IEEE Standard for Interrupter Switches for Alternating Current, Rated Above 1000 V

IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

1247™

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

6 June 2006

IEEE Std 1247™-2005
(Revision of IEEE Std 1247-1998)

Recognized as an
American National Standard (ANSI)

IEEE Std 1247™-2005
(Revision of
IEEE Std 1247-1998)

IEEE Standard for Interrupter Switches for Alternating Current, Rated Above 1000 Volts

Sponsor

Switchgear Committee
of the
IEEE Power Engineering Society

Approved 28 March 2006

American National Standards Institute

Approved 7 December 2005

IEEE-SA Standards Board

Abstract: The basic requirements of interrupter switches used indoors, outdoors, and in enclosures are covered. This standard does not apply to load-break separable insulated connectors.
Keywords: enclosed switch, indoor switch, interrupter switch, outdoor switch, switching ability, switching current, switching rating

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

Print: ISBN 0-7381-4864-4 SH95503
PDF: ISBN 0-7381-4865-2 SS95503

Introduction

This introduction is not part of IEEE Std 1247-2005, IEEE Standard for Interrupter Switches for Alternating Current, Rated Above 1000 Volts.

Over many years, standards covering interrupter switches have been developed in subcommittees other than the High Voltage Switch Subcommittee. As a result, different and sometimes conflicting requirements for interrupter switches have been developed. Where there is a clear need for different requirements in different applications, diverging standards are appropriate. However, where application requirements are similar, the body of standards should treat the requirements uniformly. As a result of this philosophy, the Switchgear Administrative Subcommittee passed the following motion at the May 1991 meeting in Fort Lauderdale.

In an effort to promote a uniform approach to standards, the following policy is set:

Future standards and revisions to standards that incorporate fuses, switches, circuit breakers, and/or reclosers and sectionalizers shall reference the basic fuse, switch, circuit breaker, and/or recloser and sectionalizer standard wherever possible and treat material differently only when there are unique application requirements.

This standard was written to provide the basic standard for interrupter switches. As such, an attempt was made to encompass as many different types of interrupter switches as practical. This standard has also provided the opportunity to update and revise the general treatment of interrupter switches, and address newer technologies that are being used to provide switching functions.

Part of the heritage of this document comes from the treatment of interrupter switches in other IEEE C37 standards. It is anticipated that material relating to interrupter switches, currently in the IEEE C37.30 series, will be removed from those documents when this document is published. Further, when this document is published, it is anticipated that other standards, not in the IEEE C37.30 series, will begin to reference this document, as outlined in the above AdsCom motion.

Although this standard does not apply to circuit-breakers, circuit-switchers, or reclosers, standards for circuit-breakers, circuit-switchers, and reclosers should reference this document for their load-interrupting requirements. A further intent of this document is to provide test circuits to be used to establish ratings for common applications of switching devices not generally covered by standards.

Although this document will be published before the work on IEEE Std C37.100.1™ (Common Clauses) is finished, it is the intention of the Interrupter Switch Working Group to adopt or reference common clauses as they become available. Specifically the treatment of:

— Altitude correction factors, and
— Total temperature limits for contacts, connections, and insulation

will conform to the Common Clauses Document.

Conformance and field testing are not covered in this document. The user is referred to apparatus-specific test documents such as IEEE Std C37.41™, ANSI C37.57, and ANSI C37.58.

This standard has adopted the approach of many other standards in avoiding asymmetrical current ratings. For example, the traditional momentary (asymmetrical) current rating is now covered in the peak current withstand. Because of the lack of a need to calculate asymmetrical currents, and the common use of data acquisition systems (which automatically calculate rms currents), IEEE Std C37.09™ is not referenced as a means to determine symmetrical or asymmetrical values.

The actual revision is limited to the correction of technical errors that have been identified in subclauses 8.3.1.3, 8.3.2.1, 8.3.2.2.1, 8.3.2.5 and 8.2.2.6, 8.3.2.3, and 8.3.2.6; Figures 1, 2, 3, 4, 7, 8, 9, 10, and 11; and Tables 6, 7, and 9.

Notice to users

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/index.html.

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 with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Participants

At the time this standard was completed, the working group had the following membership:

Lyne Brisson, *Co-Chair*
Marcel Fortin, *Co-Chair*

John Angelis
Charles Ball
Frank DeCesaro
Jim Domo
Erik M. Guillot
Ronald Lavorin
Peter Meyer
Radakrishna Ranjan
David Stone
Jan Zawadzki

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

Roy Alexander
Chris Ambrose
Edwin Averill
Charles Ball
W. J. (Bill) Bergman
Edward Bertolini
Behdad Biglar
Lyne Brisson
Robert Brown
Ted Burse
Eldridge R. Byron
Raymond Capra
Tommy Cooper
Ronald Daubert
Alexander Dixon
Randall Dotson
Denis Dufournet
Doug Edwards
Marcel Fortin
Kenneth Gettman
David Gilmer
Mietek Glinkowski
Randall Groves
Erik M. Guillot
Ian Harvey
Luther Holloman
Edward Horgan Jr.
George House
William Hurst
David Jackson
Edward Jankowich
Joseph L. Koepfinger
Thomas LaRose
Stephen R. Lambert
Ward E. Laubach
John Leach
George Lester
Jason Lin
Albert Livshitz
Gregory Luri
William Majeski
Neil McCord
Nigel McQuin
Bryan Melville
Peter Meyer
Gary Michel
Alec Monroe
Georges Montillet
Anne Morgan
Peter Morgan
Frank Muench
Yasin Musa
Jeffrey Nelson
Paul Notarian
Ray O'Leary
T. W. Olsen
Paulette Payne
Anthony Picagli
Jackson Richard
Hugh Ross
Timothy Royster
James Ruggieri
E. William Schmunk
Devki Sharma
R. Kirkland Smith
David Stone
Chand Tailor
Stanton Telander
Jane Ann Verner
Charles Wagner
Steve Whalen
James Wilson
John Wood
Elbert Worland
Zhenxue Xu
Larry Yonce
Jan Zawadzki

When the IEEE-SA Standards Board approved this standard on 7 December 2005, it had the following membership:

Contents

IEEE Standard for Interrupter Switches for Alternating Current, Rated Above 1000 V

1. Overview

1.1 Scope

This standard applies to switching devices, interrupters, and interrupter switches (as defined in IEEE Std C37.100™) for alternating current, rated above 1000 V and used indoors, outdoors, or in enclosures for which a switching rating is to be assigned. While this standard covers the basic requirements of interrupter switches used indoors, outdoors, and in enclosures, other standards such as IEEE Std C37.20.2™, IEEE Std C37.20.3™, IEEE Std C37.20.4™, and IEEE Std C37.74™ also contain requirements for switches used in enclosures. This standard does not apply to load-break separable insulated connectors, which are covered by IEEE Std 386™-1995 [B8].[1] This standard also does not apply to circuit-breakers, circuit-switchers, or reclosers.

1.2 Purpose

The purpose of this standard is to provide a basic standard for switches as defined in 3.5. The broad definition of a switch, given in 3.5, encompasses devices that meet the strict definition of an interrupter switch in IEEE Std C37.100, and also encompass devices that utilize insulating media other than air.

2. Normative references

The following referenced documents are indispensable for the application of this document. 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 C2-2002, National Electrical Safety Code ® (NESC®).[2]

ANSI C29.1-2002, Test Methods for Electrical Power Insulators.

ANSI C37.22-1997 (Reaff 2003), American National Standard Preferred Ratings and Related Required Capabilities for Indoor AC Medium-Voltage Switches Used in Metal-Enclosed Switchgear.

---

[1] The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex E.

[2] ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).

ANSI C37.32-2002, Schedule of Preferred Ratings, Construction Guidelines and Specifications for High-Voltage Air Disconnect Switches Interrupter Switches, Fault Initiating Switches, Grounding Switches, Bus supports and Accessories Control Voltage Ranges.

ANSI C37.66-1969 (Reaff 1997), American National Standard Requirements for Oil-filled Capacitor Switches for Alternating-Current Systems.

ANSI C63.2-1996, American National Standard Specifications for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 40 GHz.

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing, including IEEE 4a™-2001, Amendment to IEEE Standard Techniques for High-Voltage Testing.[3,4]

IEEE Std C37.09-1999 IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.20.2-1999, IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear.

IEEE Std C37.20.3-2001, IEEE Standard for Metal-Enclosed Interrupter Switchgear.

IEEE Std C37.20.4-2001, IEEE Standard for Indoor AC Medium-Voltage Switches for Use in Metal-Enclosed Switchgear.

IEEE Std C37.30™-1997, IEEE Standard Requirements for High-Voltage Air Switches.

IEEE Std C37.34™-2002, IEEE Standard Test Code for High-Voltage Air Switches.

IEEE Std C37.74-2002 IEEE Standard Requirements for Subsurface, Vault, and Padmounted Load-Interrupter Switchgear and Fused Load-Interrupter Switchgear for Alternating Current Systems up to 38 kV.

IEEE Std C37.100-1992 (Reaff 2001), IEEE Standard Definitions for Power Switchgear.

NEMA 107-1987 (Reaff 2000), Methods of Measurements of Radio Influence Voltage (RIV) of High Voltage Apparatus.[5]

NEMA SG6-1995, Power Switching Equipment.

