

IEEE Application Guide for AC High-Voltage Circuit Breakers > 1000 Vac Rated on a Symmetrical Current Basis

IEEE Power and Energy Society

Sponsored by the
Switchgear Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std C37.010™-2016
(Revision of
IEEE Std C37.010-1999)

IEEE Application Guide for AC High-Voltage Circuit Breakers > 1000 Vac Rated on a Symmetrical Current Basis

Sponsor

Switchgear Committee
of the
IEEE Power and Energy Society

Approved 22 September 2016

IEEE-SA Standards Board

Recognized as an American National Standard

Abstract: The application of indoor and outdoor high-voltage circuit breakers rated above 1000 Vac for use in commercial, industrial, and utility installations is covered in this guide. It deals with usage under varied service conditions, temperature conditions affecting continuous current compensation, reduced dielectrics, reclosing derating as applicable, calculation of system short-circuit current, compensation at different X/R ratios, detailed calculations with application curves, out-of-phase switching, and general application.

Keywords: ambient compensation/emergency operation, capacitor switching, high-voltage circuit breakers, IEEE C37.010™, indoor drawout, outdoor, pollution level creepage distance, power frequency, line closing, load current switching, rated maximum voltage, short-circuit consideration, transformer current switching, TRV

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

Copyright © 2017 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 17 April 2017. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-2361-8 STD21135
Print: ISBN 978-1-5044-2362-5 STDPD21135

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

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

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

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

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at <http://ieeexplore.ieee.org/> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

Errata

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

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this IEEE guide was completed, the Switchgear Committee Working Group had the following membership:

Helmut Heiermeier, *Chair*
Xi Zhu, *Vice Chair*
Michael Skidmore, *Secretary*

Syed Shahab Uddin	Edgar Dullni	Mirko Palazzo
Ahmed	John Eastman	Shawn Patterson
Roy Alexander	Kenneth Edwards	Thomas Pellerito
Michael Anderson	Leslie Falkingham	Lise Phan
Mauricio Aristizabal	Thomas Field	Reynaldo Ramos
George Becker	Victor Hermosillo	Anthony Ricciuti
Robert Behl	Todd Irwin	Jon Rogers
W. J. (Bill) Bergman	Richard Jackson	Charles Ross
Stan Billings	Cory Johnson	Roderick Sauls
Anne Bosma	Stephen Lambert	Carl Schuetz
Steven Brown	Hua Ying Liu	Jon Schumann
Arben Bufi	Albert Livshitz	Devki Sharma
Eldridge Byron	Bill Long	Shushil Shinde
Gilbert Carmona	Gary Martin	Zachary Smith
Stephen Cary	Frank Mayle	Don Steigerwalt
Steven Chen	David Mitchell	James Van de Ligt
Chih Chow	Georges Montillet	John Webb
Michael Christian	Stephanie Montoya	Jan Weisker
Patrick Di Lillo	Tom Mulcahy	Jiong Zhang
Denis Dufournet	Jeffrey Nelson	

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

Satish Aggarwal	Glenn Davis	Andrew Jones
Roy Alexander	Gary Donner	Laszlo Kadar
Chris Ambrose	Randall Dotson	John Kay
Mauricio Aristizabal	Denis Dufournet	Gael Kennedy
Ficheux Arnaud	Edgar Dullni	Yuri Khersonsky
Paul Barnhart	Donald Dunn	James Kinney
George Bartok	Douglas J. Edwards	Boris Kogan
George Becker	Kenneth Edwards	James Kulchisky
W. J. (Bill) Bergman	Keith Flowers	Saumen Kundu
Stan Billings	Rabiz Foda	Chung-Yiu Lam
William Bloethe	Marcel Fortin	Stephen Lambert
Anne Bosma	Doaa Galal	Benjamin Lanz
Jeffrey Bragg	Frank Gerleve	John Leach
Steven Brown	David Gilmer	Hua Ying Liu
Ted Burse	Mietek Glinkowski	Li Liu
William Byrd	Edwin Goodwin	Albert Livshitz
Eldridge Byron	James Graham	R. Long
Paul Cardinal	Randall Groves	Thomas Lundquist
Stephen Cary	Charles Hand	Omar Mazzoni
Steven Chen	John Harder	Nigel McQuin
Chih Chow	John Harley	Peter Meyer
Lucas Collette	Helmut Heiermeier	T. David Mills
Stephen Conrad	Jeffrey Helzer	David Mitchell
Michael Crawford	Todd Irwin	Georges Montillet

Thomas Mulcahy
 Jerry Murphy
 Arun Narang
 Jeffrey Nelson
 Arthur Neubauer
 Michael Newman
 Joe Nims
 T. W. Olsen
 Lorraine Padden
 Mirko Palazzo
 Shawn Patterson
 Christopher Petrola
 Iulian Profir
 Moises Ramos
 Reynaldo Ramos
 Samala Santosh Reedy

Charles Rogers
 Thomas Rozek
 Steven Sano
 Roderick Sauls
 Bartien Sayogo
 Carl Schneider
 Carl Schuetz
 Devki Sharma
 Sushil Shinde
 John Shullaw
 Michael Sigmon
 Veselin Skendzic
 Michael Skidmore
 James Smith
 Jeremy Smith
 R. Kirkland Smith

Gary Stoedter
 David Stone
 Malcolm Thaden
 Wayne Timm
 John Vergis
 Mark Waldron
 John Webb
 Karl Weber
 Jan Weisker
 Yingli Yen
 Kenneth White
 James Wilson
 Larry Yonce
 Jian Yu
 Xi Zhu

When the IEEE-SA Standards Board approved this guide on 22 September 2016, it had the following membership:

Jean-Philippe Faure, *Chair*
Ted Burse, *Vice Chair*
John Kulick, *Past Chair*
Konstantinos Karachalios, *Secretary*

Chuck Adams
 Masayuki Ariyoshi
 Stephen Dukes
 Jianbin Fan
 J. Travis Griffith
 Gary Hoffman
 Ronald W. Hotchkiss

Michael Janezic
 Joseph L. Koepfinger*
 Hung Ling
 Kevin Lu
 Annette D. Reilly
 Gary Robinson
 Mehmet Ulema

Yingli Wen
 Philip Winston
 Howard Wolfman
 Don Wright
 Yu Yuan
 Daidi Zhong

*Member Emeritus

Introduction

This introduction is not part of IEEE Std C37.010–2016, IEEE Guide for AC High-Voltage Circuit Breakers > 1000 Vac Rated on a Symmetrical Current Basis.

This guide is a revision of IEEE Std C37.010™-1999 (Reaff 2005) and contains substantive changes due to the efforts of three coordinated Working Groups on revision and coordination of IEEE Std C37.04™, IEEE Std C37.09™, and IEEE Std C37.010.

Although much of the approach of IEEE Std C37.010–1999 has been retained, many editorial changes, significant enhancements, and some fundamental changes have been made.

Some of the major issues include the following:

- Some background information and clarification for controlled switching (IEEE Std C37.012™).
- Some background information and clarification for inductive current switching (IEEE Std C37.015™).

Evaluate existing test data for differing dc time constants (X/R).

Contents

1. Overview.....	14
1.1 Scope.....	14
1.2 Purpose.....	14
2. Normative references	14
3. General service conditions	15
3.1 Usual service conditions.....	15
3.2 Unusual service conditions.....	16
3.3 Mechanical considerations for outdoor circuit breakers	20
4. Application considerations	20
4.1 General	20
4.2 Maximum voltage for application	21
4.3 Voltage range factor.....	21
4.4 Frequency	21
4.5 Continuous current	21
4.6 Rated dielectric withstand	34
4.7 Standard operating duty.....	35
4.8 Interrupting time.....	35
4.9 Permissible tripping delay T (determined by short-time current test duration).....	37
4.10 Reclosing time.....	38
4.11 Short-circuit current rating	42
4.12 Transient recovery voltage (TRV)	54
4.13 Load current switching capability and life (repetitive operation)	54
4.14 Capacitance current switching.....	54
4.15 Line closing (line-closing switching surge factor for circuit breakers 362 kV and above).....	55
4.16 Switching lines with series capacitors	61
4.17 Conditions of use with respect to the out-of-phase switching current rating.....	61
4.18 Shunt reactor current switching.....	62
4.19 Transformer current switching	63
4.20 Controlled switching	63
4.21 Transformer limited fault (TLF) duties.....	65
4.22 Mechanical endurance.....	65
4.23 Rated control voltage.....	66
4.24 Fluid operating pressure	66
4.25 Insulating oil for circuit breaker	66
4.26 Closed pressure system (gas-filled)	66
4.27 Circuit breakers limiting factors for associated equipment.....	66
4.28 Circuit breakers equipped with resistors.....	67
4.29 Service capability	70
5. Short-circuit considerations	70
5.1 System short-circuit currents.....	70
5.2 Methods for calculating system short-circuit currents.....	73
5.3 Electrical quantities used.....	85
5.4 Selection of applicable circuit breaker ratings.....	90
Annex A (informative) Basis for E/X method corrected for ac and dc decrements in the calculation of short-circuit currents.....	92
Annex B (informative) Circuit breakers directly connected to motors	112

