system

6.5.1 General

Three types of TLAs are commonly reported in general lighting applications: flicker, the stroboscopic effect, and the phantom array effect. Other types of TLAs have been studied but are more rarely encountered in general lighting applications. For instance, chromatic flicker may be perceived when the spectral power distribution of the light changes with time, and subjective colors may be perceived when certain achromatic patterns are illuminated by modulated white light.

6.5.2 Flicker

Flicker is defined as the perception of visual unsteadiness induced by TLM for a static observer (i.e., an observer who does not move their eyes) in a static environment (see Figure 12). Flicker may be perceived as periodic, aperiodic, random, or transient fluctuations of the light level, according to the characteristics of the light waveform.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

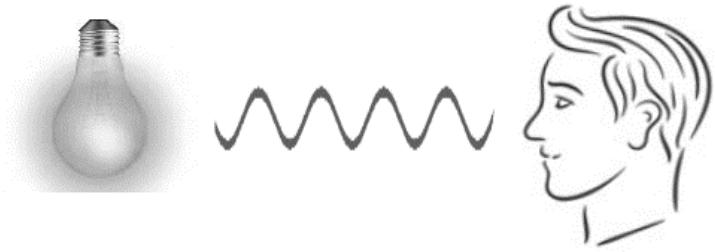


Figure 12—Flicker situation

6.5.3 Stroboscopic effect

The second type of TLA is the stroboscopic effect. It is defined by a change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a nonstatic environment. This effect may be visible when a moving or rotating object is illuminated by modulated light (CIE TN 006 [B24]). It may also be visible when the observer moves under modulated light. In this case, the stroboscopic effect may alter the perceived motion of limbs (e.g., hands and arms). With the stroboscopic effect, moving objects are perceived to move discretely rather than continuously (Figure 13). If the observer's eyes also move, then a phantom array effect (see 6.5.4) is likely to be present perhaps in addition to a stroboscopic effect.

In the context of machines and tools, if the frequency of a periodic luminance fluctuation coincides with the frequency of a rotating object, the rotating object may be perceived as static. The stroboscopic effect can change the perceived motion of rotating or reciprocating machines. In this context, it must be assessed and reduced to avoid potentially dangerous situations.

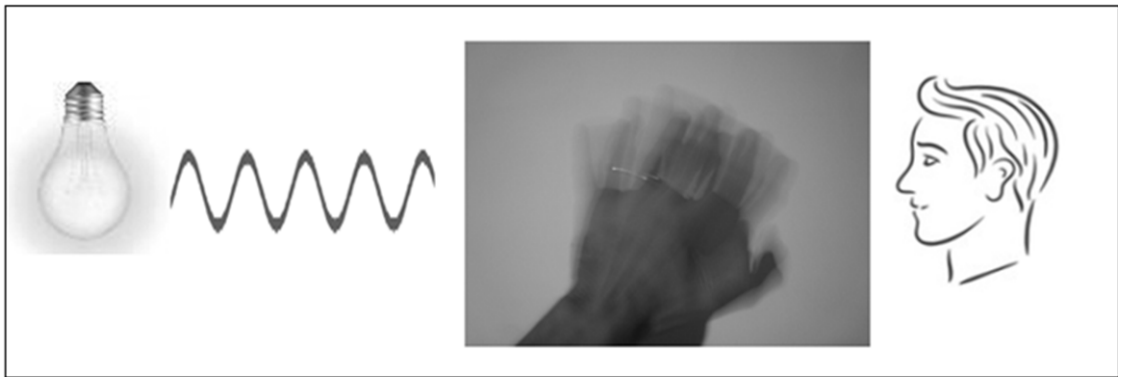


Figure 13—Stroboscopic effect situation

6.5.4 Phantom array effect

The third type of temporal light artifact is the phantom array effect, also known as “ghosting.” It is defined as a change in perceived shape or spatial positions of objects, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time for a nonstatic observer (i.e., an observer moving their eyes) in a static environment (CIE TN 006 [B24]).