3. Definitions

If a term is not defined in this standard, the definition in IEEE Std C37.100 or in *The Authoritative Dictionary of IEEE Standards Terms* [B5] applies. An asterisk (*) indicates that the definition in this standard is not contained in IEEE Std C37.100. A dagger (†) indicates that the definition in this standard differs from that in IEEE Std C37.100.

3.1 interrupter switch: (†) A switching device, designed for making specified currents and breaking specified steady state currents. (HVS, Swg)

[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).
[4] The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.
[5] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

NOTE—The nature of the current made or broken, or both, may be indicated by suitable prefix; that is, load interrupter switch, loop interrupter switch, unloaded line interrupter switch, etc. [6]

3.2 peak withstand current: (*) The maximum instantaneous current at the major peak of an offset power-frequency sinusoidal current that a switch is required to carry.

3.3 short-time (symmetrical) withstand current: (†) An abnormal power-frequency current (expressed in rms symmetrical amperes), the initial portion of which may have a dc offset that a switch is required to carry.

3.4 short-time (symmetrical) withstand current duration: (*) The maximum duration of short-time (symmetrical) withstand current that a switch is required to carry.

3.5 switch: (†) Within this standard, the noun “switch” shall refer to switching devices, interrupters, current interrupting devices, interrupting aids, or interrupter switches (as defined in IEEE Std C37.100).

4. Service conditions

4.1 Usual service conditions

Switches conforming to this standard shall be suitable for operation at their standard ratings provided that

a) The temperature of the cooling air (ambient temperature) does not exceed 40 °C (104 °F)

b) The ambient temperature is not less than –30 °C (–22 °F)

c) The altitude does not exceed 1000 m (3300 ft)

d) The wind velocity does not exceed 36 m/s (130 km/h, 80 mph)

NOTE—The interrupting ability of some switches that rely on a rapidly increasing external air gap for circuit interruption (such as whip arcing horns) may be influenced by local wind velocity and direction.

4.1.1 Outdoor switch

Switches designated as outdoor switches shall be suitable for operation outside buildings or enclosures. Outdoor switches may be exposed to the weather. They experience no restriction of heat transfer to the ambient atmosphere.

4.1.2 Indoor switch

Switches designated as indoor switches shall be suitable for operation inside buildings or weather-resistant enclosures. If an indoor switch is designed for weather-resistant enclosures, it shall also be considered an enclosed switch. If an indoor switch is designed for operation inside buildings, in a manner that does not restrict heat transfer to the ambient atmosphere, it shall be considered an indoor switch only.

4.1.3 Enclosed switch

Switches designated as enclosed switches shall be suitable for operation inside a weather-resistant enclosure that restricts heat transfer to the ambient atmosphere. Enclosed switches may also be suitable for use in enclosures filled with a dielectric medium other than air, e.g., oil or SF_6.

4.2 Unusual service conditions

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

Unusual conditions shall be considered. Examples of such conditions are as follows:

a) Altitudes greater than 1000 m (3300 ft) (see Annex A)

b) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moistures, or dripping water

c) Abnormal vibration, shocks, or tilting

d) Seismic requirements

e) Excessively high or low temperatures

f) Unusual transportation or storage conditions

g) Unusual space limitations

h) The application of an outdoor switch, indoor switch, or an enclosed switch for another purpose, which may include concerns regarding weather exposure and restricted heat transfer (see Table 1)

i) Unusual operating duty, frequency of operation, difficulty of maintenance, high harmonic content waveforms, unbalanced voltage, and special insulation requirements

Table 1 lists applications that may be considered unusual.

Table 1—Applications that may be considered unusual

Switch type	Switch exposed to weather	Installation with restricted heat transfer
Outdoor switch	Usual	Unusual
Indoor switch	Unusual	Unusual
Enclosed switch	Unusual	Usual

5. Description of ratings and capabilities

Subclauses 5.1 through 5.11 generally define the ratings and capabilities that switches may be required to have. The switch manufacturer can build a switch product that meets any combination of the ratings, or alternately, other apparatus standards may require a specific set of ratings. The preferred values for ratings and capabilities are found in Clause 6. The test procedures to establish the ratings and capabilities are found in Clause 8.

5.1 Rated power frequency

The rated power frequency is the fundamental steady-state supply voltage frequency at which the switch is designed to operate. Typical power frequencies are 50 Hz and 60 Hz.

5.2 Rated voltage

5.2.1 Rated maximum voltage

The rated maximum voltage of a switch is the highest root-mean-square (rms) three-phase system voltage of rated power frequency for which the switch is designed to operate.

5.2.2 Rated loop-switching voltage

The rated loop-switching voltage of a switch is the highest rms recovery voltage that the switch is designed to withstand upon breaking loop current.

5.2.3 Rated differential capacitance voltage range

The rated differential capacitance voltage range consists of upper and lower limits for the difference in the magnitude of the rms power-frequency voltage, with and without a capacitance connected.

5.3 Rated withstand voltages

The rated withstand voltage is the voltage of the appropriate waveshape, magnitude, and duration that the switch shall withstand under specified conditions, without damage to the insulating materials.

5.3.1 Rated power-frequency withstand voltage

The rated power-frequency withstand voltages are rms values of sinusoidal waveforms of rated power frequency.

5.3.1.1 Rated power-frequency dry withstand voltage

The rated power-frequency dry withstand voltage is a rated power-frequency withstand voltage that the switch is required to withstand for a duration of 60 s under dry conditions.

Insulation between the live parts of a switch and ground shall withstand 100% of the rated power-frequency dry withstand voltage.

Insulation across the open gap of switches shall withstand 100% or 110% of the rated power-frequency dry withstand voltage, if required by other standards such as the IEEE C37.20 series. The nameplate shall relate the 110% open-gap rated power-frequency dry withstand voltage, if appropriate.

5.3.1.2 Rated power-frequency wet withstand voltage

The rated power-frequency wet withstand voltage is the power-frequency withstand voltage that an outdoor switch is required to withstand for a duration of 10 s under wet (rain) conditions. There are no power-frequency wet withstand requirements for indoor or enclosed switches.

Insulation between the live parts of an outdoor switch and ground shall withstand 100% of the rated power-frequency wet withstand voltage.

If, utilizing good engineering judgment, one cannot determine that solid insulation that fully or partially bridges the open gap will not adversely affect the open-gap withstand, a wet-withstand test shall be made and the open gap shall withstand 100% of the rated wet power-frequency withstand voltage.

5.3.1.3 Rated power-frequency dew withstand voltage

The rated power-frequency dew withstand voltage is the power-frequency withstand voltage that an indoor or an enclosed switch is required to withstand, without flashover or damage to any insulation, for a duration of 10 s with condensate (dew) over the switch's solid insulation. There is no power-frequency dew withstand requirement for outdoor switches. If the open gap of an enclosed switch is effectively bridged by a solid insulation, a dew withstand test shall be made and the open gap shall withstand 100% of the rated power-frequency dew withstand voltage.

5.3.2 Rated lightning-impulse withstand voltage

The rated lightning-impulse withstand voltage is the peak value of 1.2×50 µs positive and negative impulses that the switch shall be required to withstand.

Insulation between the live parts of a switch and ground shall withstand 100% of the rated lightning-impulse withstand voltage.

Insulation across the open gap of switches shall withstand 100% or 110% of the rated lightning-impulse withstand voltage, if required by other standards such as IEEE Std C37.34. The nameplate shall relate the 110% open-gap lightning-impulse withstand voltage, if appropriate.

NOTE—Conformance to this rating does not necessarily provide assurance that a switch with 110% withstand across the open gap will always flashover to ground instead of across open gaps. Where surge protection of the gap is required, switch insulators may be equipped with rod gaps or similar protective devices.

5.3.3 Rated switching-impulse withstand voltage

The rated switching-impulse withstand voltage is the peak value of 250 × 2500 µs positive and negative impulses that the switch shall be required to withstand. There are no rated switching-impulse withstand requirements for switches with rated lightning-impulse withstand voltages less than 1050 kV.

All insulation, including open gaps, shall withstand 100% of the rated switching-impulse withstand voltage.

5.4 Rated currents

5.4.1 Rated continuous current

The rated continuous current is the maximum current the switch shall be required to carry continuously, under usual service conditions, without exceeding specified temperature limits. The current is in rms amperes at rated power frequency.

5.4.2 Rated short-time (symmetrical) withstand current

The rated short-time (symmetrical) withstand current has two associated ratings. They are as follows:

a) *Rated peak withstand current*. The measure of the switch's ability to withstand the magnetic forces associated with a short-circuit

b) *Rated short-time (symmetrical) withstand current duration.* The measure of the switch's ability to withstand the heat generated by a short-time current

The relationship between peak withstand current and short-time (symmetrical) withstand current is based on an approximate *X/R* of 17 at 60 Hz, which leads to a peak current to rms symmetrical current ratio of 2.6.

5.4.2.1 Rated peak withstand current

The rated peak withstand current is the maximum instantaneous current at the major peak of an offset rated power-frequency current that the switch shall be required to carry while in the closed state.

5.4.2.2 Rated short-time (symmetrical) withstand current duration

The rated short-time (symmetrical) withstand current duration is the maximum duration that the switch shall be required to carry rated short-time (symmetrical) withstand current while in the closed state.