Annex C (informative) Bibliography	116
--	-----

List of Figures

Figure 1—Current-time relationship to determine short-time load-current capability of high-voltage circuit breakers	27
Figure 2—Operating time	36
Figure 3—Interrupting capability factor for reclosing service	40
Figure 4—Examples of reclosing capability for some usual reclosing duty cycles	41
Figure 5—Graphical representation of asymmetrical current wave shape and identification of loops for single-phase condition	43
Figure 6—Clearing after a minor loop with first pole to clear factor 1.5.....	44
Figure 7—Clearing after a loop with intermediate asymmetry first pole to clear factor 1.5.....	45
Figure 8—First possible clearing after major loop with first pole to clear factor 1.5	46
Figure 9—Test performed for a time constant of 45 ms with an available time constant of 60 ms using the controlled closing method	47
Figure 10—Testing with an available time constant of 60 ms for a required time constant of 75 ms using the method to choose a different current loop.....	48
Figure 11—Duration and peak of current loop for major loops at 50 Hz	50
Figure 12—Duration and peak of current loop for minor loops at 50 Hz.....	51
Figure 13—Duration and peak of current loop for major loops at 60 Hz.....	51
Figure 14—Duration and peak of current loop for minor loops at 60 Hz.....	52
Figure 15—Power circuit breaker design requirements	53
Figure 16—Traveling wave model at contact S during step 1.....	58
Figure 17—Traveling wave model at contact S during step 2.....	58
Figure 18—Example of overvoltage surge on when reclosing a transmission line.....	60
Figure 19—PIR circuit breaker applied to the line	67
Figure 20—Comparison of different methods	68
Figure 21—Variation of switching overvoltage limitations on switching surge limitation (4.0 pu) achieved with different combinations of controlled switching and surge arrestors (SA) at the line end and the PIR [B32]	68
Figure 22—AC and dc decrement factors for three-phase faults with local generation for 8-, 5-, 3-, and 2-cycle circuit breakers.....	77
Figure 23—AC and dc decrement factors for phase-ground faults with local generation for 8-, 5-, 3-, and 2-cycle circuit breakers.....	78
Figure 24—AC and dc decrement factors for three-phase and phase-ground faults with remote generation for 8-, 5-, 3-, and 2-cycle circuit breakers	79

Figure 25—Single line diagram of example power system	80
Figure 26—Output for separate X and R reductions.....	81
Figure 27—Fault study program output: Three-phase fault current contributions	83
Figure 28—Fault study output: Single-phase fault current contribution	83
Figure 29—System illustrating large short-circuit contribution from motors	86
Figure 30— X/R range for power transformers at 60 Hz.....	89
Figure 31— X/R range for three-phase induction motors at 60 Hz.....	89
Figure 32— X/R range for small solid rotor and salient pole generators and synchronous motors at 60 Hz....	90
Figure A.1—Symmetrical and total current decrement three-phase short-circuit 107 MVA 3600 r/min conductor-cooled turbine generator.....	94
Figure A.2—Symmetrical and total current decrement three-phase short-circuit with generator and system contribution	95
Figure A.3—Symmetrical and total current decrement three-phase short-circuit representative 95– 200 MVA conventional-cooled 3600 r/min turbine generators.....	96
Figure A.4—Symmetrical and total current decrement three-phase short circuits representative 35– 65 MVA 3600 r/min turbine generators	97
Figure A.5—Relationship of $\left(\frac{I_{asym}}{I_{sym}}\right)_{nacd}$ to X/R at 60 Hz for several circuit breaker contact parting times.....	98
Figure A.6—Relationship between X/R ratio and ac decrement from accurate fault calculation at 60 Hz	99
Figure A.7—Illustration of accuracy of fault determination of hydro generation three-phase fault at high side terminals of station step-up transformers	100
Figure A.8— E/X multiplier for equivalent symmetrical amperes for actual X/R at 60 Hz	101
Figure A.9—Relationship of I_{asym}/I_{sym} to X/R (at 60 Hz) for several circuit breaker contact parting times ...	103
Figure A.10—Three-phase fault multiplying factors that include effects of ac and dc decrement at 60 Hz..	104
Figure A.11—Line-to-ground fault multiplying factors that include effects of ac and dc decrement	105
Figure A.12—Three-phase and line-to-ground fault multiplying factors that include effects of dc decrement only	106
Figure A.13—Circuit breaker asymmetrical capability.....	107
Figure A.14—Illustration of accuracy of fault determination.....	108
Figure A.15—Illustration of accuracy of fault determination single line-to-ground fault	110
Figure A.16—Illustration of accuracy of fault determination line-to-ground fault at terminals	111
Figure B.1—Methods of ac motor starting	113

List of Tables

Table 1—Environmental examples by pollution level.....	18
Table 2—Minimum nominal specific creepage distance by pollution level	19
Table 3—Ratios of (I_a/I_r) for various ambient temperatures.....	25
Table 4—Typical thermal time constants	26
Table 5—Emergency load current-carrying capability factors (I_e/I_r) based on an ambient temperature of 40 °C	30
Table 6—Emergency load current-carrying capability factor (I_{ea}/I_r) for various ambient temperatures for 4 h emergency period.....	31
Table 7—Emergency load current-carrying capability factor (I_{ea}/I_r) for various ambient temperatures for 8 h emergency period.....	31
Table 8—Example of allowable overload current with rated initial current	33
Table 9—Example of allowable overload current with 50% initial rated current	33
Table 10—Example for comparison of tested and required parameters for asymmetrical current interruption.....	49
Table 11—Example of line-closing switching surge factors for circuit breakers specially designed to control switching surge maximum voltages and parameters of standard reference transmission lines.....	56
Table 12—Impedance values of a system based on 100 MVA.....	80
Table 13—Fault current contributions for three-phase fault.....	81
Table 14—Fault current contributions for single-phase-to-ground fault	81
Table 15—Values for reactances depending on generation source	82
Table 16—Multiplying factors for Figure 11 and Figure 12 for the X/R ratios	82
Table 17—Multiplying factors to determine adjusted symmetrical current.....	84
Table 18—Adjusted fault currents for comparison with rated circuit breaker current	84
Table 19—Comparative circuit breaker selection values	84
Table 20—Subtransient reactances for use in fault current determination.....	85
Table 21—Comparison of calculated currents against circuit breaker ratings.....	87
Table 22—Approximate values of resistance	87
Table 23—Range and typical values of X/R ratios of system components at 60 Hz	87
Table 24—Equivalent system X/R ratios at 60 Hz at typical locations for quick approximation.....	88
Table 25— X/R multiplier based on transformer cooling class	88
Table 26—Application checklist.....	90
Table A.1—Calculated symmetrical current component.....	93

IEEE Application Guide for AC High-Voltage Circuit Breakers > 1000 Vac Rated on a Symmetrical Current Basis

1. Overview

1.1 Scope

This application guide applies to the ac indoor and outdoor high-voltage circuit breakers rated in accordance with the methods given in IEEE Std C37.04 and IEEE Std C37.04a, listed in IEEE Std C37.06™, and tested in accordance with IEEE Std C37.09 and IEEE Std C37.09a.¹ Circuit breakers rated and manufactured to meet other standards should be applied in accordance with application procedures adapted to their specific ratings or applications.

1.2 Purpose

The purpose of this document is to provide guidance for the application of high-voltage circuit breakers which are rated in accordance with IEEE Std C37.04 and IEEE Std C37.06 and which are tested in accordance with IEEE Std C37.09 and other related standards.

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.

ANSI C37.7, Interrupting rating factors for reclosing service for AC high-voltage circuit breakers rated on a total current basis.²

IEC 62271-100, High-voltage switchgear and controlgear—Part 100: High-voltage alternating-current circuit-breakers.³

¹Information on references can be found in [Clause 2](#).

²ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

IEEE Std 693™, IEEE Recommended Practices for Seismic Design of Substations.^{4,5}

IEEE Std C37.011™, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.012™, IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.015™, IEEE Application Guide for Shunt Reactor Switching.

IEEE Std C37.017™, IEEE Standard for Bushings for High-Voltage [over 1000 V (ac)] Circuit Breakers and Gas-Insulated Switchgear.

IEEE Std C37.04™, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

NOTE—At the time of publication, this standard was under revision.⁶

IEEE Std C37.06™, IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities for Voltages Above 1000 V.

IEEE Std C37.09™, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

NOTE—At the time of publication, this standard was under revision.

IEEE Std C37.20.2™, IEEE Standard for Metal-Clad Switchgear.

IEEE Std C37.24™, IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear.

IEEE Std C37.81™, IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies.

IEEE Std C37.100™, IEEE Standard Definitions for Power Switchgear.

IEEE Std C37.100.1™, IEEE Standard of Common Requirements for High Voltage Power Switchgear Rated Above 1000 V.

IEEE Std C57.106™, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

3. General service conditions

3.1 Usual service conditions

Service conditions for circuit breakers are defined in IEEE Std C37.04. These conditions specify limits in altitude and in ambient temperature and other environmental conditions.

⁴The IEEE standards or products referred to are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

⁵IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

⁶Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

3.1.1 Provision for system growth

Power system facilities are expanded or modified from time to time to serve larger loads. This usually results in higher values of short-circuit current and continuous current. Therefore, it is advisable to provide sufficient allowance for expected future increase in short-circuit current and continuous current.

3.1.2 System design

Methods of limiting the magnitude of short-circuit currents or reducing the probability of high-current faults by system design are outside the scope of this guide. Such methods should be considered where short-circuit currents approach the maximum capability of the circuit breakers. Many station design features may depend on available circuit breaker ratings. System design should take into account the necessity for circuit breaker inspection and maintenance.

3.2 Unusual service conditions

Some unusual service conditions are listed in 3.2.1 through 3.2.15. Special installation, operation, and maintenance provisions should be considered where these conditions are encountered. For further reference, IEEE Std C37.100.1 should be considered.