When making an eye saccade over a light source exhibiting TLM, the light source is perceived as a series of spatially extended ghost images, the so-called “phantom array” rather than a smooth streak. The phantom array is aligned with the saccade trajectory but appears to be entirely displaced on one side of the

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

light source toward the end point of the saccade. The tail end of the array coincides with the light source. The multiple ghost images appear sequentially in the reverse direction of the saccade (Figure 14). The multiple images will blur together in different degrees, depending on the details of the TLM (e.g., its modulation depth, duty cycle, and frequency).

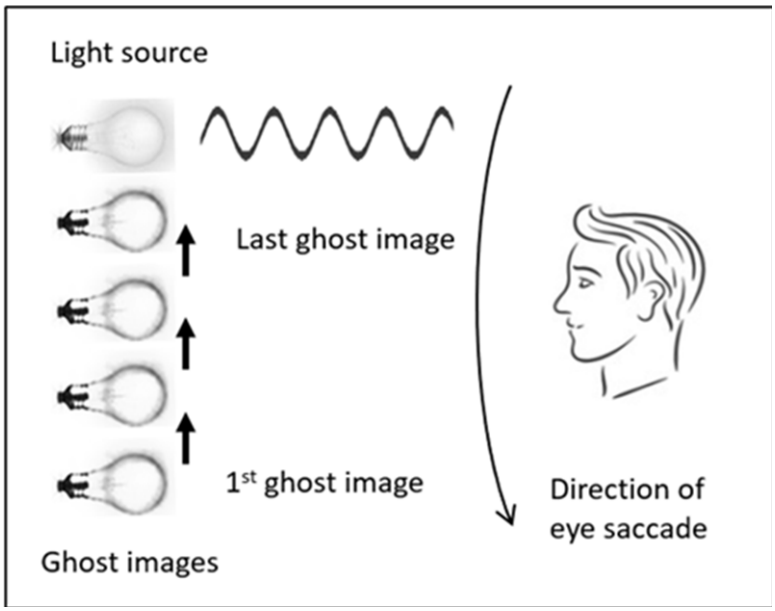


Figure 14—Phantom array situation

In specific situations such as driving, both the observer and the environment are not static. In this case, the stroboscopic and phantom array effects appear together.

The visibility of phantom array effects in dark environments is common with pulse-width modulation (PWM) systems used at low light levels. The effect is more pronounced with light sources and objects having bright edges against a darker background. It may also be visible in photopic conditions with objects that have a dark edge and are seen against a bright background illuminated by modulated light.

The phantom array effect is caused by different parts of the retina being stimulated at different times, with gaps in the visual stimulus in between. The phantom array effect is not well understood in terms of visibility threshold or a sensitivity curve. It is an active subject of research in the lighting and display scientific community (CIE TN 008 [B24]).

6.5.5 Temporal light artifacts observed on electronic devices

TLM can interfere with electronic image sensors used in cameras and electronic devices. Several types of undesirable artifacts may be produced on captured images and videos [e.g., dark bands (banding), part of an object missing, edge distortion, or color artifacts]. The exact nature of these artifacts depends on technical parameters of the sensors themselves, such as the type of shutter (rolling shutter, global shutter), the integration time, and the frame rate.

High-speed cameras, operating at shutter speeds above 150 frames per second (fps), and often between 300 fps and 600 fps, are often used to film sporting events. The European standard EN 12193 [B32] identifies the TLM of luminaires as being responsible for unwanted visual artifacts during filming. It states that when lighting systems are used with fast cameras, the undesirable visual artifacts can be controlled as follows:

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

— Using a lighting system complying with TLM limits expressed in terms of the modulation depth (see 6.9 on published limits) as a function of the integration time of the cameras

— The use of electronic ballasts

— Avoiding using PWM to control the light level

Several sports lighting standards have been issued by professional sports federations (e.g., soccer federations FIFA and UEFA and the USA hockey federation FIH). Their specifications of TLM are generally like the EN 12193 [B32] requirements. However, they provide additional specifications concerning the onsite testing of TLM: vertical measurement plane, measurement azimuthal angles, measurement positions across the field, and measurement heights.