5.4.3 Rated fault-making current

The rated fault-making current is the maximum rms power-frequency current, expressed in symmetrical amperes, that the switch shall be required to make and carry at its rated maximum voltage for a specified duration. The switch shall have the related ability to make and carry the asymmetrical current (based on an approximate *X/R* of 17 at 60 Hz with a peak current of 2.6 times the symmetrical fault-making current) associated with the symmetrical fault-making current.

Only switches having a closing speed that is independent of operating personnel can have a fault-making current rating. Switches having a closing speed that is dependent on operating personnel may have a fault-making current capability, which indicates that successful circuit closing is dependent upon proper operation of the switch. Nameplates of switches with a fault-making current capability shall have a caution that references the switch's instruction manual and indicates that successful circuit closing is dependent upon proper operation of the switch.

5.4.4 Rated switching abilities

The following ratings and abilities are common duties associated with switches. To be classified as an interrupter switch, the switch must be rated for at least one of the duties described in 5.4.4.1 through 5.4.4.6, but need not be rated for all of them.

The ability to make a switching current does not imply the ability to fault-close. The ability to fault-close is explicitly determined by a rated fault-making current.

The rated switching abilities are established under the conditions prevalent in non-effectively grounded systems. Any of the ratings can be modified to apply to systems with grounded sources and loads only (where the system on both sides of the switch is grounded); but, in such cases, the words "for systems with grounded sources and loads only" shall appear with the rating.

5.4.4.1 Rated load-switching current

The rated load-switching current is the maximum rms symmetrical power-frequency load current flowing in a circuit that the switch shall be required to make and interrupt at its rated maximum voltage.

5.4.4.2 Rated loop-switching currents

5.4.4.2.1 Rated line or cable loop-switching current

The rated line or cable loop-switching current is the maximum rms symmetrical power-frequency circulating current flowing in a line or cable formed loop circuit that the switch shall be required to make and interrupt at its rated loop-switching voltage.

5.4.4.2.2 Rated parallel transformer loop-switching current

The rated parallel transformer loop-switching current is the maximum rms symmetrical power-frequency circulating current flowing between adjacent parallel transformers that the switch shall be required to make and interrupt at its rated loop-switching voltage.

5.4.4.3 Rated line-charging switching current

The rated line-charging switching current is the maximum rms symmetrical power-frequency charging current flowing into an unloaded line that the switch shall be required to make and interrupt at its rated maximum voltage.

NOTE—The making current will include a transient that has a magnitude that is much higher than that of the rated line-charging switching current.

5.4.4.4 Rated cable-charging switching current

The rated cable-charging switching current is the maximum rms symmetrical charging current flowing into an unloaded cable that the switch shall be required to make and interrupt at its rated maximum voltage.

NOTE—The making current will include a transient that has a magnitude that is much higher than that of the rated cable-charging switching current.

5.4.4.5 Rated unloaded transformer switching current

The rated unloaded transformer switching current is the maximum transformer exciting current that the switch shall be required to make and interrupt at its rated maximum voltage. The current is expressed in rms symmetrical amperes. Optionally, the rating may be expressed as the maximum transformer size associated with the exciting current that can be switched.

NOTE—The making current may include a transient current several orders of magnitude larger than that of the rated unloaded transformer switching current.

5.4.4.6 Rated shunt capacitor bank-switching current

The rated shunt capacitor bank-switching current is the maximum rms symmetrical power-frequency capacitor bank current that the switch shall be required to make and interrupt at its rated maximum voltage within its rated differential capacitance voltage. Filter bank-switching requires special consideration and is not currently covered by this document. The capacitive switching current rating has two associated ratings. They are as follows:

a) *Rated peak capacitive inrush current.* Determines the switch's suitability for switching back-to-back applications.

b) *Rated shunt capacitor bank switching endurance.* Determines the switch's suitability for long-term repetitive switching of capacitors.

The capacitive switching current rating also has a class of rating. Class of shunt capacitor bank-switching current ratings are Class A, B, and C, as defined by differences in the specified test procedure in 8.3.2.6. Class A is the most severe with respect to restriking, Class B is somewhat less severe, and Class C has no test criteria directed at restrikes.

Grounded systems have lower transient recovery voltage requirements. Switches rated "systems with grounded sources and loads only" may not be used in non-grounded systems.

The harmonic content of the rated switching current shall be <10% and should cause no extraneous current zeros.

5.4.4.6.1 Rated peak capacitive inrush current

The rated peak capacitive inrush current is the maximum instantaneous value of transient inrush current that the switch shall be required to make when energizing either single or parallel capacitor banks. (See Figure 10 and Figure 11.)

NOTE—Expected maximum ratios of (rated peak capacitive inrush current) / (rated capacitive switching current) are in the range of 200 for back-to-back capacitors. For single capacitors, the ratio is normally <20.

5.4.4.6.2 Shunt capacitor switching endurance

The shunt capacitor switching endurance is the number of shunt capacitor switching operations that the switch shall be capable of successfully performing while maintained per the manufacturer's instructions.

5.5 Rated ice breaking ability

The rated ice breaking ability is the maximum thickness of ice, as defined by the ice loading test of Clause 8, under which the switch shall be required to successfully open or close.

5.6 Rated control voltage

The rated control voltage is the nominal voltage for which a power-operated mechanism is designed to operate.

5.7 Rated mechanical operations

The rated mechanical operations is the minimum number of mechanical operating cycles that a switch shall be required to perform without requiring maintenance or adjustment. An operating cycle shall be one close operation and one open operation.

5.8 Rated mechanical terminal load

The rated mechanical terminal load is the static force, (equivalent to an external mechanical load) applied at each terminal in specified directions, that a switch shall withstand while stationary and during operation.

5.9 Visible corona-free voltage

The visible corona-free voltage is the line-to-ground voltage at which there is an onset of visible plumes or spikes under dark conditions. (See IEEE Std C37.34.)

5.10 Radio-influence voltage limit

The radio-influence voltage limit is the maximum allowable radio-influence voltage (at a specified detection frequency and at a specified distance) produced by a switch when energized at a specified voltage at rated power frequency.

5.11 Partial discharge limits

This item is currently under study and is intended to appear in a subsequent revision to this document.

6. Preferred ratings

Preferred ratings for outdoor, indoor, and enclosed switches are given in referenced standards (see 6.1, 6.2, and 6.3). Where the referenced standard does not specify a preferred rating, the preferred rating given in 6.4, if appropriate, shall apply.

The ratings designated in this standard and in referenced standards are preferred and are not considered restrictive. Non-preferred ratings based on performance are acceptable, under the provisions of this standard, when accepted by the equipment user.

6.1 Preferred ratings—Outdoor switches

Preferred ratings for outdoor switches are given in ANSI C37.32.

6.2 Preferred ratings—Indoor switches

6.2.1 General

Preferred ratings for indoor switches are given in ANSI C37.32.

6.2.2 For metal-enclosed switchgear

Preferred ratings for indoor ac medium voltage switches to be used in metal-enclosed switchgear are given in ANSI C37.22.

6.3 Preferred ratings—Enclosed switches

6.3.1 For metal-enclosed switchgear

Preferred ratings for enclosed switches to be used in metal-enclosed switchgear are given in ANSI C37.22.

6.3.2 For manually operated subsurface load interrupting switchgear

Preferred ratings for enclosed switches to be used in manually operated subsurface load interrupting switchgear are given in IEEE Std C37.74.

6.3.3 For padmounted fused switchgear

Preferred ratings for enclosed switches to be used in padmounted fused switchgear are given in IEEE Std C37.74.

6.4 Other preferred ratings

6.4.1 Preferred rated power frequency

The preferred rated power frequency of interrupter switches shall be 60 Hz.

6.4.2 Rated loop-switching voltage

The preferred rated loop-switching voltage is 20% of the rated maximum voltage.

6.4.3 Rated differential capacitance voltage range

The preferred limits for the differential capacitance voltage range are

a) 100 V for the lower limit

b) 4% of rated maximum voltage for the upper limit

7. Construction requirements

7.1 Nameplates

Where there is a single preferred rating, and the rating of the switch matches the preferred rating, inclusion of the rating on the nameplate shall be optional.

For outdoor switches, the nameplates shall be weatherproof and corrosion-proof.

If the switch consists of several independent poles, each pole shall be provided with a nameplate.

7.1.1 Interrupter switch's nameplate

Switches and their operating devices shall be provided with nameplates that are permanently and indelibly marked with the manufacturer's name and address, the year of manufacture, the manufacturer's model or type designation, the rated maximum voltage, and continuous current.

Additional requirements for nameplates may be found in appropriate standards such as:

- IEEE Std C37.20.2
- IEEE Std C37.20.3
- IEEE Std C37.20.4
- IEEE Std C37.30
- IEEE Std C37.74

In addition, any rating, not normally appearing on the nameplate that varies from the associated preferred rating as listed in Clause 6 of this standard shall appear on the nameplate.

Such nameplates shall be permanently and securely fixed in position.

7.1.2 Interrupter-attachment's nameplate

Interrupter attachments shall be supplied with nameplates on each interrupter pole bearing the bold inscription "interrupter" and with an additional mountable nameplate to be added near the operating mechanism. Each nameplate will contain the information listed in Clause 6 of ANSI C37.32, as applicable, as well as any rating, not normally appearing on the nameplate, that varies from the preferred ratings listed in Clause 6 of this standard.