3.2.1 Special temperatures

Service conditions where the ambient temperature is lower than $-30\text{ }^{\circ}\text{C}$ or higher than $40\text{ }^{\circ}\text{C}$ should be considered as special.

Temperatures below $-30\text{ }^{\circ}\text{C}$ create a harsh environment for circuit breakers. Many users in colder climates routinely experience $-50\text{ }^{\circ}\text{C}$ temperatures. Subclause 2.2.3 of IEEE Std C37.100.1–2007 applies.

Temperatures above $40\text{ }^{\circ}\text{C}$ create a harsh environment for circuit breakers. Many users in warmer climates routinely experience temperatures above $40\text{ }^{\circ}\text{C}$ temperatures.

Temperatures lower than $-30\text{ }^{\circ}\text{C}$ or higher than $40\text{ }^{\circ}\text{C}$ may require special attention.

- Special elastomers for seals
- Special lubricants
- Cooling fans for mechanisms
- Heating
- Derating of nominal current-carrying capability

3.2.2 Applications at altitudes above 1000 m (3300 ft)

Derating the breaker's dielectric capabilities is not always necessary and usually not the most economical approach. The need for derating depends on whether arresters are used on both sides of the circuit breaker (line and load) and on their protective levels. If at least a 20% margin exists between the arrester protective level and the breaker basic lightning impulse insulation level (BIL), no derating should be necessary. If gas circuit breakers are present, and depending on the technology used for the density monitor, a readjustment may be required.

3.2.3 Exposure to excessive dust or abrasive, magnetic, or metallic dust

If a circuit breaker is used in special areas where it is exposed to excessive dust containing abrasive magnetic or metallic particles, then considerations should be taken into account as follows:

- a) Totally enclosed non-ventilated equipment or compartments may be necessary.
- b) Where current-carrying equipment designed for ventilated operation is enclosed in a non-ventilated compartment, derating may be necessary.
- c) Installation in a positive pressure room with appropriate filtration equipment may be necessary.

3.2.4 Exposure to explosive mixtures of dust or gases

Standard circuit breakers are not designed for use in explosive atmospheres. For this type of service, special consideration should be given in conjunction with requirements of applicable regulatory bodies so that acceptable equipment is selected.

3.2.5 Exposure to abnormal vibration, shock, or tilting

Standard circuit breakers are designed for mounting on substantially level structures free from excessive vibration, shock, or tilting. Where any of these abnormal conditions exists, recommendations for the particular circuit breaker's application should be obtained from the manufacturer.

Circuit breakers being applied in locations of known seismic activity should be specified with seismic withstand requirements as per IEEE Std 693 and IEEE Std C37.81–1989 as necessary for indoor drawout and outdoor circuit breakers. The user should specify the operational requirements—including whether functionality must be maintained—as follows:

- Before and after the seismic event or
- Before, during, and after the seismic event

3.2.6 Seasonal or infrequent use

Equipment stored or de-energized for long periods should be protected against accelerated deterioration. Before energizing for service, operating performance and insulation integrity should be checked.

3.2.7 Exposure to damaging fumes, vapor, steam, oil vapors, salt air, and hot and humid climate

To mitigate accelerated deterioration, the following precautions should be taken:

- a) Provisions may be necessary to avoid condensation on all electrical insulation and current-carrying parts.
- b) Bushings with extra creepage distance may be required.
- c) In cases where particular exposure represents a hazard to insulation integrity, special maintenance including insulator washing may be necessary.
- d) Materials resistant to fungus growth may be required.
- e) Installation in a positive pressure room system with appropriate filtration equipment may be required.
- f) Installation of heaters in mechanism cabinets and indoor switchgear may be required.

3.2.8 Exposure to excessive pollution

Creepage distance (see IEEE Std C37.100–1992) over external insulation is listed in IEEE Std C37.06. These minimum values are for the normal conditions (i.e., light pollution level) of atmospheric contamination and provide generally satisfactory service operation under these conditions.

For standardization, five levels of pollution are qualitatively defined—from very light pollution to very heavy pollution.

Table 1 gives for each level of pollution, an approximate description of some typical corresponding environments. Other extreme environmental conditions exist that merit further consideration (e.g., snow and ice in heavy pollution, heavy rain, and arid areas).

For each level of pollution described in **Table 1**, the corresponding minimum nominal specific creepage distance, in millimeters per kilovolt (inches per kilovolt) of the highest voltage (phase-to-ground) for an equipment is given in **Table 2**. The values in **Table 2** apply to glass and ceramic insulators. Values for other materials are under consideration.

Table 1—Environmental examples by pollution level

Pollution class	Typical environment
Very light	a) More than 50 km from any sea coast, desert, or open dry land. b) More than 10 km from industrial pollution sources or a major city. c) Distances may be shorter than above, but the following may be taken into consideration: — Prevailing wind is not directly from these pollution sources. — Regular monthly rain washing.
Light	a) Between 10 to 50 km from the sea, a desert, or open dry land. b) Between 5 to 10 km from industrial pollution sources or a major city. c) Distances may be shorter than above, but the following may be taken into consideration: — Prevailing wind is not directly from these pollution sources. — Regular monthly rain washing.
Medium	a) Between 3 to 10 km from the sea, a desert, or open dry land. b) Between 1 to 5 km from industrial pollution sources or a major city. c) Within a shorter distance than mentioned above, but the following may be taken into consideration: — Prevailing wind is not directly from these pollution sources. — Regular monthly rain washing. d) Further away from above pollution sources than mentioned, but the following may be taken into consideration: — Dense fog or drizzle often occurs after a long (several weeks or months) dry pollution accumulation season; — And/or heavy, high conductivity rain occurs; — And there is a high non soluble surface deposits (NSDD) level [between 5 and 10 times the equivalent salt deposit density (ESDD)].
Heavy	a) Within 3 km of the sea, a desert, or open dry land. b) Within 1 km of industrial pollution sources or a major city. c) With a greater distance from pollution sources than mentioned but the following may be taken into consideration: — Dense fog or drizzle often occurs after a long (several weeks or months) dry pollution accumulation season; — And/or there is a high NSDD level (between 5 and 10 times the ESDD).
Very heavy	Within the same distance of pollution sources as specified for “heavy” areas, and the following conditions: — Directly subjected to sea-spray or dense saline fog; — Or directly subjected to contaminants with high conductivity, or cement type dust with high density, and with frequent wetting by fog or drizzle. — Desert areas with fast accumulation of sand and salt, and regular condensation.

NOTE 1—The use of fertilizers by spraying or the burning of crop residues can lead to a higher pollution level due to dispersal by wind.

NOTE 2—Distances from seacoast depend on the topography of the coastal area and on the extreme wind conditions.

Table 2—Minimum nominal specific creepage distance by pollution level

Pollution class	Minimum nominal specific creepage distance	
	mm/kV of phase-to-phase voltage (in/kV phase-to-phase voltage)	mm/kV of phase-to-ground voltage (in/kV phase-to-ground voltage)
Very light	12.7 (0.5)	22.0 (0.87)
Light	16 (0.63)	27.8 (1.09)
Medium	20 (0.79)	34.7 (1.37)
Heavy	25 (1)	43.3 (1.70)
Very heavy	31 (1.22)	53.7 (2.11)
NOTE 1—In the case of exceptional pollution severity, a nominal specific creepage distance of 31 mm/kV may not be adequate. Depending on service experience and/or laboratory test results, a higher value of nominal specific creepage distance can be used, however in some instances the feasibility of washing or greasing may have to be considered. NOTE 2—The specific creepage distance values given in this table are for insulators between phase and ground, and are the same as those given in IEC 60815-2. The values are expressed both in terms of the rated maximum voltage (line-to-line), Column 2, and in terms of the equivalent voltage line-to-ground, Column 3. NOTE 3—The specific creepage distance values given in Table 2 apply to glass and ceramic insulators. Values for other materials are under consideration. IEC 60815-3 recommends that the creepage distance of polymeric insulators should be the same as that of the ceramic insulators.		

Experience has shown that the criterion of “minimum nominal specific creepage distance”, which implies linearity under pollution between withstand voltage and creepage distance, applies to most insulators used on existing systems.

Some insulators specially shaped for particular kinds of pollution may not satisfy these conditions even though they perform satisfactorily in service.

3.2.9 Exposure to unusual transportation or storage conditions

Exposure to unusual transportation or storage conditions should be considered special.

3.2.10 Unusual space limitations

Unusual space limitations should be considered special.

3.2.11 Normally open

Circuit breakers normally operated open but energized, may require surge protection against lightning and switching voltage transient surges. If the circuit breaker contains grading capacitors or cross gap arrestors, the manufacturer should be advised of the normal open-gap voltage stress. In such a case, either disconnector requirements or a higher dielectric rating may be specified.

Open tie circuit breakers used under out-of-phase voltage conditions may be stressed by voltage up to 2.0 per unit across the open contacts. Such applications should be reviewed with the manufacturer.

3.2.12 Short-circuit current with X/R greater than 17

Short-circuit current with X/R greater than 17 should be considered special and reviewed with the manufacturer.

3.2.13 Nonstandard reclosing (see IEEE Std C37.04)

Nonstandard reclosing should be considered special.