High-speed cameras are also used in a variety of applications to capture fast phenomena, such as research, testing, and high-resolution imaging. Similar requirements may apply to the lighting systems used in these specific contexts.

The operation of bar-code scanners can also be potentially affected by the TLM of the ambient electric lighting.

6.6 Neurophysiological and health effects of temporal light modulation

6.6.1 Known neurophysiological effects of temporal light modulation

The known neurophysiological effects of TLM are the modifications of ocular movements and alterations of visual performances.

6.6.2 Psychological effects

Several effects of TLM were revealed by psychological investigations, including changes of mood, modification of cognitive performances, and effects on emotions.

6.6.3 Known health effects of temporal light modulation

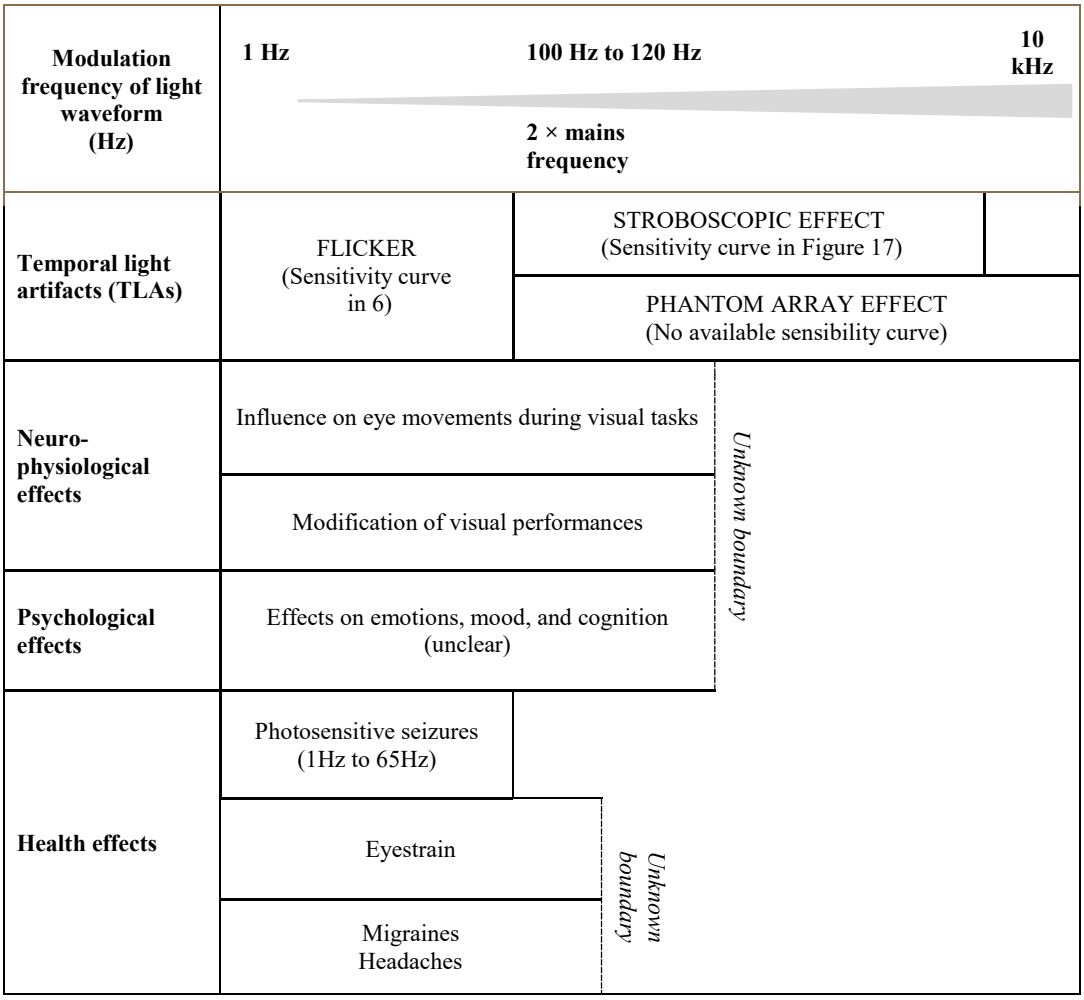
The known and proven health effects of TLM are eyestrain (asthenopia), headaches, migraine, and photosensitive epilepsy.