7.1.3 Power-operating mechanism's nameplate

For a power-operating mechanism combined with a switching device, it may be sufficient to use only one combined nameplate. If the operating mechanism is supplied separately, it shall have a separate nameplate.

7.2 Contact position indicator

Interrupter switches shall be provided with a mechanical position indication device unless their operating position (e.g., contact's open or closed position) is self evident from inspection.

7.3 Accessories

Operating mechanisms and switch hooks or sticks shall conform to Clause 11 of ANSI C37.32. Heaters may be specified and included as accessories for operating devices and control cabinets needing humidity and temperature control.

7.4 Instructions

Instruction manuals for interrupter switches shall be supplied with the equipment. These may include directions for inspection, storage, unpacking, assembling, and testing the interrupter switch. Additional information may be contained in maintenance manuals and spare parts lists, which may be available from the manufacturer.

7.5 Terminal pads

The arrangement and size of bolt holes in terminal pads, for field assembled joints when used, shall be in accordance with ANSI C37.32.

8. Test code

Test designs are specified in 8.1 through 8.11. Production tests are specified in 8.12. Conformance and field tests have not been addressed in this document.

The following tests may be performed independently and in any order unless otherwise specified. Testing of switches not in accordance with IEEE Std C37.74 need not be performed on the same switch nor conform to the following sequence. Testing of switches also covered by IEEE Std C37.74 will be done on the same switch and conform to the sequence in IEEE Std C37.74.

NOTE—The user is also referred to other apparatus-specific test documents such as IEEE Std C37.41, ANSI C37.57, and ANSI C37.58.

8.1 Withstand voltage tests

Withstand voltage tests are performed to verify the voltage withstand ability of the switch with specified magnitudes and waveshapes of test voltages applied under specified test conditions. All test voltages are to be corrected to standard atmospheric conditions per IEEE Std 4 and amendment IEEE Std 4a.

For multi-pole switches not mounted on a common base, the manufacturer shall test pole-to-pole withstand at a specified minimum pole-to-pole clearance. As an option, the manufacturer may waive testing pole-to-pole withstand, but must then specify the pole-to-pole clearances given in ANSI C37.32 as the minimum pole-to-pole clearance.

8.1.1 Power-frequency withstand voltage tests

Power-frequency voltage withstand tests should meet the following requirements:

- The power-frequency dry withstand voltage test shall be made in accordance with IEEE Std C37.34.
- The power-frequency wet withstand voltage test shall be made in accordance with IEEE Std C37.34. Water resistivity and rate of precipitation for wet tests shall be made in accordance with IEEE Std 4.
- The power-frequency dew withstand voltage test shall be made in accordance with IEEE Std C37.34. Preparation of the test specimen and mounting arrangement shall be made in accordance with ANSI C29.1.

8.1.2 Lightning-impulse withstand voltage tests

The full wave impulse voltage test shall be made in accordance with IEEE Std C37.34.

8.1.3 Open gap withstand voltage test

The open gap withstand voltage test shall be made in accordance with IEEE Std C37.34, except that withstand voltages across open gaps may be tested at 100%, or 110% as required, of the rated withstand to ground per the rating of the switch.

8.1.4 Switching-impulse withstand voltage tests

The switching-impulse withstand voltage tests shall be made in accordance with IEEE Std C37.34.

8.2 Continuous current tests

Continuous current tests are performed to demonstrate a switch's ability to carry a current equal to its continuous current rating without exceeding temperature limits as specified in 8.2.5.

8.2.1 Mounting

The switch shall be mounted in the usual service position for which it is designed in a closed room substantially free from air currents other than those generated by heat from the switch being tested.

For enclosed switches, the continuous current test should be done in the actual switch enclosure. The smallest enclosure should be used if the switch is intended to be rated for use in multiple enclosures.

8.2.2 Connections

The switch shall be tested with cables or buses of a size corresponding to the rated continuous current of the switch, and connected to the switch terminals by means of typical terminal connectors of corresponding rating. If the cables, buses, or connectors are sized so that they provide a heat-sinking function for the switch terminal, the continuous current rating shall be contingent upon using similar connections in the application. Alternately, the conductors attached to each switch terminal shall be sized to maintain a temperature rise at least equal to the limit of observable temperature rise, at rated continuous current, of the current-carrying terminal parts of the switch under test.

8.2.3 Test procedure

The rated continuous current at rated power frequency shall be applied continuously to all poles of the switch until the temperature becomes stable. If individual poles of a three-pole switch do not affect the temperature rise of the other poles, then testing of a single pole is permitted. The temperature shall be considered stable when, for each point of measurement, three consecutive values of temperature rise (taken at 30-minute intervals) show a maximum variation of one degree, for all readings taken. The switch is judged to have passed the continuous current test if, for all parts of the switch, the observed temperature rise is not greater than the maximum observable temperature rise as defined in 8.2.5. All temperature determinations shall be made as follows in 8.2.3.1 and 8.2.3.2.

8.2.3.1 Method of temperature determination

The measurement of temperature shall be made using devices such as thermocouples, resistance-temperature detectors, or thermometers and controlled to minimize extraneous effects. The accuracy of said units shall be ±1 °C (1.8 °F).

8.2.3.2 Value of ambient temperature during test

The ambient temperature shall not be less than 10 °C (50 °F), nor more than 40 °C (104 °F).

The value of the ambient temperature during these tests shall be taken as that of the air surrounding the switch. For enclosed switches, the value of the ambient temperature during these tests shall be taken as that of the air surrounding the enclosure.

8.2.4 Determination of ambient temperature

The ambient temperature shall be determined by averaging readings from three thermocouples that are each placed 30 cm (12 in) horizontally to the side of the switch or enclosure. In the case of a switch, the vertical placement of the three thermocouples shall be as follows:

— One at the level of the center of the current carrying parts of the switch
— One 30 cm (12 in) above the level of the center of the current carrying parts of the switch
— One 30 cm (12 in) below the level of the center of the current carrying parts of the switch

In the case of an enclosure, the vertical placement of the three thermocouples shall be as follows:

— One 30 cm (12 in) above the ground or floor
— One at the top level of the enclosure
— One at a level midway between the first two

In order to avoid errors due to the time lag between the temperature of the apparatus and the variations in the ambient temperature, all reasonable precautions must be taken to reduce these variations and the errors arising there from. Thus, when the ambient temperature is subject to such variations that error in taking the temperature rise measurement might result, the thermocouple for determining the ambient temperature should be immersed in a suitable liquid (such as oil) in a suitably heavy cup. A convenient form for such an oil cup consists of a metal cylinder with a hole drilled partly through it. This hole is filled with oil. The thermocouple’s response to various rates of temperature change will depend largely upon the size, kind of material, and the mass of the containing cup. It may be further regulated by adjusting the amount of oil in the cup. For large apparatus under test, larger cylinders may be employed as an oil cup. The smallest size of oil cup employed in any case shall consist of a metal cylinder 2.5 cm (1 in) in diameter and 5 cm (2 in) high.

8.2.5 Observable temperature-rise

The observable temperature-rise of any part of the switch is the steady-state temperature-rise above the ambient temperature when the switch under test has reached stability per 8.2.3. The maximum observable temperature-rise is the difference between the appropriate total temperature, as specified in Table 2, and the maximum ambient temperature specified in 4.1 and listed in Column 3 of Table 2.

CAUTION

The temperature-rise limits in Table 2 do not provide for a loadability of 1.22 at 25 °C (77 °F). If a loadability of 1.22 is to be assigned to the switch, the temperature limits of IEEE Std C37.30 shall be used.

Table 2—Total temperature limits for contacts, connections, and insulation[1]

Description of part and dielectric material [2,3,4]	Total temperature (°C)	Temperature-rise over 40 °C ambient (°C)
1. Contacts [5]		
Bare copper and bare copper alloy		
In air	75	35
In SF_6	90	50
In oil	80	40
Silver-coated, nickel-coated, or equivalent		
In air	105	65
In SF_6	105	65
In oil	90	50
Tin-coated		
In air	90	50
In SF_6	105	65
In oil	90	50
2. Connections, bolted or the equivalent [6]		
Bare copper, bare copper, or aluminum alloy		
In air	90	50
In SF_6	100	60
In oil	100	60
Silver-coated, nickel-coated, tin-coated, or equivalent		
In air	125	85
In SF_6	125	85
In oil	100	60
3. All other contacts or connections made of bare metals or coated with other materials [7]		
4. Terminals for bolted connection to external conductors [8, 9]		
Bare	90	50
Silver, nickel, or tin-coated equivalent	105	65
5. Oil for oil switching devices		
Top oil [measured 2.5 cm (1 in) below the surface]	90	50
6. Metal parts acting as springs [10]		
7. Non-energized parts subject to contact by personnel		
Handled by operator	50	10
Accessible to operator	70	30
External surfaces accessible to operator	110	70
8. Insulating material in contact with current carrying parts		
Class 90 insulation	90	50
Class 105 insulation	105	65
Class 130 insulation	130	90
Class 155 insulation	155	115

Description of part and dielectric material [2,3,4]	Total temperature (°C)	Temperature-rise over 40 °C ambient (°C)
Class 180 insulation	180	140
Class 220 insulation	220	180
9. Other current carrying parts		
Copper or copper alloy casting	105	65
Hard-drawn copper parts [11]	80	40
Heat treated aluminum parts	105	65
Woven-wire flexible connectors	75	35

Conditions applicable to Table 2 are below:

— 1. The treatment of total temperature limits for contacts, connections and insulation will conform to the Common Clauses Document, IEEE Std C37.100.1, when it becomes available.