3.2.14 Wind load

For outdoor circuit breakers, wind loading conditions ≥ 40 m/s (144 km/h, 90 mi/h) is considered an unusual service condition (see IEEE Std C37.100.1 and IEEE Std C37.04). If the user's wind specification is ≥ 40 m/s then the mechanical loading for the circuit breaker and foundation should be analyzed and the circuit breaker manufacturer notified.

3.2.15 Ice load

Ice loading ≥ 20 mm (3/4 in) for outdoor circuit breakers is considered an unusual service condition (see IEEE Std C37.04). If the user's specification requires ≥ 20 mm (3/4 in) of ice, mechanical loading for the circuit breaker and foundation should be reviewed by the user, and the circuit breaker manufacturer should be notified for this application.

3.3 Mechanical considerations for outdoor circuit breakers

3.3.1 Foundation loading

The circuit breaker should be firmly attached to a suitable foundation that supports the dead weight and any applicable dynamic loads on the circuit breaker (e.g., wind loads, terminal connection loads, seismic loads, or ice loads).

3.3.2 Terminal connection loading (line pull)

Circuit breaker terminals are designed only to accept nominal mechanical loads as would be adequate to support relatively short leads. The required capabilities are listed in IEEE Std C37.017. Care must be taken not to exceed these loads under any expected environmental conditions. Exceeding the mechanical load on the terminals can result in leaks, circuit breaker malfunction, or mechanical failure of the terminal. Flexible cable connections to the terminals are often most appropriate. If rigid connections are used, care must be taken to prevent thermal expansion of the rigid connection from producing excessive stress on the terminal.

4. Application considerations

4.1 General

In the application of circuit breakers to electrical systems, careful attention must be given to many items of technical importance to help ensure that a misapplication does not occur. In the usual application, the principal function of the circuit breaker is to carry load current and interrupt short-circuit current. However, it may be used for frequent load, exciting current, or capacitive current switching. In some cases, switching requirements may be the determining factor in selection, rather than the requirements of short-circuit current interruption. Special attention must also be given to applications where frequent operations are expected.

When selecting a circuit breaker, consideration must be given to the future and present needs for interrupting capacity and for current-carrying capability. These considerations include possible connected circuit changes, such as the following:

- The addition of supplemental cooling means for transformers.
- The connection of multiple cable or overhead lines to the circuit breaker.
- Possible future transfer of the circuit breaker from its initial position to some other location.

Various types of indoor and outdoor circuit breakers are available for use, as classified by their interruption technologies. Some of these types include vacuum, oil, air magnetic, two-pressure air blast, and two-pressure and single-pressure SF₆. Each interruption technology has its own set of strengths and weaknesses and therefore, its own set of application considerations. The preferred ratings listed in IEEE Std C37.06 may not be available in all interruption technologies, so the required ratings will limit the user's choice of interruption technologies. The choice of interruption technology may be influenced by the following conditions:

- Switching frequency
- Special load switching (capacitor or reactor)
- Contaminated atmosphere
- Environmental considerations
- Maintenance
- Ease of handling the interrupting medium
- Monitoring capabilities
- Electrical life

4.2 Maximum voltage for application

The operating voltage should not exceed the rated maximum voltage of the circuit breaker. The rated maximum voltage is the voltage on which all the corresponding type tests have been based. The type tests values include some margins in order to accommodate aging as well as statistical behavior.

4.3 Voltage range factor

The voltage range factor K , defined in earlier standards, has been changed to 1.0 for future circuit breakers, which allows simplification of the rating structure and circuit breaker application by eliminating the voltage range factor completely. However, it is recognized that circuit breakers rated in accordance with older standards and having voltage range factor K differing from 1.0 are still available, and will be in service for many years. If there is a K factor, it should be noted on the circuit breaker nameplate. For circuit breakers that have a voltage range factor K differing from 1.0, the user should refer to IEEE Std C37.04–1979, IEEE Std C37.06–1987, IEEE Std C37.09–1979, and IEEE Std C37.010–1979 (or earlier editions of the same documents) for rating, application, and testing information.

4.4 Frequency

Rated power frequencies for circuit breakers are 50 Hz and 60 Hz. Calculations used in this guide are based on 60 Hz.

Interruption of all currents on systems operating at frequencies other than rated frequency may require modification of mechanisms to change the speed of opening or may require a change in interrupting ratings of the circuit breaker.

The manufacturer should be consulted for applications at frequencies differing from 50 Hz or 60 Hz.

4.5 Continuous current

Circuit breakers are designed for normal application where the sustained load current does not exceed the rated continuous current, where the altitude above sea level is 1000 m (3300 ft) or less, and where the ambient temperature does not exceed 40 °C. Rated continuous current of a circuit breaker should not be exceeded un-

der normal operation except for short periods; examples of short periods include starting motors or synchronous condensers, energizing cold loads, or under conditions outlined in 4.5.3.

4.5.1 Normal operation

The criteria to be followed when selecting a circuit breaker are as follows:

- a) Circuit breakers designed for installation in an enclosure may be applied without derating if the enclosure volume and ventilation area is equal to or greater than the volume and ventilation area of the enclosure used in the design (type) tests performed according to IEEE Std C37.09.
- b) Circuit breakers designed for use in open rooms and outdoors cannot be used in enclosures without derating or retesting to ensure that none of their temperature limits are exceeded.
- c) As far as temperature limits are concerned, any non-enclosed high-voltage circuit breaker may be used with cables having an 85 °C (185 °F) or lower temperature limit, provided that the temperature limit of the cable insulation is not exceeded. Indoor drawout circuit breakers are applied in accordance with IEEE Std C37.20.2, and a 90 °C (194 °F) cable limit is recognized. The methods of reducing temperature at cable connections are as follows:
 - 1) Operating the circuit breaker at a continuous current sufficiently below its rating.
 - 2) Using a section of oversized conductor or a special terminal connector ahead of the cable to reduce the temperature at the cable terminal.
- d) The possible adverse effect on, or by closely associated equipment operating at a higher or a lower temperature than the circuit breaker should be examined.
- e) When a circuit breaker is properly selected for continuous current operation, it may also be used for starting such equipment as motors, synchronous condensers, and cold loads. Under this condition, the continuous current rating may be momentarily exceeded without causing damage to the circuit breaker.
- f) Special attention is needed when circuit breakers are used in a location near or above another heat generating source (i.e., current-carrying component). It may be necessary to choose a circuit breaker with higher nominal current-carrying capability.

4.5.2 Rated continuous current for capacitor banks

When a high-voltage circuit breaker is used in a circuit supplying capacitors, the continuous current rating should be selected to include the effects of the following:

- Operation at voltages below and up to 10% above the capacitor rated voltage.
- The positive tolerance in capacitance of static capacitors (0% + 10%).
- The additional heating caused by harmonic currents.
- The effect of grounded or ungrounded neutral connection of the capacitor bank.

In the absence of specific information, it will usually be conservative to use 1.25 times the nominal capacitor current at rated capacitor voltage for ungrounded neutral operation, or 1.35 times the nominal current for grounded neutral operation.

NOTE—The National Electrical Code® (NEC®), NFPA 70, article 460.24 (A)(1) requires that disconnects be sized based on 135% of the rated current of the capacitor installation.

4.5.3 Load current-carrying capability under various conditions of ambient temperature and load

4.5.3.1 General

Circuit breakers are designed for normal application in accordance with IEEE Std C37.04, where the sustained load current does not exceed the rated continuous current and the ambient temperature does not exceed 40 °C (104 °F). The rated continuous current is based on the maximum permissible total temperature limitations of the various parts of the circuit breaker when it is carrying rated current at an ambient temperature of 40 °C. The total temperature of these parts under service conditions depends both on the actual load current and the actual ambient temperature. It is, therefore, possible to operate at a current higher than rated continuous current when the ambient temperature is less than 40 °C, provided that the allowable total temperature limit is not exceeded for the circuit breaker or its various parts. Similarly, when the ambient temperature is greater than 40 °C, the current must be reduced to less than rated continuous current to keep total temperatures within allowable limits.

Operation at a current higher than rated continuous current will usually cause the allowable temperature limitations to be exceeded and should be avoided except in the following instances:

- For short periods (e.g., the starting of motors or synchronous condensers, or when energizing cold loads). Generally, the time duration of this type of current increase is short enough and does not raise temperatures significantly.
- When operating at an ambient temperature below 40 °C, as covered in 4.5.3.2.
- For short periods following operation at a current less than that permitted by the existing ambient temperature, as covered in 4.5.3.3.

The method of calculating the allowable current at an ambient temperature other than 40 °C is given in 4.5.3.2. For some high ambient temperature conditions, it may not be practical to reduce current sufficiently to keep the total temperatures within their allowable limits. Forced air cooling of metal-enclosed switchgear is covered in IEEE Std C37.20.2™, and will help in many cases. Temperature limits of associated equipment such as cables and current transformers must be considered. Effect of solar radiation must also be considered (see IEEE Std C37.24–1986). Where ambient temperature is below the minimum limit of –30 °C, special lubricants may be required, and additional heater capacity beyond that which is normally used should be provided in mechanism enclosures. Whenever freezing temperatures occur, precautions may be necessary to dry the air in pneumatic systems to avoid condensation and freezing.