A possible effect of TLM on the aggravation of autistic behaviors has been reported in two studies carried out in 1976 and 1985 on a limited number of subjects. However, it is not possible to prove or disprove the existence of this effect, given the limited available research on this topic.

Table 5 gives a summary of the known visual and nonvisual effects of TLM.

Copyright © 2023 IEEE. All rights reserved.
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

Table 5—Summary of the visual and nonvisual effects of TLM



6.6.4 Sensitive populations

Industrial and commercial lighting systems may be used in the presence of individuals particularly sensitive to TLM. This population is not well understood but includes those sensitive to flicker, those suffering from photosensitive epilepsy, some people who have suffered head injuries (deliberate introduction of flickering light is a medical diagnosis tool for head injuries), and some migraine sufferers.

6.6.5 Sensitive activities

Many sensitive activities are involved with industrial lighting. They are usually associated with an increased illuminance requirement (refer to ANSI/IES RP-7-21 [B151]). This category of activities includes (but is not limited to) quality control, work on assembly lines, painting, fabrication of clothing, engraving, micromechanical work, and mounting of electronic components.

In some activities, avoidance of TLM can be critical because the visual task is difficult to achieve without stable illumination. Errors may also be critical.

Sensitive activities may require a lower level of TLM and TLA than other applications require. Insufficient data exist to define the sensitive population and/or to indicate desired levels.

Copyright © 2023 IEEE. All rights reserved.
Documents Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

6.7 Metrics describing temporal light artifacts

6.7.1 Short-term flicker visibility index

The short-term flicker visibility index Pst^{LM} is defined in IEC TR 61547-1:2020 [B46]. It is a measure of the visibility of flicker evaluated over a short duration of at least 180 s and, typically, 10 min. Its calculation is performed in the time domain from the light waveform using an algorithm, sometimes called the "IEC light flicker meter." The calculation uses a standard human visual response function to temporal contrasts (temporal contrast sensitivity function; see Figure 15). This function is defined for pure sinusoidal waves. It has a maximum sensitivity at approximately 9 Hz, and the critical fusion frequency (maximum frequency above which a modulated light source appears steady when the observer is fixed) is approximately 60 Hz. The human response function used in the calculation of Pst^{LM} was originally derived using a small-size luminous stimulus with sharp edges, seen in central vision in well-lit conditions. However, Pst^{LM} can be assessed and is now used outside its original range of lighting conditions, including in dim environments (mesopic conditions).

