



IEEE Standard for Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Amendment 2: To Change the Description of Transient Recovery Voltage for Harmonization with IEC 62271-100

IEEE Power & Energy Society

Sponsored by the
Switchgear Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA
3 April 2009

IEEE Std C37.04b™-2008
(Amendment to
IEEE Std C37.04™ -1999)

IEEE Standard for Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Amendment 2: To Change the Description of Transient Recovery Voltage for Harmonization with IEC 62271-100

Sponsor

Switchgear Committee

of the

IEEE Power & Energy Society

Approved 10 December 2008

IEEE-SA Standards Board

The working group thanks the International Electrotechnical Commission (IEC) for permission to reproduce information from its International Standard 62271-100 (Ed. 2.0)-2008. All such extracts are copyright of IEC, Geneva, Switzerland. All rights reserved. Further information on the IEC is available from www.iec.ch. IEC has no responsibility for the placement and context in which the extracts and contents are reproduced by the author, nor is IEC in any way responsible for the other content or accuracy therein. Royalty-free permission to use this material is granted for world rights distribution, with permission to modify (with the appropriate notification to IEC in writing) and reprint in all future revisions and editions in all media known or hereinafter known.

Abstract: This standard is revised to change the descriptions of the standard transient recovery voltage (TRV) envelope and ratings. This is applicable for ac high-voltage circuit breakers rated above 1000 V and on a symmetrical current basis. The capability limits of these circuit breakers are determined to a major degree by the TRV. The revised descriptions of TRV bring the TRV requirements in IEEE standards into harmony with the TRV requirements in IEC standards that apply to the same type and class of equipment.

Keywords: high-voltage circuit breakers, transient recovery voltage

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

Copyright © 2009 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 3 April 2009. 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 registered trademarks in the U.S. Patent & Trademark Office, owned by The National Fire Protection Association.

PDF: ISBN 978-0-7381-5889-1 STD95871
Print: ISBN 978-0-7381-5890-7 STDPD95871

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.

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

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “AS IS.”

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. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, 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 publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received 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 interpretation requests except in those cases where the matter has previously received formal consideration. 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, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

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

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, 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.

Introduction

This introduction is not part of IEEE Std C37.04-2008, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Amendment 2: To Change the Description of Transient Recovery Voltage for Harmonization with IEC 62271-100.

This standard has been revised to change the TRV descriptions to harmonize with IEC 62271-100 (Ed. 1.1)-2003 (formerly IEC 60056)^a per Amendment 1 17A-625-FDIS as produced by IEC SC17A/WG23, which is a joint IEC and IEEE Working Group on the Harmonization of Power Test Procedures for AC High Voltage Circuit Breakers. Consistent with the changes discussed in this amendment of IEEE Std C37.04TM, changes are also proceeding in parallel in other standards to align the text and preferred ratings values with these new TRV requirements. The other standards being revised concurrently are IEEE Std C37.06TM, ANSI C37.06, IEEE Std C37.09TM-1999, and IEEE Std C37.011TM-2005.

The major changes implemented in this amendment are listed as follows.

- The TRV capability of circuit breakers according to this amendment to IEEE Std C37.04 is described by two- or four-parameter envelopes in place of 1-cosine and exponential-cosine envelopes. For breakers rated 100 kV and above, the TRV envelope is defined by four parameters where the short-circuit currents are above 30% of the breaker's capability. At 30% and below, the TRV envelope is described by two parameters. For breakers rated 72.5 kV and below, the TRV envelope is described by two parameters over the entire current range.
- Three-phase to ground faults are the basis for rating, in accordance with the present and revised IEEE Std C37.04-1999:
 - a) For circuit breakers applied on systems less than 100 kV, the TRV ratings assume that the systems can be operated ungrounded. This is equivalent to defining three-phase ungrounded faults as the basis for rating. There are two choices for TRVs on systems less than 100 kV.
 - 1) The first choice is for line connected systems, and the TRV values are those referred to as outdoor circuit breakers in prior revisions of ANSI standards.
 - 2) The second choice is for cable connected systems, and the TRV values are those found in IEC 62271-100 (Ed. 1.1)-2003 and are similar to the values for indoor circuit breakers in prior revisions of ANSI standards.
 - b) For circuit breakers applied on systems of 100 kV and above, there is also a choice:
 - 1) For systems 100 kV through 170 kV, the systems can be operated either ungrounded or effectively grounded so two TRV ratings are available for these systems.
 - 2) For systems 245 kV and above, the preferred TRV ratings assume that the systems are all effectively grounded, and the first-pole-to-clear factor is 1.3, which is similar to the approach taken by the IEC. There is also another table of values based on a first-pole-to-clear factor of 1.5 that provides alternative TRV values, which are similar to the prior revision of ANSI standards that use the three-phase ungrounded fault as the basis of rating.
- Annex A: The methods of drawing TRV envelopes are included to illustrate the application of the four-parameter and two-parameter methods of drawing TRV envelopes to various examples.