4.5.3.2 Continuous load current capability based on actual ambient temperature

Enclosed circuit breakers are covered by IEEE Std C37.20.2 for ambient compensation and overload conditions. Emergency load current capability is not available. The continuous current that a non-enclosed circuit breaker can carry at a given ambient temperature without exceeding its total temperature limitations is given by Equation 1:

$$I_a = I_r \left[\frac{\theta_{\max} - \theta_a}{\Delta\theta_r} \right]^{1.8} \quad (1)$$

where

I_a is allowable continuous load current at the actual ambient temperature θ_a (I_a is not to exceed two times I_r) (A),

I_r is rated continuous current (A),

$\theta_{\max}$ is allowable hot-spot total temperature ($\theta_{\max} = \Delta\theta_r + 40^\circ\text{C}$),

θ_a is actual ambient temperature expected (between $-30\text{ }^{\circ}\text{C}$ and $60\text{ }^{\circ}\text{C}$),
 $\Delta\theta_r$ is allowable hot-spot temperature rise at rated current ($^{\circ}\text{C}$)

NOTE—The temperature rise of a current-carrying part is proportional to an exponential value of the current flowing through it. Experience has shown that although the exponent may have different values, depending on circuit breaker design and components within a circuit breaker, it is generally in the range of 1.6 to 2.0. The exponent value of 1.8 represents a compromise that is suitable for this application guide.

The constructional features of a circuit breaker dictate the appropriate values of $\theta_{\max}$ and $\Delta\theta_r$ to be used in the calculation. The major components of a circuit breaker have several different temperature limitations that are specified in IEEE Std C37.04 for circuit breakers, and IEEE Std C57.13 for instrument transformers.

To help ensure that none of these limitations are exceeded when the load current is adjusted to the value permitted by the actual ambient temperature, the values for $\theta_{\max}$ and $\Delta\theta_r$ should be determined as follows:

- a) If the actual ambient is less than $40\text{ }^{\circ}\text{C}$, the component with the highest specified values of allowable temperature limitations should be used for $\theta_{\max}$ and $\Delta\theta_r$.
- b) If the actual ambient is greater than $40\text{ }^{\circ}\text{C}$, the component with the lowest specified values of allowable temperature limitations should be used for $\theta_{\max}$ and $\Delta\theta_r$.

The use of these values in the calculation will result in an allowable continuous current that will not cause the temperature of any part of the circuit breaker to exceed the permissible limits.

NOTE—Although circuit breakers are designed to carry rated current continuously while exposed to an ambient temperature of $40\text{ }^{\circ}\text{C}$, most circuit breakers in service are subjected to a much less severe ambient temperature condition that varies with time of day and season of year. The average outdoor air temperature during any 24 h period is usually $5\text{ }^{\circ}\text{C}$ to $10\text{ }^{\circ}\text{C}$ lower than the maximum, and the maximum is usually less than $40\text{ }^{\circ}\text{C}$. This fact is one important reason for the long life that circuit breakers historically have demonstrated. Continuous operation at rated current and at an ambient temperature of $40\text{ }^{\circ}\text{C}$ would likely result in a life somewhat shorter than usually experienced.

Modern composite material should not be sensitive to such a temperature increase. However, if doubt exists then the manufacturer should be consulted.

It may not be necessary to include the extreme values of highest and lowest allowable temperature limitation. Refer to IEEE Std C37.04 for summary of temperature limitation for circuit breaker components. The lowest value is for circuit breaker parts handled by the operator in the normal course of duty. The highest value generally is for external surfaces of a circuit breaker not accessible to an operator in the normal course of duty (see IEEE Std C37.04). In many cases, overheating of these external parts beyond the specified allowable limitations will not impair circuit breaker performance or expected life. If these parts are neglected, a higher value of permissible continuous load current can be obtained from the calculation. In most cases, this higher value of current may safely be used. However, in some circuit breaker designs, gaskets or other components may be located near such inaccessible external surfaces and would be damaged if overheated. The use of dry-type current transformers with a maximum temperature of $80\text{ }^{\circ}\text{C}$ would place a further limit on the allowable current for operation at an ambient of less than $40\text{ }^{\circ}\text{C}$. Evaluation of the circuit breaker design should be made to determine whether these extreme values of temperature limitation are acceptable, and the manufacturer should be consulted.

Table 3 lists the calculated values of I_d/I_r for each specified temperature limit for the various component parts of the circuit breaker over a range of typical ambient temperatures. The allowable current in any given situation can be estimated from Table 3 or may be calculated directly from the equation given at the beginning of this subclause.

Table 3—Ratios of (I_a/I_r) for various ambient temperatures

Maximum ambient temperature (°C)		Limiting temperature of different circuit breaker components								
	θ_{max} 50	70	80	85	90	105	110	115	150	
	θ_r 10	30	40	45	50	65	70	75	110	
60	—	0.54	0.68	0.72	0.75	0.81	0.82	0.842	0.89	a
50	—	0.79	0.85	0.87	0.88	0.91	0.91	0.924	0.95	a
40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
30	1.46	1.17	1.13	1.11	1.10	1.08	1.07	1.072	1.05	b
25	1.66	1.25	1.19	1.17	1.15	1.12	1.11	1.107	1.08	b
20	1.84	1.32	1.25	1.22	1.20	1.16	1.15	1.14	1.10	b
10	2.00	1.47	1.36	1.32	1.29	1.23	1.22	1.206	1.14	b
0	2.00	1.60	1.46	1.42	1.38	1.30	1.29	1.268	1.19	b
−10	2.00	1.72	1.56	1.51	1.46	1.37	1.34	1.328	1.23	b
−20	2.00	1.84	1.66	1.60	1.54	1.43	1.41	1.386	1.28	b
−30	2.00	1.95	1.75	1.68	1.61	1.50	1.46	1.442	1.32	b

^aFor limiting current use lowest θ_r and θ_{max} .

^bFor limiting current, use highest θ_r and θ_{max} .

Example 1: Consider an SF₆ circuit breaker with silver-coated contacts and 65 °C rise current transformers. When operating at an ambient temperature of 25 °C, the current could be increased by a factor corresponding to the component with the highest temperature rise. In this case, these components are the silver-coated contacts with a maximum temperature limit of 105 °C (refer to IEEE Std C37.04 Table 1); and according to Table 3, the factor of increase is 1.12 times the rated current.

When operating at an ambient temperature of 50 °C, the current must be reduced by a factor that corresponds to the component with the lowest temperature limit. In this case, the components are the bushings and the current transformers, with a temperature rise limit of 65 °C; and according to Table 3, the reduction factor is 0.91.

Example 2: Consider an oil circuit breaker with silver-to-silver contacts and with 55 °C rise current transformers. When the ambient temperature is 25 °C, the continuous current can be increased by a factor of 1.12. This factor of increase corresponds to the component with the highest temperature limit, which in this case are the bushings and the current transformers. If the ambient temperature was 50 °C, the reduction should be included. In case of doubt, the factor would be 0.85, corresponding to the component with the lowest temperature limit, which in this case is the top oil.

Example 3: Consider an oil-less circuit breaker with silver-to-silver contacts in air, with 55 °C rise current transformers, and with terminals connected to 85 °C insulated cable. When the ambient temperature is 25 °C, the current can be increased by a factor of 1.12, corresponding to the temperature rise limitations of 65 °C of the silver-to-silver contacts and the current transformers.

If the ambient temperature was 50 °C, the reduction factor would be 0.87 corresponding to the temperature rise limitation of 45 °C of the connected cable.

Current transformers that form part of a circuit breaker assembly or that are normally considered a part of the circuit breaker installation will usually have heating characteristics similar to those of the circuit breaker. The continuous current permitted by the equation will not cause overheating of a current transformer connected to a ratio tap corresponding to rated current of the circuit breaker. However, if a lower ratio tap is used, the expected secondary current must be evaluated in terms of the continuous thermal-rating factor of the current transformer. The effect of the secondary current on apparatus connected to the current transformer terminals should also be considered.

4.5.3.3 Short-time load current capability

When a circuit breaker has been operating at a current level below its allowable continuous load current I_a , it is possible to increase the load current for a short time to a value greater than the allowable current without exceeding the permissible temperature limitations. The length of time that the short-time load current I_s can be carried depends on the following factors:

- The magnitude of the short time load current I_s to be carried.
- The magnitude of initial current I_i carried prior to application of I_s .
- The thermal-time characteristics of the circuit breaker.

The time duration of the short-time current may be calculated directly or may be obtained as described by [Figure 1](#). The time duration of the current I_s determined in one of these ways will not cause the total temperature limits of the circuit breaker to be exceeded, provided the following requirements are fulfilled:

- The circuit breaker—particularly the main contacts—have been well maintained and are in essentially new condition.
- The value used for the current I_i is the maximum current carried by the circuit breaker during the 4 h period immediately preceding the application of current I_s .
- At the end of the time period, the current I_s is reduced to a value that is no greater than the current I_a .
- The value of current I_s is limited to a maximum value of two times rated continuous current I_r .

NOTE—If $\theta_s < \theta_{\max}$ the loading is an acceptable steady state. In other words, the allowable time is indefinite. This should be checked before trying to use [Figure 1](#) or directly calculating the allowable duration of I_s .

4.5.3.3.1 Determination of allowable time for I_s , by using [Figure 1](#)

One method for determining the allowable duration of current I_s is shown in [Figure 1](#). The values of time obtained from the figure are given in “time constant units.” The actual time is determined by multiplying the time constant units by the proper thermal time constant listed in [Table 4](#). The time constants given below are those of the contacts, which normally determine the limits. However, in special cases other time constants or material properties (e.g., insulation material) may be the limiting factor.