— 2. The same part may belong to several categories as listed in the table. In this case the total temperature limits and temperature-rise limits are the lowest among the relevant categories.

— 3. For vacuum switching devices, the total temperature limits and temperature rise limits are not applicable for parts in vacuum. The remaining parts shall not exceed the limits given in the table.

— 4. Total temperature limits may be restricted by the temperature of surrounding insulating materials not directly in contact with current carrying parts.

— 5. When contact parts have different coatings, the total temperature limit and temperature rise limit shall be those of the part having the lower limits in the table.

— 6. When connection parts have different coatings, the total temperature limits and temperature rise limit shall be the lower of the limits for the different parts as listed in the table.

— 7. When other materials than those given in the table are used, their properties shall be considered in order to determine the total temperature limit and temperature-rise limits.

— 8. The total temperature limits and temperature-rise limits are valid even if the conductor connected to the terminals is bare.

— 9. The temperature of terminals may be limited by the temperature limits of insulated cable, of connectors, or of terminators connected to the terminals.

— 10. The temperature shall not reach a value where the spring force of the material is impaired.

— 11. If annealing will not affect the performance of the switch, the total temperature and temperature rise over a 40°C ambient for copper or copper alloy castings may be used.

8.3 Switching tests

Switching tests are performed to determine the adequacy of the design of a particular type, style, or model of switch or its component parts to meet its assigned switching abilities.

8.3.1 General

The switching abilities shall be stated in terms of

a) The test voltage

b) The test current

c) The test circuit

d) The number of operations

8.3.1.1 Condition of the switch to be tested

The switch shall be new or in good condition.

8.3.1.2 Mounting of switch

The switch shall be mounted in the usual service position for which it is designed. The base, or other normally grounded metal parts, shall be grounded, except as explained in the last paragraph below.

The interrupting ability of a switch that relies on a rapidly increasing external air gap for circuit interruption (such as whip arcing horns) may be dependent on mounting position. In this case, the mounting arrangement should be recorded to assist in the application of the device.

Due consideration shall be given to the choice of source side connections. When the switch is intended for power supply from both sides and the physical arrangement of one side differs from that of the other side, the live side of the test circuit shall be connected so as to represent the most onerous conditions. In case of doubt, some of the operations shall be carried out with the supply connected to one side and the remaining operations with the supply connected to the other side.

If the switch is to be rated for use in enclosures, the tests shall be made in the smallest enclosure for which the switch is intended to be used, OR the tests shall be made with metallic screens placed in the vicinity of the live parts and separated from them by a minimum clearance specified by the manufacturer. The enclosure, or screens, as well as the frame and other normally grounded parts shall be insulated from ground, but connected thereto through a suitable device to indicate any significant current to ground. A fuse consisting of a 5 cm (2 in) long #38 AWG copper wire is sufficient to detect significant current to ground.

8.3.1.3 Single-phase vs. three-phase testing

Interrupting tests on three-pole, gang-operated switches are preferably made three-phase at rated maximum voltage but may be made single-phase. However, the following standards may require three-phase testing:

— IEEE Std C37.20.2

— IEEE Std C37.20.3

— IEEE Std C37.20.4

— IEEE Std C37.74

Test voltages for single-phase tests to establish a three-phase rating are given in Table 3. Test voltages for single-phase tests to establish a rating "for systems with grounded sources and loads only" shall be computed by the formula:

$$\frac{\textbf{rated maximum voltage}}{\sqrt{3}}$$

Single-phase testing to establish a three-phase rating performed on an integrally mounted three-pole switch shall be performed with the non-energized poles grounded.

Interrupting tests on single-pole switches (or single-pole switches combined in a three-pole assembly, but operated pole after pole) shall be performed single-phase at rated maximum voltage.

Table 3 —Test voltages for single-phase tests to establish three-phase ratings

Duty	Single-phase test voltage per unit of rated maximum voltage (unless otherwise noted)
Load-switching	$\frac{1.5}{\sqrt{3}}$
Loop-switching	$\frac{1.5}{\sqrt{3}}$ pu of rated loop-switching voltage
Cable-charging switching Shielded cables, C_1/C_0 = 1.0 (source effectively grounded)	$\frac{1.0}{\sqrt{3}}$
Cable-charging switching Belted cables, (switch non-simultaneity <60°; C_1/C_0 = 2.0)	$\frac{1.1}{\sqrt{3}}$
Cable-charging switching Belted cables, (switch non-simultaneity > 60°; C_1/C_0=2.0)	$\frac{1.29}{\sqrt{3}}$
Line-charging switching (Rated voltage ≤48.3 kV; switch non-simultaneity <60°; C_1/C_0=3.0)	$\frac{1.17}{\sqrt{3}}$
Line-charging switching (Rated voltage ≤48.3 kV; switch non-simultaneity >60°; C_1/C_0=3.0)	$\frac{1.46}{\sqrt{3}}$
Line-charging switching (Rated voltage ≤48.3 kV; switch non-simultaneity <60°; C_1/C_0=1.6)	$\frac{1.08}{\sqrt{3}}$
Line-charging switching (Rated voltage ≤48.3 kV; switch non-simultaneity >60°; C_1/C_0=1.6)	$\frac{1.2}{\sqrt{3}}$
Capacitor bank switching (Switch non-simultaneity <90°)	$\frac{1.25}{\sqrt{3}}$
Capacitor bank switching (Switch non-simultaneity >90° but <210°)	See Table 4
Capacitor bank switching (Switch non-simultaneity >210°)	$\frac{2.05}{\sqrt{3}}$
Unloaded transformer switching	**1.0**

Conditions applicable to Table 3 are shown below:

— 1. C_1/C_0 ratio is the ratio of positive sequence capacitance to zero sequence capacitance.

— 2. Non-simultaneity is the maximum time, for the switch design under test, between the instants that first pole and the last pole break contact and is measured in electrical degrees (360° = 1 cycle).

— 3. Belted cables refer to three-phase cables that share a common dielectric shield (i.e., the three phases do not have individual, grounded shields and the ratio C_1/C_0 is not 1.0).

Table 4—Single-phase test voltages for ungrounded capacitor bank switching for switches with pole non-simultaneity between 90° and 210°

Pole non-simultaneity	Test voltage (per unit of rated maximum voltage)
90°	$\frac{1.25}{\sqrt{3}}$
105°	$\frac{1.33}{\sqrt{3}}$
120°	$\frac{1.43}{\sqrt{3}}$
135°	$\frac{1.55}{\sqrt{3}}$
150°	$\frac{1.68}{\sqrt{3}}$
165°	$\frac{1.81}{\sqrt{3}}$
180°	$\frac{1.93}{\sqrt{3}}$
195°	$\frac{2.02}{\sqrt{3}}$
210°	$\frac{2.05}{\sqrt{3}}$

8.3.1.4 Operating mode

Tests shall be made on a close/open duty cycle. An unspecified time may be allowed to elapse between making the circuit and breaking it. The switch may be allowed an unspecified time to cool between operations.

Switches with manual operation may be operated by remote control or power operating means, provided that an operating speed equivalent to that of the manual operator is obtained.

If the switch is power-operated, the switch operating device shall be operated in the manner specified by the manufacturer. In particular, if the switch is electrically, hydraulically, or pneumatically operated, and if the switch's performance is affected by the operating voltage or fluid pressure, it shall be operated at

— Nominal voltage or fluid pressure for 60% of all operations of each applicable duty of Table 5

— Minimum voltage or fluid pressure for 20% of all operations of each applicable duty of Table 5

— Maximum voltage or fluid pressure for 20% of all operations of each applicable duty of Table 5

The provisions for operating under various voltages or fluid pressures do not apply to switches with manual operation that are operated by power operating means for testing purposes only.

8.3.1.5 Frequency

The frequency of the supply voltage shall be the rated power frequency of the switch being tested ±2%. However, for convenience of testing, some deviations from the above tolerance are allowable, for example, when switches rated at 60 Hz are tested at 50 Hz and vice versa. Testing at frequencies outside the specified tolerance shall be allowed only if:

a) It can be shown that the characteristic being tested is independent of frequency over the range of frequencies between the rated power frequency and the test frequency, or

b) The testing is done at a more onerous frequency.

In either case, test frequency shall not be more than 20% away from the rated frequency.

NOTE—An example of item a), above, is continuous current tests, which can be run at either 50 Hz or 60 Hz to verify a rating at either frequency. An example of item b), above, is testing for a Class A or Class B shunt capacitor bank switching current rating at 60 Hz (which is more onerous than at 50 Hz) to demonstrate a 50 Hz rating as well as the 60 Hz rating.

8.3.1.6 Test current

The current to be interrupted shall be symmetrical with negligible dc offset. The contacts of the switch shall not be separated until transient currents, due to the making of the circuit, have subsided.

For three-phase tests, the current is the average rms value of the currents interrupted in all poles. The difference between the average of these currents and the values obtained in each pole shall not exceed 10% of the average value.

The test current shall be equal to or greater than the rated value. Exceptions are stated in Table 5.