^aInformation on references can be found in Clause 2.

- Annex B: A comparison between the TRV terminology and symbols is included as a cross-reference of TRV terms between those terms previously used in IEEE standards and those now employed in this standard and in IEC standards.
- Annex C: TRV envelopes.
- Annex D: TRV multipliers for related required capabilities.
- Annex E: The origin of out-of-phase TRV envelopes and values is included to explain the reasoning behind the choices for out-of-phase TRV descriptions.
- Annex F: A list of references is included to provide the background for various statements made in this standard about the historical origin of TRV descriptions and values and of the system study basis for recent revisions.

Notice to users

Laws and regulations

Users of these documents should consult all applicable laws and regulations. Compliance with the provisions of this standard 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

This document is copyrighted by the IEEE. It is made available 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 this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

Updating of IEEE documents

Users of IEEE standards 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. 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 Standards Association web site at <http://ieeexplore.ieee.org/xpl/standards.jsp>, or contact the IEEE at the address listed previously.

For more information about the IEEE Standards Association or the IEEE standards development process, visit the IEEE-SA web site at <http://standards.ieee.org>.

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/updates/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/interp/>.

Patents

Attention is called to the possibility that implementation of this guide may require use of subject matter covered by patent rights. By publication of this guide, no position is taken with respect to the existence or validity of any patent rights in connection therewith. 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 guide 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 standard was completed, the TRV Working Group had the following membership:

R. Kirland Smith, *Chair*

Robert J. Behl
William J. Bergman
Stan Billings
Anne Bosma
John H. Brunke
Frank Chapman
Chih C. Chow
Patrick DiLillo
Randall Dotson
Denis Dufournet
Kenneth S. Edwards
Leslie T. Falkingham
Thomas E. Field

Marcel Fortin
Detlef Fredrich
Ruben D. Garzon
Charles R. Hampe, Jr.
Helmut Heiermeier
Richard Jackson
Paul P. Leufkens
R. William Long
Antonio Mannarino
Neil McCord
Georges Montillet
Yasin I. Musa

Hugh Ross
Jim Ross
Roger A. Sarkinen
Roderick Sauls
Devki Sharma
H. Mel Smith
R. Kirkland Smith
David Stone
Charles L. Wagner
Keith Wallace
Terry Williams
Richard A. York
Xi Zhu