Table 4—Typical thermal time constants

Circuit breaker category	Typical time constant τ (h)
Circuit breakers in metal clad switchgear	0.5
Circuit breaker in gas insulated switchgear (GIS)	0.5
Circuit breakers not in metal-enclosed switchgear and not GIS	0.5

Example: A 1200 A oil circuit breaker with silver-to-silver contacts and American National Standard (ANSI) bushings is operating at 1000 A ($I_i = 1000$ A). It is desired to increase the current to 1600 A ($I_s = 1600$ A) for a short time. The maximum ambient temperature expected is 25 °C. For how long can the circuit breaker carry this current?

The allowable continuous current is determined according to [Equation \(1\)](#). Since the ambient is less than 40 °C, the highest temperature rise limitation of 65 °C is used, the temperature rise limit of the bushing. From

Table 3, the ratio of 1.12 is determined for the ambient temperature of 25 °C. Therefore, $I_a = 1.12 \times 1200 = 1344 \text{ A}$.

The ratio (I_i/I_s) is $(1000/1600) = 0.625$. The corresponding value t_i from **Figure 1** is 0.58 time constant units. The ratio (I_a/I_s) is $(1344/1600) = 0.84$. The corresponding value t_a from **Figure 1** is 1.31 time constant units. The period of time for which the excess current can be carried $t_a - t_i = 1.31 - 0.58 = 0.73$ time constant units. The actual time is obtained by multiplying this value by the thermal time constant of 0.5 h taken from **Table 4** $(0.73 \times 0.5\text{h}) = 0.365\text{h}$ or about 22 min. After this time, the current must be reduced to 1344 A or lower in order to prevent overheating of the bushings.

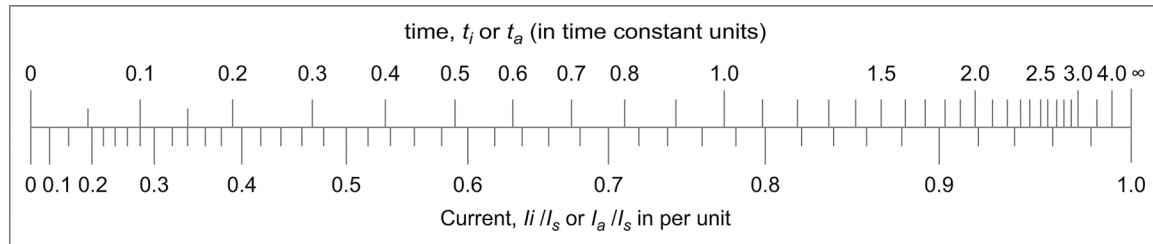


Figure 1—Current-time relationship to determine short-time load-current capability of high-voltage circuit breakers

The required initial data is as follows:

- Initial steady state current I_i
- Allowable continuous load current based on actual ambient temperature [from **Equation (1)**] I_a
- Desired short-time load current I_s
- Total temperature and temperature rise limits of circuit breaker and its components

The calculation procedure is as follows:

- a) Determine I_i / I_s per unit initial current
- b) From chart determine corresponding time t_i
- c) Determine I_a / I_s per unit allowable continuous current
- d) From chart determine corresponding time allowable t_a
- e) Calculate $t_a - t_i =$ time (in time constant units) that the circuit breaker can carry, starting from initial continuous current of I_i with ambient temperature and permitting continuous operation at I_a

NOTE—This procedure and the design of this chart are based on the following assumptions:

- At constant current, the temperature approaches its steady state value at an exponential rate. During any time interval equal to the thermal time constant of the circuit breaker, the temperature rise will be equal to 63.2% of the remaining increment of possible increase existing at the start of the period. This is represented by the “time” scale at the top of the chart.

- The temperature of a circuit breaker part increases as the 1.8 power of the current increase. This is represented by the current scale at the bottom of the chart. Here, the current in per unit value is plotted to a scale representing the temperature produced by that current.

4.5.3.3.2 Determination of allowable time for I_s by direct calculation

Equation (2) and Equation (3) are used to calculate the time duration t , for a short-time load current I_s as follows:

$$t_s = \tau \left[-\ln \left\{ 1 - \frac{\theta_{\max} - Y - \theta_a}{Y \left((I_s / I_r)^{1.8} - 1 \right)} \right\} \right] \quad (2)$$

$$Y = (\theta_{\max} - 40^\circ\text{C}) (I_i / I_r)^{1.8} \quad (3)$$

where

- $\theta_{\max}$ is allowable hottest-spot total temperature from IEEE Std C37.04 ($^\circ\text{C}$),
- θ_a is actual ambient expected (between -30°C and 60°C),
- I_i is initial current carried prior to application of I_s (A) (the maximum current carried by the circuit breaker during the 4 h period immediately preceding the application of current I_s),
- I_s is short-time load current (A),
- I_r is rated continuous current (A),
- $\mathbf{A}$ is thermal time constant of the circuit breaker from Table 5 (h),
- t_s is permissible time for carrying current I_s at ambient θ_a after initial current I_i (in same units as T)

NOTE—These equations are derived in the following manner:

Let

θ_s is the total temperature that would be reached if current I_s were applied continuously at ambient θ_a ($^\circ\text{C}$)

θ_i is the total temperature due to continuous current I_i at ambient θ_a ($^\circ\text{C}$)

θ_t is the total temperature at some time t after current is raised from I_i to I_s ($^\circ\text{C}$)

Then

$$\theta_t = (\theta_s - \theta_i) (1 - e^{-t/\tau}) + \theta_i \quad (4)$$

Let $\theta_t = \theta_{\max}$; solve for t .

Then

$$t_s = -\tau \ln \left[1 - \frac{\theta_{\max} - \theta_i}{\theta_s - \theta_i} \right] \quad (5)$$

where

$$\theta_i = (\theta_{\max} - 40^\circ\text{C}) (I_i / I_r)^{1.8} + \theta_a \quad (6)$$

and

$$\theta_s = (\theta_{\max} - 40^\circ\text{C}) (I_s / I_r)^{1.8} + \theta_a \quad (7)$$

For the special case where the initial current is 0, the equations in this form are useful. By substitution and further manipulation, the equations given above in terms of Y are obtained; these equations are convenient to use in the more typical case where the initial current is not 0.

4.5.4 Emergency load current-carrying capability

During emergency periods, operation may be required at higher load currents than permitted by the ambient compensation procedure outlined in 4.5.3. Under these conditions, all the general considerations for ambient compensation are applicable to emergency loading with additional considerations and limitations as outlined in this subclause.

The limits of total temperature for the circuit breaker will be exceeded under the specified emergency load currents, and these higher temperatures may cause a reduction in the operating life of the circuit breaker. Inspection and maintenance of the circuit breaker are required following each emergency cycle as outlined in 4.5.4.5.

4.5.4.1 Conditions for emergency load current-carrying capability

- a) Emergency load current carrying-capability factors can only be applied to circuit breakers not in metal-enclosed switchgear and not in GIS, as listed in IEEE Std C37.06. These factors can be applied to circuit breakers used in gas-insulated substations until specific standards for that equipment are issued. Circuit breakers used in metal-clad switchgear are thought to be coordinated with overall application limitations of the total switchgear. Load current-carrying capability under various conditions of ambient temperature for these circuit breakers is covered in IEEE Std C37.20.2.
- b) Prior to the application of the emergency load, the circuit breaker current-carrying circuit (including external connections) are well maintained and should be essentially in new condition.
- c) Following the emergency period, the load current is limited to 95% of I_a (the rated continuous current as modified by ambient compensation according to 4.5.3) for a minimum of 2 h.
- d) During and following an emergency cycle, and prior to maintenance, the circuit breaker is capable of one interruption at its rated short-circuit current.
- e) Circuit breakers operated at temperatures that exceed their limits of total temperature may experience a reduction in operating life. Mandatory inspection and maintenance procedures are required following this duty in accordance with 4.5.4.5, and as recommended by the manufacturer.

NOTE—The thermal capability of associated equipment such as cables, reactors, line traps, disconnecting switches, and current transformers, also should be suitable for emergency loading. These pieces of equipment may limit the emergency rating to less than that calculated for the circuit breaker.

4.5.4.2 Emergency load current-carrying capability factors for 4 h and 8 h

Emergency load current-carrying capability factors with ambient temperature at 40 °C are listed in [Table 5](#) for each limiting temperature of various circuit breaker components.

The factors have been selected to allow operation at 15 °C above the limits of total temperature for an emergency period of 4 h, or 10 °C above for an emergency period of 8 h. The factors are expressed as the ratio of emergency load current I_e allowed at an ambient temperature of 40 °C to the rated continuous currents I_r , and can be applied with the following restrictions:

- a) The circuit breaker component with the highest values of limiting temperatures, θ_{max} and θ_r , will be used to select the proper emergency load current-carrying capability factor from Table 5.

NOTE—Circuit breakers with contacts and conducting joints in other than oil or air may be operated at higher temperatures than listed in Table 1 of IEEE Std C37.04 if it can be shown that accelerated deterioration will not occur. Unless otherwise specified by the manufacturer, contacts and conducting joints in other than oil or air are assumed to have the temperature limitations of silver, silver alloy, or equivalent materials in air (65 °C hot-spot temperature rise, 105 °C hot-spot total temperature).

- b) The 4 h factor can be used for a cycle of operation consisting of separate periods of no longer than 4 h each, with not more than four such occurrences before maintenance.
- c) The 8 h factor can be used for a cycle of operation consisting of separate periods of no longer than 8 h each, with not more than two such occurrences before maintenance.
- d) Each cycle of operation is separate, and no time-current integration is permissible to increase the number of periods within a given cycle. However, any combination of separate 4 h and 8 h emergency periods may be used. However, when they total 16 h, the circuit breaker should preferably be inspected and maintained according to 4.5.4.5 before being subjected to additional emergency cycles.