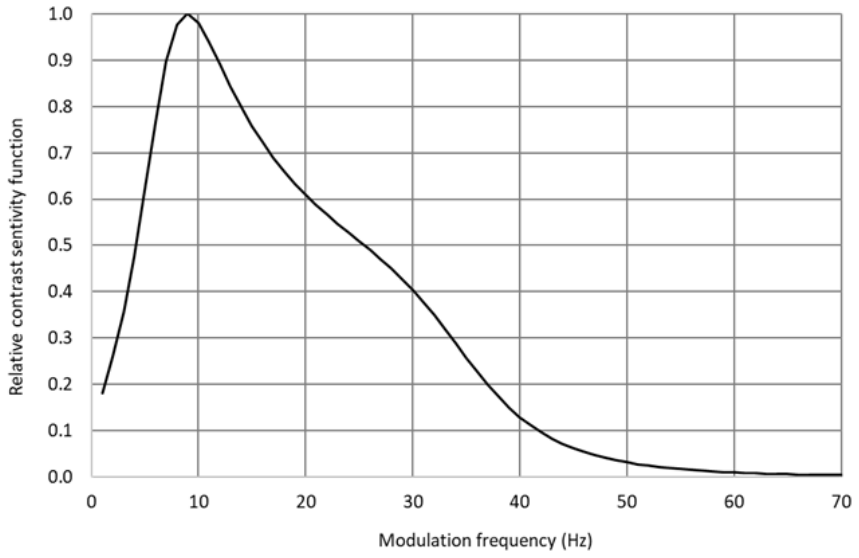


Figure 15—Sensitivity function to flicker, used in the calculation of Pst^{LM}

The short-term visibility index P_{st}^{LM} has been extensively used to test the immunity of lighting systems to voltage fluctuations. It is now the standard metric for testing flicker at the product level in normal (stable) power supply conditions. This metric has the advantage of being applicable to all types of light waveforms (e.g., transient, periodic, highly distorted, and variable duty cycle).

The mathematical procedure is described in IEC TR 61547-1:2020 [B46] and NEMA-77 [B71]. By definition, when P_{st}^{LM} equals 1, an average observer has a 50% chance of perceiving flicker.

6.7.2 Flicker perception metric

The flicker perception metric (M_p) was developed by the Alliance for Solid-State Illumination Systems and Technologies (ASSIST) [B19].

Copyright © 2023 IEEE. All rights reserved.
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

The flicker perception metric is a measure of the visibility of flicker evaluated over a shorter duration than that used for P_{st}^{LM}. It is at least 2 s and typically 10 s. Its calculation is performed in the frequency domain using the Fourier transform of the light waveform, weighed by a slightly different human temporal contrast sensitivity function than used for Pst^{LM} (Figure 16). This function is also defined for pure sinusoidal waves.

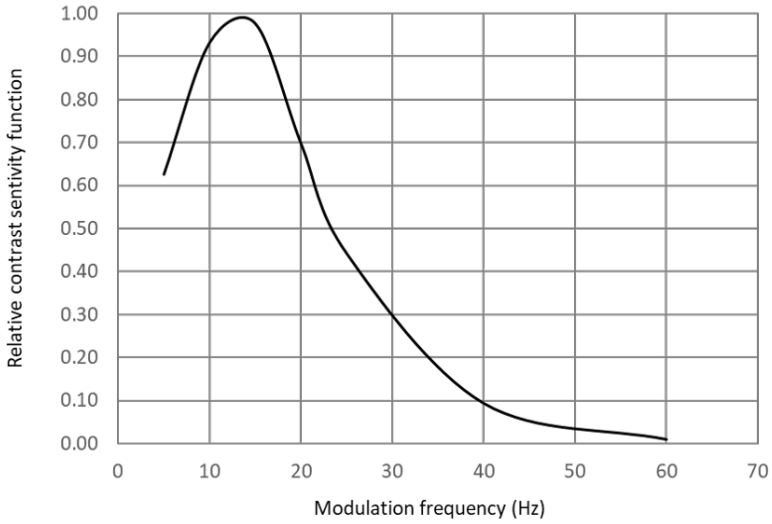


Figure 16—Sensitivity function to flicker, used in the calculation of the flicker perception metric M_p

According to the NEMA 77 [B71] standard, the respective values of the flicker perception metric M_p and the P_{st}^{LM} index corresponding to the same light waveform are close.