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

Roy Alexander	George Gela	Michael S. Newman
Mauricio Aristizabal	Kenneth Gettman	Joe Nims
Adam Bagby	Randall Groves	T. Olsen
Munnu Bajpai	Helmut Heiermeier	Miklos Orosz
Robert Barnett	Gary Heuston	Donald Parker
William J. Bill Bergman	Scott Hietpas	R. Parry
Stan Billings	David Horvath	David Peelo
Wallace Binder	Dennis Horwitz	Paulette Payne Powell
Thomas Blair	James Houston	Iulian Profir
Frank Blalock	Richard Jackson	Ryland Revelle
William Bloethe	Anders Johnson	Michael Roberts
Anne Bosma	Yuri Khersonsky	Charles Rogers
Steven Brockschink	J. Koepfinger	Steven Sano
Steven Brown	Jim Kulchisky	Devki Sharma
Gustavo Brunello	Saumen Kundu	Hyeong Sim
John H. Brunke	Carl Kurinko	H. Mel Smith
Ted Burse	Chung-Yu Lam	James E. Smith
Eldridge Byron	Stephen Lambert	R. Kirkland Smith
Yunxiang Chen	Gerald Lee	David Stone
Chih C. Chow	Boyd Leuenberger	James Swank
Tommy Cooper	Jason Yy-Shung Lin	S. Telander
John Crouse	Hua Liu	Malcolm Thaden
Stephen Dare	Albert Livshitz	Norbert Trapp
Randall Dotson	R. William Long	Michael Wactor
Dana Dufield	G. Luri	Charles L. Wagner
Denis Dufournet	Keith Malmedal	Keith Wallace
Douglas J. Edwards	Frank Mayle	Joe Watson
Kenneth S. Edwards	Peter Meyer	James Wilson
Gary Engmann	Gary Michel	Larry Yonce
C. Erven	Georges Montillet	Richard A. York
Leslie T. Falkingham	Charles Morse	Janusz Zawadzki
Thomas E. Field	Jerry Murphy	Xi Zhu
Marcel Fortin	Yasin I. Musa	Ahmed Zobaa
	Jeffrey Nelson	

When the IEEE-SA Standards Board approved this standard on 10 December 2008, it had the following membership:

Robert M. Grow, *Chair*
Tom A. Prevost, *Vice Chair*
Steve M. Mills, *Past Chair*
Judith Gorman, *Secretary*

Victor Berman	James Hughes	Ronald C. Petersen
Richard DeBlasio	Richard H. Hulett	Chuck Powers
Andrew Drozd	Young Kyun Kim	Narayanan Ramachandran
Mark Epstein	Joseph L. Koepfinger*	Jon Walter Rosdahl
Alexander Gelman	John Kulick	Anne-Marie Sahazizian
William R. Goldbach	David J. Law	Malcolm V. Thaden
Arnold M. Greenspan	Glenn Parsons	Howard L. Wolfman
Kenneth S. Hanus		Don Wright

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Michael Janezic, *NIST Representative*

Michelle Turner
IEEE Standards Program Manager, Document Development

Matthew J. Ceglia
IEEE Standards Program Manager, Technical Program Development

Contents

2. Normative references.....	2
3. Definitions and special terms	2
3.1 Definitions	2
3.2 Special terms.....	2
5. Ratings.....	3
5.9 Rated transient recovery voltage (TRV).....	3
Annex A (normative) Methods of drawing TRV envelopes	27
Annex B (informative) Comparison between the TRV terminology and symbols.....	31
Annex C (informative) TRV envelopes.....	33
Annex D (informative) TRV multipliers for related required capabilities	35
Annex E (informative) Basis for out-of-phase TRV envelopes and values.....	40
Annex F (informative) Bibliography.....	44

IEEE Standard for Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Amendment 2: To Change the Description of Transient Recovery Voltage for Harmonization with IEC 62271-100

IMPORTANT NOTICE: *This standard is not intended to ensure safety, security, health, or environmental protection in all circumstances. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.*

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

NOTE—The editing instructions contained in this amendment define how to merge the material contained herein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make small corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strike through~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. Insert adds new material without disturbing the existing material. Insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make large changes in existing text, subclauses, tables, or figures by removing existing material and replacing it with new material. Editorial notes will not be carried over into future editions because the changes will be incorporated into the base standard.

Replace header and opening paragraph to Clause 2 with the following:

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so that 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.

Delete the following reference from Clause 2:

IEC 60056 Ed. 4.0b: 1987, High-Voltage Alternating-Current Circuit-Breakers.

Change the following references in Clause 2 as follows:

IEEE Std C37.011TM-1994~~2005~~, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers ~~Rated on a Symmetrical Current Basis~~.^{1, 2}

~~ANSI~~IEEE Std C37.06TM-1997, ~~American National Standard for Switchgear—~~AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.

Change the header for Clause 3 as follows:

3. Definitions and special terms

Replace the text in Clause 3 with the following:

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards* [B9]³ should be referenced for terms not defined in this clause.

3.1.1 circuit breaker class S1: A circuit breaker intended to be used in a cable system.