Table 5—Emergency load current-carrying capability factors (I_e/I_r) based on an ambient temperature of 40 °C

Emergency period	Limiting temperature (°C) of different circuit breaker components								
	θ_{max}	70	80	85	90	105	110	115	150
	θ_r	30	40	45	50	65	70	75	110
4 h		1.25	1.19	1.17	1.15	1.12	1.11	1.107	1.08
8 h		1.17	1.13	1.11	1.10	1.08	1.07	1.074	1.05

4.5.4.3 Emergency operation at an ambient temperature other than 40 °C

When a circuit breaker is operating at an ambient temperature other than 40 °C, the emergency load current-carrying capability I_{ea} can be calculated by the following equation:

$$I_{ea} = I_r \left[\left(\frac{I_a}{I_r} \right)^{1.8} + \left(\frac{I_e}{I_r} \right)^{1.8} - 1 \right]^{\frac{1}{1.8}} \quad (8)$$

where

- I_{ea} is emergency load current at actual ambient temperature (A),
- I_r is rated continuous current (A),
- I_e is emergency load current at 40 °C ambient temperature (A),
- I_a / I_r is ambient compensation factor from Table 3 or calculated according to 4.4.3.2,
- I_e / I_r is emergency load current-carrying capability factor from Table 5

The ratio of (I_{ea} / I_r) should not exceed the value of 2.0. Calculated values of the ratio (I_{ea} / I_r) over a range of typical ambient temperatures are shown in Table 6 for a 4 h emergency period and in Table 7 for an 8 h emergency period. If the calculation does not provide the emergency current desired, then a circuit breaker with the next higher continuous current rating should be selected.

Table 6—Emergency load current-carrying capability factor (I_{ea}/I_r) for various ambient temperatures for 4 h emergency period

Maximum ambient temperature (°C)	Limiting temperature (°C) of different circuit breaker components								
	θ_{max}	70	80	85	90	105	110	115	150
	θ_r	30	40	45	50	65	70	75	110
60	0.90	0.92	0.93	0.93	0.95	0.95	0.967	0.98	
50	1.08	1.06	1.06	1.04	1.04	1.03	1.065	1.03	
40	1.25	1.19	1.17	1.15	1.12	1.11	1.107	1.08	
30	1.40	1.30	1.27	1.24	1.19	1.17	1.154	1.13	
25	1.47	1.36	1.32	1.29	1.23	1.21	1.184	1.16	
20	1.53	1.41	1.37	1.33	1.27	1.25	1.238	1.17	
10	1.66	1.51	1.46	1.41	1.33	1.31	1.265	1.21	
0	1.78	1.61	1.55	1.50	1.40	1.38	1.316	1.26	
−10	1.89	1.70	1.64	1.57	1.47	1.43	1.366	1.30	
−20	2.00	1.79	1.72	1.65	1.52	1.50	1.414	1.35	
−30	2.00	1.88	1.80	1.72	1.59	1.54	1.460	1.38	
NOTE 1—For limiting current, where the factor is 1.0 or greater, use highest θ_r and θ_{max} .									
NOTE 2—For limiting current, where the factor is less than 1.0, use lowest θ_r and θ_{max} .									

Table 7—Emergency load current-carrying capability factor (I_{ea}/I_r) for various ambient temperatures for 8 h emergency period

Maximum ambient temperature (°C)	Limiting temperature (°C) of different circuit breaker components								
	θ_{max}	70	80	85	90	105	110	115	150
	θ_r	30	40	45	50	65	70	75	110
60	0.79	0.85	0.86	0.87	0.90	0.90	0.931	0.94	
50	0.99	1.00	0.99	0.99	1.00	0.99	1.000	1.00	
40	1.17	1.13	1.11	1.10	1.08	1.07	1.065	1.05	
30	1.32	1.25	1.21	1.19	1.16	1.14	1.126	1.10	
25	1.40	1.30	1.27	1.24	1.19	1.17	1.154	1.13	
20	1.46	1.36	1.31	1.29	1.23	1.21	1.183	1.15	
10	1.60	1.46	1.41	1.37	1.30	1.28	1.240	1.19	
0	1.72	1.56	1.50	1.46	1.37	1.35	1.291	1.23	
−10	1.81	1.66	1.60	1.54	1.43	1.41	1.341	1.28	
−20	1.95	1.75	1.68	1.61	1.51	1.46	1.390	1.32	
−30	2.00	1.84	1.75	1.68	1.56	1.51	1.437	1.36	
NOTE 1—For limiting current, where the factor is 1.0 or greater, use highest θ_r and θ_{max} .									
NOTE 2—For limiting current, where the factor is less than 1.0, use lowest θ_r and θ_{max} .									

4.5.4.4 Short-time emergency load currents

A circuit breaker can be subjected to currents higher than the 4 h emergency load current I_{ea} if all the following conditions are satisfied:

- Prior to the application of a short-time emergency load current, the circuit breaker is assumed to carry a current not greater than I_a —the allowable continuous load current at actual ambient temperature.

- b) The duration of the short-time emergency load current should be limited to a time that will not result in any circuit breaker component exceeding by more than 15 °C the limits of total temperature specified in IEEE Std C37.04. The allowable time can be determined by the method outlined in [Figure 1](#).

NOTE—When making this calculation, the 4 h emergency rating should be substituted for I_a . Under no condition should the time exceed 4 h.

4.5.4.4.1 Emergency overload less than 4 h

For emergency overload less than 4 h, the allowable short time can also be computed using [Equation \(2\)](#).

By substituting θ_{max} (maximum allowable short-time emergency total temperature) for θ_{max} in the following:

$$t_s = -\tau \ln \left[1 - \frac{\theta_{max} - \theta_i}{\theta_s - \theta_i} \right] \quad (9)$$

The θ_{max} in the following two equations should be the rated maximum allowable total temperatures.

$$\theta_i = (\theta_{max_i} - 40^\circ\text{C}) (I_i / I_r)^{1.8} + \theta_a \quad (10)$$

$$\theta_s = (\theta_{max_s} - 40^\circ\text{C}) (I_s / I_r)^{1.8} + \theta_a \quad (11)$$

4.5.4.4.2 Computing allowable time of emergency overload less than 4 h

Given I_s , compute θ_s and t_s from the following two equations:

Given t_s , compute θ_s from the following equation:

$$\theta_s = \left(\frac{\theta_{max_s} - \theta_i}{1 - e^{t_s/\tau}} \right) + \theta_i \quad (12)$$

and compute I_s from the following equation:

$$I_s = I_r \left[\frac{\theta_s - \theta_a}{\theta_{max_s} - 40^\circ\text{C}} \right]^{\frac{1}{1.8}} \quad (13)$$

Examples: For circuit breakers, observe the following:

$$\begin{aligned}
 \tau &= 0.5 \\
 \theta_r &= 105\text{ }^{\circ}\text{C} \\
 \theta_{\max_s} &= 120\text{ }^{\circ}\text{C} \\
 t_s &= -0.5 \ln \left(1 - \frac{120 - \theta_i}{\theta_s - \theta_i} \right) \\
 \theta_s &= \left(\frac{120 - \theta_i}{1 - \frac{1}{e^{t_s/\tau}}} \right) + \theta_i \\
 \theta_i &= (65) (I_i / I_r)^{1.8} + \theta_a \\
 \theta_s &= (65) (I_s / I_r)^{1.8} + \theta_a \\
 \frac{I_s}{I_r} &= \left[\frac{\theta_s - \theta_a}{65} \right]^{\frac{1}{1.8}}
 \end{aligned} \tag{14}$$

For short-time overloads at rated temperature and current, observe the following (see Table 8):

$$\begin{aligned}
 I_i &= I_r \\
 \theta_i &= \theta_r \\
 \theta_a &= 40\text{ }^{\circ}\text{C} \\
 \theta_s &= \left(\frac{120 - 105}{1 - \frac{1}{e^{t_s/\tau}}} \right) + 105 \\
 \text{and} \\
 \frac{I_s}{I_r} &= \left[\frac{\theta_s - 40}{65} \right]^{\frac{1}{1.8}}
 \end{aligned} \tag{15}$$

Table 8—Example of allowable overload current with rated initial current

t_s (h)	θ_s (°C)	I_s/I_r
3	120.04	1.122
2	121.28	1.124
1	122.34	1.140
0.5	128.73	1.189
0.25	143.12	1.292

For short-time overloads at rated temperature initial current 50% rated, observe the following (see Table 9):

$$\begin{aligned}
 \theta_a &= 40\text{ }^{\circ}\text{C} \\
 \frac{I_i}{I_r} &= 0.5 \\
 \theta_i &= 65 \times (0.5)^{1.8} + 40 = 58.62
 \end{aligned} \tag{16}$$

Table 9—Example of allowable overload current with 50% initial rated current

t_s (h)	θ_s (°C)	I_s/I_r
3	120.15	1.123
2	121.14	1.131

Table continues



Documents
Document Sharing Hub

Table 9—Example of allowable overload current with 50% initial rated current (*continued*)

t_s (h)	θ_s (°C)	I_s/I_r
1	129.60	1.190
0.5	155.60	1.370
0.25	214.54	1.730

- Each isolated application of short-time emergency load current is considered equal to one 4 h emergency period. However, a short-time emergency rating can be used in conjunction with a 4 h rating if the total time does not exceed 4 h.
- Following the application of a short-time emergency load current, the current needs to be reduced to a level not exceeding the 4 h emergency load current I_{ea} for the remainder of the 4 h period, or if an isolated application, to no more than 95% of I_a for a minimum of 2 h.