8.3.1.7 Power-frequency test voltage

The power-frequency test voltage is the average of the phase-to-phase voltages, and shall be measured in the interval between 1 cycle and 1 1/2 cycle after the final phase arc-extinction. An exception is made for capacitive-switching, where the power-frequency test voltage is measured immediately before opening the contacts.

The test voltage in the case of three-phase tests shall be equal to or greater than the rated maximum voltage of the switch, except for tests with closed loop breaking currents for which the test voltage shall be the rated loop-switching voltage. Test voltages for single-phase tests are given in Table 3 and Table 4. The three-phase voltages shall not vary more than ±10% of the average value.

The rated power-frequency test voltage shall be maintained for at least 0.1 s after arc extinction.

8.3.1.8 Test sequence

Switches rated for two or more of the duties outlined in Table 5 are likely to be called upon to switch these duties randomly throughout their life. All tests outlined in Table 5, for which ratings are desired, are to be performed on the same switch and in any order except that cable-charging switching, line-charging switching, and unloaded transformer switching shall be performed in any order after load-switching and loop-switching tests. The complete set of rated test duties need not, however, be performed for each design modification of a previously certified switch design. To assure that the overall switch performance has not been adversely affected as a result of design modification, the manufacturer shall certify that the modified switch will pass all omitted switching tests. Test duties for which the switch will not be rated shall be skipped. Capacitor bank current switching tests are specifically not part of the sequence outlined in Table 5. Maintenance that could be expected to enhance subsequent interrupting test results during the sequential testing shall not be performed on the switch. Such maintenance may be, but is not limited to, replacing, filtering, or reconditioning the insulation medium or repairing the current-carrying contacts. Equipment repairs may be made where it can be demonstrated that such repairs would not influence the cumulative conditioning effects of previous tests in the design test sequence.

The number of operations specified in Table 5 are meant only to test the ability of the switch to interrupt the specified duty. If a switch is to be rated for an extended number of operations, a new switch may be used in a separate test to confirm the extended number of operations.

Table 5—Test duties

Test type	Number of operations	Current
Load-switching	10	100% rated load
Loop-switching	10	100% rated loop
5% load-switching	20	5% rated load
Unloaded transformer switching (may be waived under the conditions of 8.3.2.5)	20	100% rated unloaded transformer
Cable-charging switching	20	100% rated cable-charging
Line-charging switching	20	100% rated line-charging

8.3.1.9 Unit testing

Interrupting switches may be constructed with similar interrupter units connected in series and actuated in tandem. Consistent with the allowance for design testing of interrupter units in IEEE Std C37.09 and discussed in the clause entitled "Conditions Which Make Unit Testing Possible" of the document, interrupter units of interrupter switches may be tested to provide assurance of the proper functioning of higher voltage rated devices made up of two or more effectively identical series units.

As instructed in IEEE Std C37.09, when all units are not identical, tests may be made on each type of unit to the most severe recovery voltage that would be imposed on any unit of that type.

Units are operated in series with voltage division determined by the impedance of each unit at the instant of greatest recovery stress. The unit stress may be a function of the following:

a) Nature of the units
   — The relative unit impedance
   — Contamination
b) Simultaneity of operation
c) Supply of the arc-extinguishing medium
d) Exhaust conditions in the insulation system of the switch
e) Post arc conductivity

Switching surge dielectric tests of the complete interrupter are used to verify the satisfactory voltage division of the interrupter switch as inherently provided under condition a) above. The surge test voltage is applied with the interrupter switch positioned as though it were performing an interruption but mechanically stopped at the position of current interruption. The applied surge voltage should exceed the maximum recovery voltage requirement for the interrupter switch pole.

Simultaneity of operation is determined by timing tests of the complete interrupter switch. These tests are taken after completion of the mechanical endurance test, with consideration for the effects of magnetic forces and arc plasma pressure present during both an interruption and the making of a circuit. The synchronization of complete interrupter assemblies is controlled appropriately for the type of unit under test so as to demonstrate control of reignition and restrike tendencies as the design intends.

The supply of arc extinguishing media and the possible exhaust of the interrupter is considered and simulated for dielectric integrity during both an interruption and the making of a circuit. These considerations are made for all possible terminal voltages to be experienced by the switch.

Post arc conductivity is monitored in unit testing for consideration of the effect it may have on voltage division between units.

Unit testing is performed with a single-phase circuit and with appropriate transient recovery voltage and current that produces or exceeds the maximum electromechanical stress on an operating unit as may be experienced in the complete interrupter. The range of performance must be demonstrated for the rated duties, including the operating life.

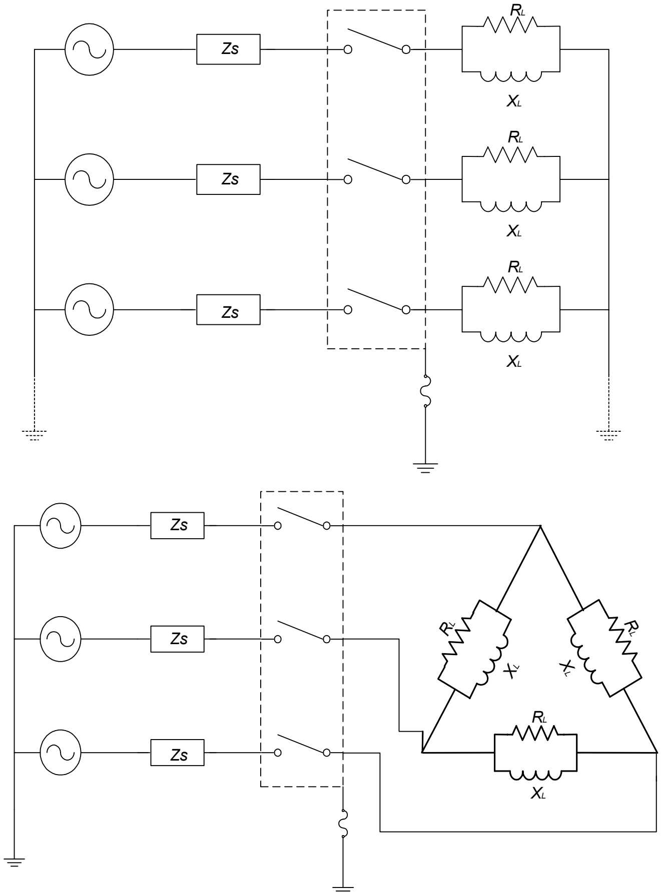
8.3.2 Test duties

8.3.2.1 Load-switching tests

Making and breaking operations shall be randomly timed. For three-phase, group-operated switches, the tests shall be made at the rated maximum voltage of the switch on a three-phase circuit with a parallel-connected load having a power factor between 1.0 and 0.7 lagging (except as noted in next paragraph), using one of the circuits shown in Figure 1. For single-phase or three-phase non-gang-operated switches, the test shall be made at the voltage given in Table 3 on a single-phase circuit with a parallel-connected load having a power factor between 1.0 and 0.7 lagging (except as noted in next paragraph), using the circuit shown in Figure 2.

Testing at lower power factors is allowed if the resulting transient recovery voltage (TRV) is more severe than that specified. (See Annex B.)

For rated current tests, the test current shall be the rated current –0, +10%. For lower than rated current tests, the source impedance (Z_s) and TRV setting components shall be the same as for the 100% load tests. For lower than rated current tests, a tolerance of ±10% is allowed on the test current.



X_s/R_s = under consideration $\quad Z_s = 10\% \text{ to } 20\% \dfrac{(\text{Rated maximum voltage})}{\sqrt{3}(\text{Rated load switching current})}$

Figure 1—Three-phase load current-switching test circuit[7]

Conditions applicable to Figure 1 are shown below:

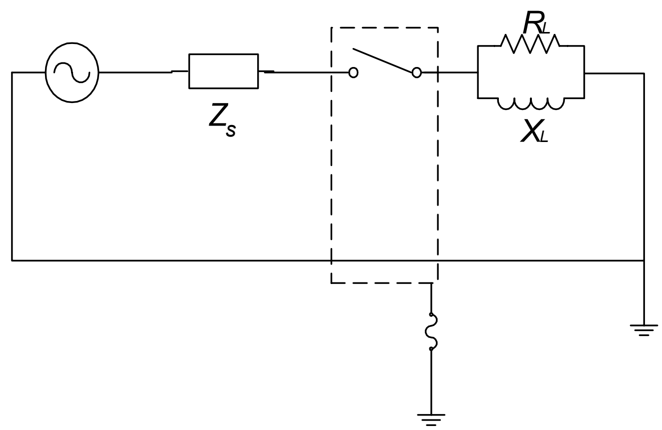
— 1. See 8.3.1.2 for grounding of the switch frame, base or screens.

— 2. For rated maximum voltage less than 242 kV, either the neutral of the source or the neutral of the load may be grounded, not both.

— 3. Once calculated and set for a specific test series, Z_s remains the same for the reduced load-switching current test.

— 4. TRV: per Figure 3 and Table 6.

[7] The source side impedance X_s/R_s is under consideration and is expected to be specified in the next update of this standard. IEEE Std C37.74-2002 specifies an X_s/R_s of 5 to 7 and IEC 60265-1 and IEC 60265-2 specify an X_s/R_s of 5 or higher.



X_s/R_s = under consideration

$$Z_s = 10\% \text{ to } 20\% \frac{(\text{Rated maximum voltage})}{\sqrt{3}(\text{Rated load switching current})}$$

Figure 2—Single-phase load current-switching test circuit[8]

Conditions applicable to Figure 2 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base or screens.