3.1.2 circuit breaker class S2: A circuit breaker intended to be used in a line system or in a cable system with a direct connection (without cable) to overhead lines.

3.2 Special terms

3.2.1 cable system: A system in which the transient recovery voltage (TRV) during interrupting of terminal fault at 100% of short-circuit interrupting current that does not exceed the two-parameter envelope derived from Column 5 of Table 2A in this standard.

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

²The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

³The numbers in brackets correspond to those of the bibliography in Annex F.

This definition of cable systems is restricted to systems of rated voltages higher than 1 kV and less than 100 kV. Circuit breakers located in indoor substations with cable connections are generally in cable systems. A circuit breaker in an outdoor substation is considered to be in a cable system if the total length of cable (or equivalent length when capacitors are also present) connected on the supply side of the circuit breaker is at least 100 m. However, if in an actual case with an equivalent length of cable shorter than 100 m a calculation can show that the actual TRV is covered by the envelope defined from Column 5 of Table 2A, then this system is considered a cable system. The capacitance of cable systems on the supply side of circuit breakers is provided by cables and/or capacitors and/or insulated bus.

3.2.2 line system: A system in which the TRV during interrupting of terminal fault at 100% of short-circuit interrupting current is covered by the two-parameter envelope derived from Column 4 of Table 2A in this standard and exceeds the two-parameter envelope derived from Column 5 of Table 2A.

This definition of line systems normally applies to systems of rated voltages equal to or higher than 15 kV and less than 100 kV. In line systems, no cable is connected on the supply side of the circuit breaker, with the possible exception of a total length of cable up to 100 m between the circuit breaker and the supply transformer(s). Systems with transmission lines directly connected to a busbar (without intervening cable connections) are typical examples of line systems.

5. Ratings

Replace the text in 5.9 with the following:

5.9 Rated TRV

5.9.1 TRV basics

The TRV related to the rated short-circuit interrupting current in accordance with 5.8.1 is the reference voltage that constitutes the limit of the prospective transient recovery voltage of circuits, which the circuit breaker shall be capable of withstanding under fault conditions. Each transient recovery voltage rating is defined for a three-phase circuit breaker.

- At its rated maximum voltage for all rated voltages, each circuit breaker must be capable of interrupting three-phase grounded terminal faults at rated short-circuit current in any circuit in which the transient recovery voltage does not exceed the rated transient recovery voltage envelope.
- At its rated maximum voltage for rated voltages below 100 kV, each circuit breaker must be capable of interrupting three-phase ungrounded terminal faults at rated short-circuit current in any circuit in which the transient recovery voltage does not exceed the rated transient recovery voltage envelope.
- At its rated maximum voltage for rated voltages 100 kV and above, the user can specify whether the circuit breaker must be capable of interrupting three-phase grounded or three-phase ungrounded terminal faults at rated short-circuit current in any circuit in which the transient recovery voltage does not exceed the rated transient recovery voltage envelope. The first phase to clear in an ungrounded fault produces the highest TRV magnitude and is therefore the worst case. A graphical explanation is provided in Annex C of IEEE Std C37.011™-2005.
- This standard does not cover many three-phase line faults when the circuit breaker is applied above 80% of its short-circuit rating. By agreement between the manufacturer and the user, the circuit breaker may be acceptable for three-phase line fault duty.

Both the rated system voltage and the grounding of the class of the circuit are major factors affecting the TRV of the circuit.