NOTE—The thermal time constants may differ from circuit breaker type as well as from size of the circuit breaker. The given time constants of 4 h and 8 h are based on experience from oil circuit breakers and may be different for other types of circuit breakers.

4.5.4.5 Inspection and maintenance after an emergency cycle of operation

After each cycle of operation in which any combination of short-time 4 h and 8 h emergency periods is equivalent to 16 h, the circuit breaker should be inspected. All required maintenance should be accomplished in accordance with the manufacturer's recommendations before the circuit breaker is subjected to additional emergency cycles. The more important items to be checked are as follows:

- Primary current path resistance, which is not allowed to exceed the manufacturer's service limits.
- Insulation power factor; a test on the circuit breaker insulation system should show no significant increase over the pre-emergency load value.
- Gaskets, O-rings, and similar components used to seal various parts; these components should show no deterioration.

NOTE—If, during the inspection and maintenance changes are noticed in any of the three areas, the manufacturer should be consulted before returning the circuit breaker to operation. If no differences are found, the emergency cycle can be repeated.

4.6 Rated dielectric withstand

4.6.1 Power frequency withstand voltage

The power frequency withstand voltage is specified in rating tables in IEEE Std C37.06 for various circuit breakers ratings. This test provides a margin for normal deterioration, for minor contamination, and for normal voltage surges encountered in service. These apply to new circuit breakers tested at the factory. Tests after delivery on free-standing circuit breakers are normally limited to 75% of factory values and tests on circuit breakers used in gas insulated substations are normally limited to 80% of factory values.

In some types of circuit breakers, dielectric withstand voltage may be reduced below a safe value by loss of vacuum, air, or gas pressure caused by a stuck valve or other malfunctioning device. Automatic isolation of the circuit breaker should be considered in such cases. Where possible, the automatic isolation must be completed before the dielectric withstand of the circuit breaker is reduced so far that dielectric failure may occur from the transient overvoltage produced by the isolating device. When slow operating disconnect switches (either air

switches or GIS switches) are used, restrikes are almost certain, and switching overvoltages in the 2.5-per-unit range are possible.

4.6.2 Lightning impulse withstand voltage

The rated lightning impulse withstand voltage of circuit breakers are specified in rating tables in IEEE Std C37.06 for various circuit breaker ratings. When applying to circuit breakers, it is necessary to make certain that the insulation levels of all facilities at a terminal are properly coordinated. The application of gapped silicon carbide and metal oxide surge arresters is covered in IEEE Std C62.2™ and IEEE Std C62.22™, respectively. Since this is a matter of system insulation coordination, it is outside the scope of an application guide for circuit breakers.

When surge arresters are installed on the bus or on transformers and not on each circuit breaker, the surge voltage at the circuit breaker can exceed that at the arresters. The amount by which it is exceeded depends upon the steepness of the wave front and the distance from the circuit breaker to the surge arresters. When the circuit breaker is in open position (either intentionally left open or during operation), an incoming surge voltage may be doubled by reflection at the open contacts. Selection of too low an insulation level for circuit breakers—if not individually protected by arresters—may result in line-to-ground, or open gap dielectric failure of the circuit breaker. Use of individual line entrance surge arresters may be required if the lightning trip-out rate of the line exceeds 1 per year or any value acceptable to the user.

4.6.3 Switching impulse withstand voltage

This test requirement applies to circuit breakers having maximum design voltages 362 kV and higher. New circuit breakers must withstand the crest voltage of a standard $250 \times 2500 \mu\text{s}$ impulse wave, when tested wet or dry. This test demonstrates that the circuit breaker insulation can withstand switching transients occurring under open-circuit, loaded, or faulted conditions. Test values are specified in the rating tables of IEEE Std C37.06.

4.6.4 Chopped wave withstand voltage

On new circuit breakers having chopped wave requirements, they must be able to withstand the stress related to the operation of a protection spark gap. Such an operation creates a steep voltage breakdown, which stresses the insulating material. Test values are specified in the rating tables of IEEE Std C37.06.

4.7 Standard operating duty

Power circuit breakers are rated for current interrupting ability on the basis of a standard operating duty (see IEEE Std C37.04).

If the actual duty cycle application is different from the standard operating duty, refer to 4.9.

4.8 Interrupting time

The rated interrupting time of a circuit breaker is the maximum permissible interval measured from the energization of the trip circuit at rated control voltage and rated mechanism pressure and the interruption of the current in the main circuit in all poles.

The rated interrupting time may be exceeded for close-open operations. The increase in interrupting time on close-open operation may be important from the standpoint of possible system instability. For low values of current, these considerations are less important.

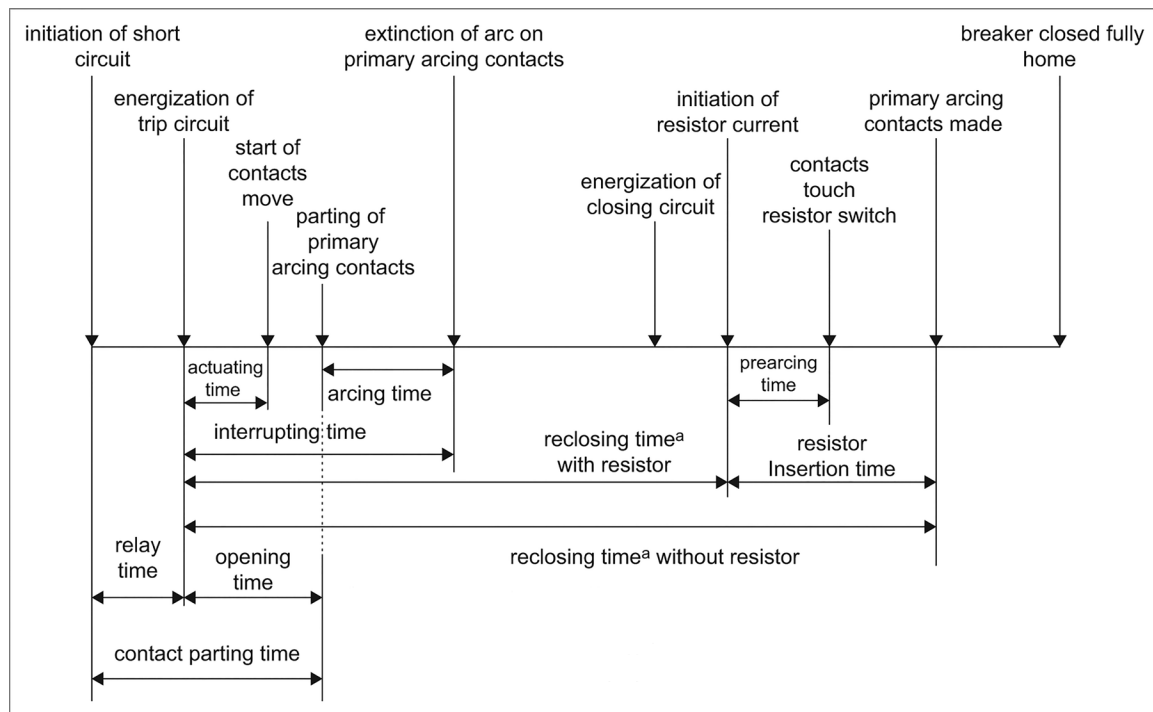
At duties below 25% of the required interrupting capability at rated maximum voltage, the time required for interruption for oil and air magnetic circuit breakers may be greater than the interrupting time by as much as

50% for 5-cycle and 8-cycle circuit breakers, and one cycle for circuit breakers of three cycles or less. For SF₆ and vacuum circuit breakers such a behavior is very rarely reported.

The preferred rated interrupting times of specific circuit breaker ratings are given in the tables of IEEE Std C37.06. Short interrupting times may be necessary where system stability is critical. Application considerations including required margins should be incorporated in determining expected maximum interrupting time.

For line-to-ground faults, the interrupting time is estimated to exceed the rated interrupting time by 0.1 cycle. The reason for this is that the rated interrupting time is based on three-phase faults. In a three-phase condition, more and earlier current zero crossings happen where the circuit breaker will interrupt the fault. For asymmetrical faults, it is estimated that the interrupting time may exceed rated time by an additional 0.2 cycle. Hence, for grounded asymmetrical faults, the last phase to clear is estimated to be 0.3 cycle slower than the rated interrupting time. This extension of the rated interrupting time is based on standard X/R ratios. In case of much higher X/R ratios, a longer extension may be seen. The rationale behind is the fact that the current zeroes at which the circuit breaker is able to interrupt, are delayed. Additionally, rated interrupting time may be exceeded during extreme cold weather (see 3.2.1) or when the circuit breaker has been closed for an extended period of time. Also, the circuit breaker may be slower at the lower limits of control voltage and/or mechanism stored energy. These longer interrupting times are in the range of several milliseconds.

Figure 2 shows the sequence of events in the course of a circuit interruption and reclosure.



^aReclosing time is the time interval between energizing the trip circuit and making the arcing contacts. This is the shortest possible time the circuit breaker itself is able to achieve. Where low ohmic resistors are used, making the resistor contact on reclosure may be more significant. In service an additional time delay (300 ms) is inserted to allow the fault location to be deionized.

Figure 2—Operating time