— 2. Once calculated and set for a specific test series, Z_s remains the same for the reduced load-switching current test.

— 3 TRV: per Figure 3 and Table 6.

[8] The source side impedance X_s/R_s is under consideration and is expected to be specified in the next update of this standard. IEEE Std C37.74-2002 specifies an X_s/R_s of 5 to 7 and IEC 60265-1 and IEC 60265-2 specify an X_s/R_s of 5 or higher.

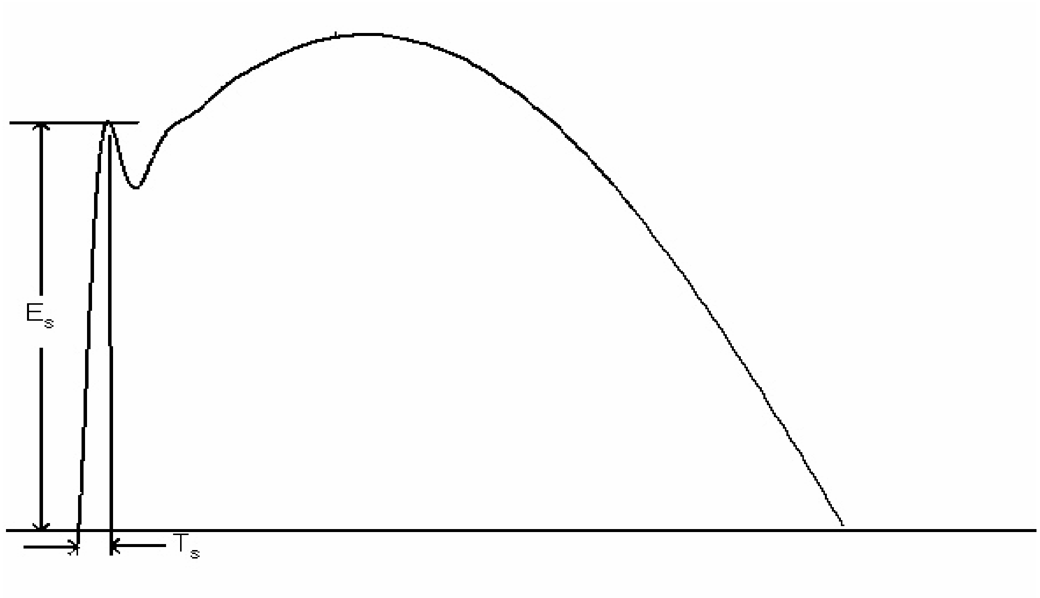


Figure 3—Inherent total TRV for rated load-switching current tests

Table 6—Inherent total TRV parameters for rated load-switching current test

Rated maximum voltage (kV)	Minimum peak TRV E_s (kV)[1, 3, 4]	Maximum time-to-peak T_s (μs)[2, 4]
4.8	1.04	75
8.25	1.9	110
15.0	3.9	175
15.5	4.0	180
25.8	7.2	280
27	7.6	290
38	13	310
48.3	18	550
72.5	15	33
121	25	47
145	30	52
169	35	59
242	34	77
362	50	95
550	76	115
800	110	135

Conditions applicable to Table 6 are shown below:

— 1. E_s values for distribution voltages (up to 48.3 kV) are based on: 10% source; 1.5 amplitude factor; and a 1.5 phase factor.

— 2. Time-to-peak values are based on the load-side TRV and source TRV frequencies from IEEE Std C37.41-1994 [B10], Table 3, which are indicative of substation TRVs with the system highly interconnected (note breaker TRV frequencies are based on a last device to clear and represent station TRVs with the system under abnormal conditions).

— 3. For transmission voltages (greater than 48.3 kV), the TRV parameters are based on IEC 60265-2 (1988-03) [B4], modified to yield time-to-peak values rather than the IEC T3 values.

— 4. Interpolation for other rated voltages is permitted.

8.3.2.2 Loop-switching Tests

The switch shall be capable of making and interrupting all loop currents up to and including its rated loop-switching current. Making and breaking operations shall be randomly timed. For three-phase gang-operated switches, the tests shall be made at rated loop-switching voltage of the switch on a three-phase circuit with a lagging power factor of less than 20%, using the circuit shown in Figure 4. For single-phase or three-phase non-gang-operated switches, the test shall be made at rated loop-switching voltage of the switch on a single-phase circuit with a lagging power factor of less than 30%, using the circuit shown in Figure 5.

Testing with a load-switching circuit (Figure 1 or Figure 2) that utilizes a 20% source impedance may be substituted for the loop-switching test.

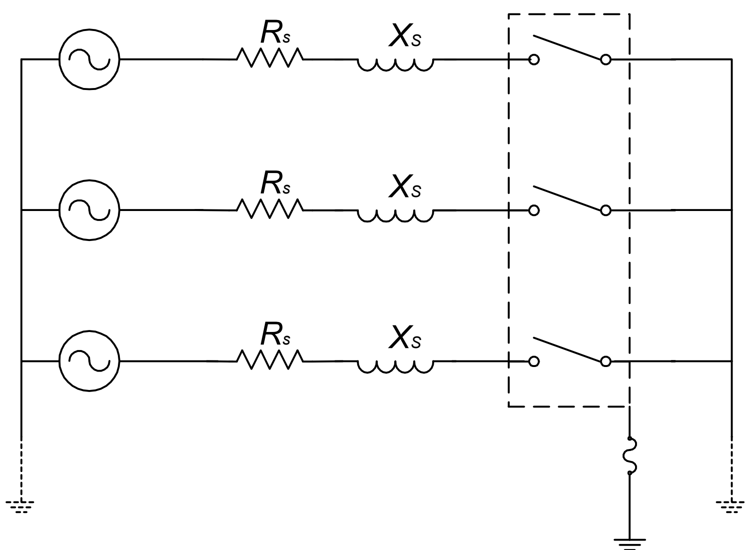


Figure 4—Three-phase loop current switching test circuit

Conditions applicable to Figure 4 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.

— 2. For rated maximum voltage rated less than 242 kV, either the neutral of the source or the neutral of the load may be grounded, but not both.

— 3. Part or all of the source impedance, R_s and X_s may appear on either side of the switch.

— 4. TRV per Figure 6.

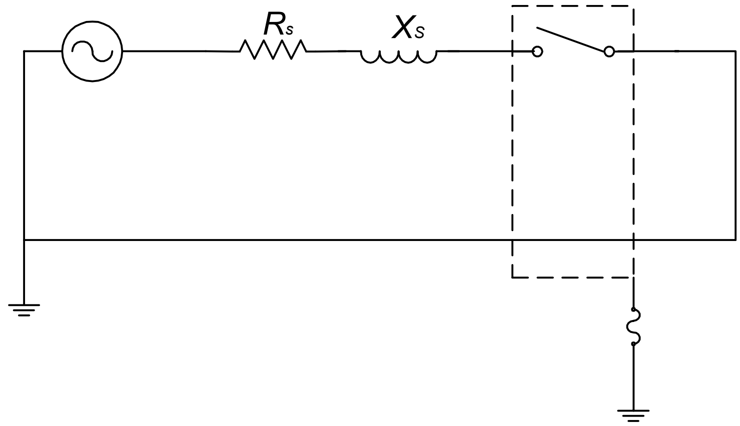


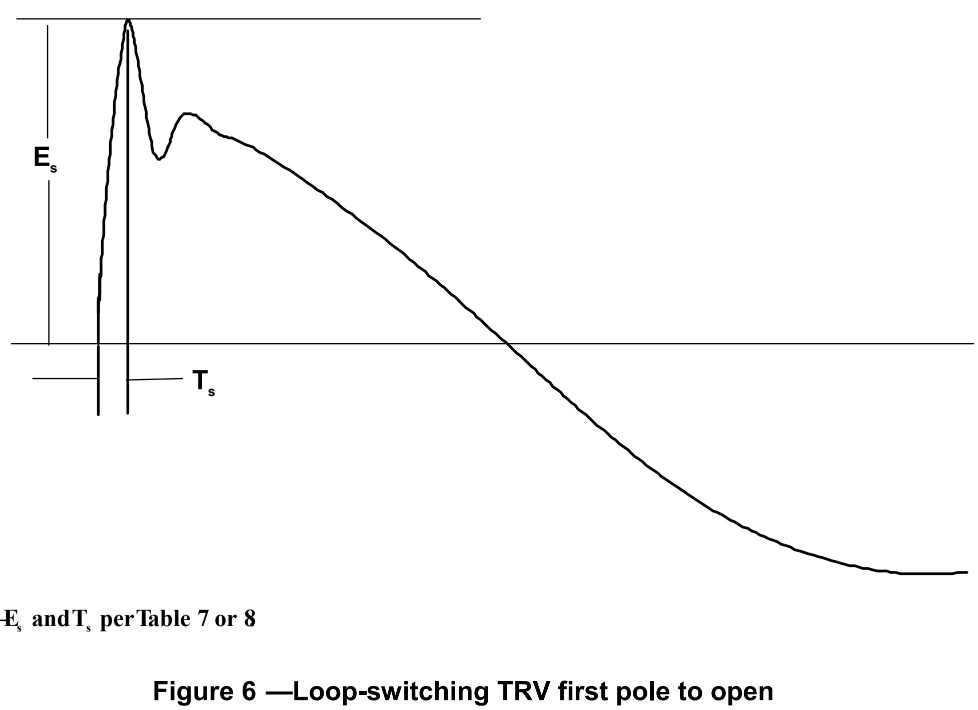
Figure 5—Single-phase loop current switching test circuit

Conditions applicable to Figure 5 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.