- At rated voltages up to 100 kV, ungrounded systems are fairly common, and although single-phase to ground faults are the most common, three-phase ungrounded faults are also fairly common. Therefore, all circuit breakers in this range of rated voltages are required to interrupt three-phase ungrounded terminal faults.
- In the range of rated voltages from 100 kV to 170 kV, the grounding is sometimes accomplished through an impedance, which makes these systems effectively ungrounded. In addition, three-phase ungrounded faults are still fairly common, although less so than at voltages less than 100 kV. Therefore, the user can specify the circuit breakers for use in these impedance grounded systems be required to interrupt three-phase ungrounded terminal faults as well.
- For rated voltages of 100 kV and above, most systems have the neutral grounded, except in the range of rated voltages from 100 kV to 170 kV as noted above. In addition, system experience has shown that three-phase ungrounded faults are very rare (Baltensperger et al. [B1]), accounting for less than 1.3% of all faults. So, although three-phase ungrounded faults produce the highest TRV peaks, the probability of their occurrence is very small. Based on these statistics, the CIGRE working group [B1] recommended that three-phase grounded faults be considered as the basis of rating for circuit breakers rated 100 kV and above and applied in effectively grounded systems; this recommendation is so implemented in IEC 62271-100 (Ed. 2.0)-2008 [B8]. This standard also considers the three-phase grounded fault as the most typical basis of rating for circuit breakers rated 100 kV and above. However, this standard also provides the user the option to specify three-phase ungrounded faults as the basis of rating to cover all application conditions where the user considers that the higher TRV capability is required. Because earlier editions of IEEE standards were based on the three-phase ungrounded fault for all voltages, this option also provides the user with a choice where replacement of older breakers is contemplated.
- Clause 171 of the National Electrical Code® (NEC®) (NFPA 70, 2007 Edition) [B18] states the following concerning circuit breaker applications:

Circuit breakers, circuit switchers, reclosers, switches, and fuses should be utilized with due regard to their assigned ratings of voltage and continuous and momentary currents. Devices that are intended to interrupt fault current shall be capable of safely interrupting the maximum short-circuit current they are intended to interrupt, and for the circumstances under which they are designed to operate. The interrupting capacity should be reviewed prior to each significant system change.

 - a) This clause is interpreted by some users to mean that three-phase ungrounded faults must be used as the basis for circuit breaker applications, even though the rate of occurrence is very low.
 - b) However, testing with an ungrounded system will result in shorter maximum arcing times and lower TRV values for the second and third phase to clear. Therefore, it is not clear that using the three-phase ungrounded condition as the basis for applications will increase the overall margins of performance for the circuit breaker.
 - c) The user will have to judge which basis of the application is most suitable for a given situation.

The choice between the three-phase grounded versus the three-phase ungrounded condition is accomplished by choosing of the value of the first-pole-to-clear factor k_{pp} in calculating the TRV peak. For ungrounded systems, which are often found at lower rated voltages, the value of k_{pp} is 1.5. For effectively grounded systems, which are the norm at higher rated voltages, the value of k_{pp} is 1.3, which accounts for the reduction of the TRV peak produced by the effectively grounded condition. The tables of preferred ratings in IEEE Std C37.06 include the option of both the first-pole-to-clear factors at 100 kV and above.

The waveform of the transient recovery voltage as a function of time varies according to the arrangement of the actual circuit. Actual TRV waveforms as a function of time all have a similar general shape. The TRV waveform starts at zero volts and zero time at the point in time when the current comes down to zero and is interrupted. The TRV then increases at some rate reaching a peak value after which the TRV reduces and is damped out. Actual TRV waveforms observed in a power system can be as simple as a single-frequency oscillation produced by a lumped parameter R-L-C circuit, or it can be more complicated, with various oscillatory components and traveling wave reflections that are found in transmission systems where traveling waves describe parts of the TRV envelope.

For the purposes of industry standards for electrical power switchgear, these TRV waveforms are described in simplified terms with some straight lines called reference lines. The first reference line is horizontal and tangent to the TRV waveform at only one point and does not intersect or contact the waveform at any other points. This line then provides the upper bound to the TRV magnitude. Another reference line starts at the origin with zero volts at zero time and increases with some positive slope; it is tangent to the TRV waveform at only one point. In this way, the sloped line is also an upper boundary that the TRV waveform never crosses. These lines then in combination form an upper boundary that the actual TRV waveform never exceeds. A voltage and a time pair define the point of intersection of the horizontal line and the sloped line. The voltage and time values are called “parameters.” The voltage and time pair also define the upper end of the sloped straight reference line segment. The intersection of the straight lines always occurs at a point in time sooner than the point at which the actual TRV reaches its peak. For two straight lines, one sloped and one horizontal, two parameters, a voltage and a time, are enough to define the intersection of the two lines and to specify the TRV envelope. Some TRV waveshapes start with an exponential rise and then a 1-cosine rise to the peak as defined in older IEEE standards. For these waveshapes, there are three straight lines that form the envelope in which two of them are tangent to the maximum rate of rise on the two different rising slopes, and the third is tangent to the peak. For three straight lines, two sloped and one horizontal, four parameters, two voltages and two times, are required to define the two intersection points.