6.7.3 Stroboscopic visibility measure

The stroboscopic visibility measure (SVM) is defined in IEC TR 63158:2018 [B47]. It is a measure of the visibility of the stroboscopic effect perceived with movements of the hand or the arm of moderate speed (less than 4 m/s) under modulated light. It is evaluated over a short duration of at least 1 s. Its calculation is performed in the frequency domain using the Fourier transform of the light waveform, weighted by a sensitivity curve shown in Figure 17 and defined for pure sinusoidal waves. This graph shows that the maximum visibility of the stroboscopic effect for moderate-speed hand and arm motions occurs at ~80 Hz. The upper frequency limit is ~1000 Hz. The calculation of SVM is detailed in IEC TR 63158:2018 [B47] and NEMA 77 [B71]. An average observer has a 50% chance of perceiving the stroboscopic effect when SVM equals 1.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...

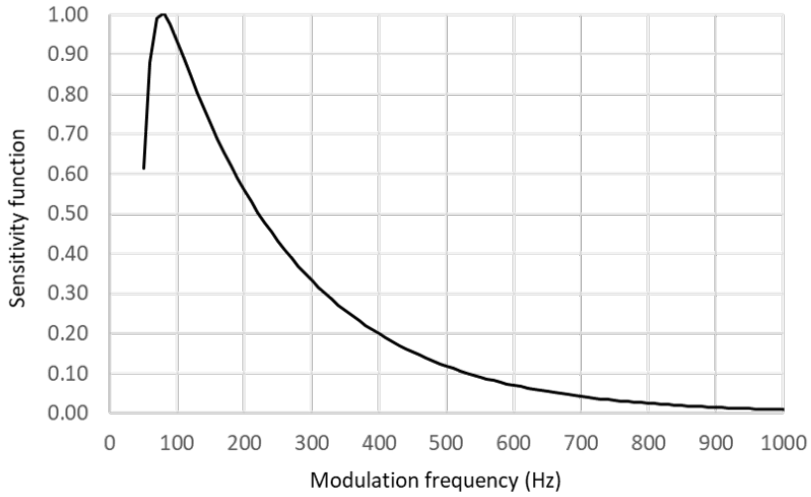


Figure 17—Sensitivity function used in the calculation of the stroboscopic visibility measure SVM

The SVM metric is used to quantify the visibility of the stroboscopic effect in applications where speeds of the order of human motion are dominant and the illuminance level is greater than 100 lx. It is not applicable in dark environments, nor in outdoor lighting.

SVM is not adapted to assess the stroboscopic effects observed on high-speed rotating or reciprocating machinery under modulated light, where motion may be considerably faster than 4 m/s.

6.7.4 Metric for the phantom array effect

No metric currently quantifies the visibility threshold or the sensitivity function for the phantom array effect. IEEE Std 1789™-2015 [B62] and CIE TN 006 [B24] both mention research studies showing that the phantom array effect is visible with small light sources in high contrast with their background (i.e., in dark environments) at modulation frequencies from 120 Hz to 2500 Hz.

In real-life application, the phantom array is best seen in indoor and outdoor luminaires (and displays) using PWM dimming at low illuminance levels. It is also noticeable in automotive headlights and rear lights (not in the scope of this standard).

6.7.5 Metrics applicable to temporal light artifacts produced by image sensors and visible on electronic displays

The metrics SVM and P_{st}^{LM} were designed to predict the visibility of flicker and the stroboscopic effect in humans. These metrics are not applicable to artifacts created by image sensors on electronic displays.

No standard metric currently associates with TLAs observed on electronic devices. The imaging and display industry uses light waveform parameters such as the modulation depth and dominant modulation frequency.

Copyright © 2023 IEEE. All rights reserved.
Documents
Document Sharing Hub
Authorized licensed use limited to: Tsinghua University. Downloaded on March 06,2026 at 23:47:14 UTC from IEEE Xplore. Restrictions apply.
Full document details: 3001.9/IES RP-48-2023 - IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commerci...