Although two straight lines work well for a simple, single-frequency waveform, a third line segment is useful for more complicated TRV waveforms where returning traveling waves describe parts of the TRV envelope. The simpler case is more typical of systems with rated voltages below 100 kV, whereas the more complicated case is more typical of systems with rated voltages 100 kV and above. In recognition of this, two types of TRV waveforms at rated short-circuit current are used based on the voltage class of the equipment.

- A four-parameter TRV is used for system voltages of 100 kV and above.
- A two-parameter TRV is used for system voltages up to 100 kV.

The two-parameter TRV is also used at all rated voltages for the TRVs for fault currents that are 30% or less of the rated short-circuit current as discussed in 5.9.4.3.1. The two- and four-parameter TRV waveforms are qualitatively described below and are described with equations in 5.9.2 through 5.9.4. Methods of drawing TRV envelopes by constructing the tangent lines are given in Annex A. The numerical values of the parameters for preferred ratings are listed in tables in IEEE Std C37.06.

NOTE—TRV terminology and symbols in this standard are harmonized between IEC and ANSI/IEEE. The relationships between the new terms used in standard and older terms used in are shown in Table B.1.⁴

The TRV reference lines form a voltage–time boundary that is essential for both testing and applying circuit breakers. The relationship of the test TRV envelope to the rated TRV envelope for the purpose of testing the circuit breaker is described in IEEE Std C37.09™-1999. The relationship of the TRV envelope in a specific application to the rated TRV envelope for the purpose of applying the circuit breaker is described in IEEE Std C37.011-2005. The objective of the test is to produce a TRV whose envelope formed by the

⁴Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

reference lines meets or exceeds the standard envelope. The objective of the application is to ensure that the TRV envelope produced by the actual system is at or below the standard envelope. In this way, a successful application is made when the interrupting stress imposed by the system does not exceed the capability of the circuit breaker as demonstrated by test. It appears that every part of the TRV wave may influence the interrupting capability of a circuit breaker. For some types of circuit breakers, the initial rate-of-rise is most important, whereas for others, the peak value is most important. Therefore, the entire TRV envelope must be considered for testing and application.

5.9.1.1 Four-parameter TRV for system voltages of 100 kV and above

In some cases, particularly in systems 100 kV and above and where the short-circuit currents are relatively large in relation to the maximum short-circuit current at the point under consideration, the transient recovery voltage contains first a period of high rate of rise, followed by a later period of lower rate of rise. This waveform is more complicated in shape than a single-frequency damped oscillatory transient. The initial portion is typically an exponentially increasing function asymptotic to some voltage value. The exponential waveform is produced by the parallel combination of the local source inductance and the resistance of the transmission line surge impedance. The later portion is formed by the return of the initial portion as a traveling wave from the connected transmission lines. A four-parameter TRV envelope consisting of three line segments as described below adequately represents this waveform.

The four parameters are described as follows.

u_1 = first reference voltage, in kilovolts

t_1 = time to reach u_1 , in microseconds

u_c = second reference voltage (the TRV peak value), in kilovolts

t_2 = time to reach u_c , in microseconds

These four parameters, plus the origin, form two sloped line segments and a third horizontal line segment. These reference lines form an upper boundary to the rated TRV.

- The first line segment extends from the volt-time origin up to the point u_1, t_1 .
- The second line segment begins at point u_1, t_1 and extends to point u_c, t_2 .
- The third line segment is a horizontal line at the peak voltage u_c .

As stated, the actual TRV waveform bounded by this four-parameter set of straight lines reaches its peak at a point in time that is later than the point t_2 where the straight lines intersect. Figure 2 shows the reference line segments that form the four-parameter TRV envelope.

NOTE—Figure C.1 shows a comparison of four-parameter TRV reference lines to the former ANSI/IEEE exponential-cosine TRV envelope.