— 2. Part or all of the source impedance, R_s and X_s may appear on either side of the switch.

— 3. TRV per Figure 6.



NOTE—E_s and T_s per Table 7 or 8

Figure 6 —Loop-switching TRV first pole to open

8.3.2.2.1 Line or cable loop-switching

For the line or cable loop-switching test, the transient recovery voltage shall be equal to or greater than that specified in Table 7.

Table 7—TRV parameters for line or cable loop-switching

Rated voltage (kV)[3]	**Minimum peak TRV, E_s (kV)**[1, 4]	**Maximum time-to-peak, T_s (μs)**[2, 4]
4.76	1.7	120
8.25	2.9	150
15.0	5.1	211
15.5	5.3	215
25.8	8.9	285
27	9.3	295
38	13	335
48.3	17	370
Rated voltage (kV)	**Minimum peak TRV, E_s (kV)**	**Minimum time-to-peak factor, K_1**[9] **kV/(kA-μs)**
72.5	29	0.267
121	48	0.267
145	57	0.267
169	66	0.267
242	95	0.267
362	107	0.205
550	165	0.205
800	240	0.205

Conditions applicable to Table 7 are shown below:

— 1. E_s values for distribution voltages are based on a 20% recovery voltage, a 1.4 amplitude factor; and a 1.5 phase factor.

— 2. The time-to-peak values are based on TRV frequencies IEEE Std C37.41-1994 [B10], Table 6 and are representative of TRVs on distribution systems, away from substations.

— 3. Values for transmission voltages are based on IEC 60265-2 (1988-03) [B4], modified to yield time-to-peak values rather than the IEC T3 values.

— 4. Interpolation for other rated voltages is permitted.

[9] $T_s = \frac{E_s}{K_1 \times I}$

8.3.2.2.2 Parallel transformer loop-switching

For the parallel transformer loop-switching test, the transient recovery voltage shall be equal to or greater than that specified in Table 8.

Table 8—TRV parameters for parallel transformer loop-switching

Rated voltage (kV)	Minimum peak TRV, E_s (kV)[1, 3]	Maximum time-to-peak factor, K_2[10] (μs) [2, 3]
4.76	0.8	0.27
8.25	1.3	0.35
15.0	2.3	0.48
15.5	2.4	0.49
25.8	4.0	0.62
27	4.2	0.64
38	5.9	0.76
48.3	7.5	0.87
Rated voltage (kV)	**Minimum peak TRV, E_s (kV)**	**Maximum time-to-peak factor, K_3[11] (μs)**
72.5	11.5	1.05
121	19	1.35
145	23	1.48
169	27	1.60
242	26	1.91
362	38	2.34
550	58	2.88
800	84	3.48

Conditions applicable to Table 8 are shown below:

— 1. E_s values are based on a 1.7 amplitude factor; a 1.5 phase factor for non-grounded systems below 242 kV or a 1.0 phase factor for systems with grounded sources and loads at or above 242 kV; and a transformer impedance of 15% based on its forced cooling rating.

— 2. Time-to-peak factor is based on TRV frequencies obtained by low voltage current-injection of transformers (see Harner, Rodriguez [B3]).

— 3. Interpolation for other rated voltages is permitted.

---

10 $$T_s = K_2 \times \sqrt{\frac{1480 + 1187 \times I}{13.3 \times I}}$$

11 $$T_s = K_3 \times \sqrt{\frac{1650 + 2240 \times I}{13.3 \times I}}$$

8.3.2.3 Cable-charging switching tests

The switch shall be capable of making and interrupting cable-charging currents up to and including its cable-charging switching current rating. Making and breaking operations shall be randomly timed. For three-phase gang-operated switches, the tests shall be made at rated maximum voltage of the switch on a three-phase circuit with a leading power factor of less than 20%, using the circuit shown in Figure 7. For single-phase or three-phase non-gang-operated switches, the tests shall be made at the voltage given in Table 3 on a single-phase circuit with a leading power factor of less than 20%, using the circuit shown in Figure 8.

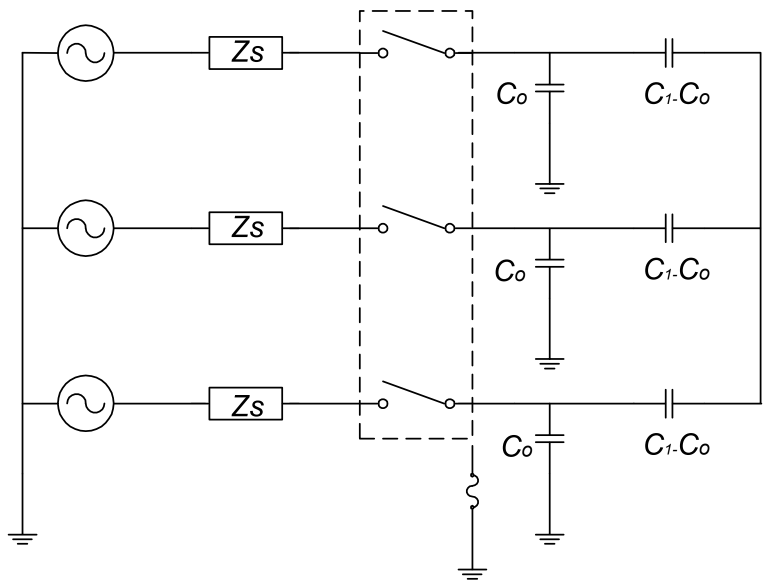


Figure 7—Three- phase test circuit for cable-charging or line-charging switching tests

Conditions applicable to Figure 7 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.

— 2. C_1 is selected to yield the test current; C_0 is determined by C_1/C_0 ratio given in Table 3. For shielded cables, $C_1 = C_0$ and the wye-connected capacitors on the right are not used.

— 3. Z_s shall be less than 10% of the capacitive reactance of C_1.

— 4. For cable-charging tests, R_s may be 10 W or less to simulate, in part, the surge impedance of the cables. For line-charging tests, R_s may be 115 W or less to simulate, in part, the surge impedance of the lines.

— 5. The source TRV is unimportant except in determining restrike-free performance, in which case the differential capacitive voltage of the test circuit shall be less than 1%. See 8.3.2.6.3.

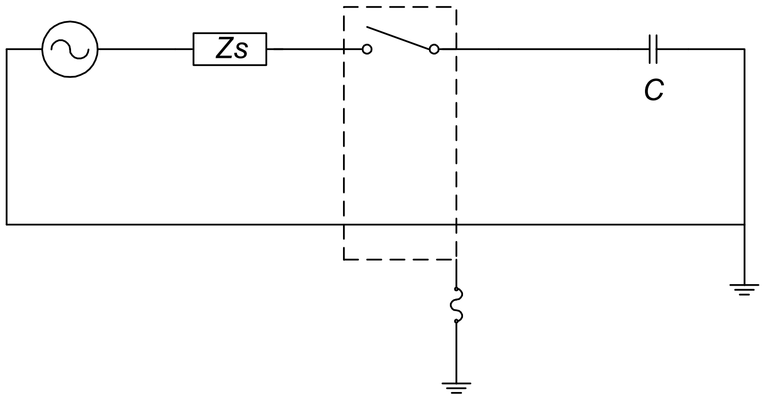


Figure 8—Single-phase test circuit for cable-charging or line-charging switching tests

Conditions applicable to Figure 8 are shown below:

- 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.
- 2. *C* is selected to yield the test current.
- 3. Z_s shall be less than 10% of the capacitive reactance of *C*.
- 4. For cable-charging tests, R_s may be 10 W or less to simulate, in part, the surge impedance of the cables. For line-charging tests, R_s may be 115 W or less to simulate, in part, the surge impedance of the lines.
- 5. The source TRV is unimportant except in determining restrike-free performance, in which case the differential capacitive voltage of the test circuit shall be less than 1%. See 8.3.2.6.3.

8.3.2.4 Line-charging switching tests

The switch shall be capable of making and breaking line-charging currents up to and including its line-charging switching current rating. Making and breaking operations shall be randomly timed. For three-phase gang-operated switches, the tests shall be made at the rated maximum voltage of the switch on a three-phase circuit with a leading power factor of less than 5%, using the circuit shown in Figure 7. For single-phase or three-phase non-gang-operated switches, the tests shall be made at the voltage given in Table 3 of the switch on a single-phase circuit with a leading power factor of less than 5%, using the circuit shown in Figure 8.

8.3.2.5 Unloaded transformer switching tests

It is assumed that a switch that has passed the load-switching tests specified in Table 5 will also interrupt unloaded transformer magnetizing currents corresponding to a distribution transformer, rated 38 kV or less and also rated 2500 kVA or less; therefore, no tests are specified.

For larger transformers, transmission class transformers, or switches that have not passed the load-switching tests of Table 5, the test shall consist of switching an actual transformer, excited at its rated voltage. As an alternate, one of the circuits shown in Figure 9 may be used. The load in the circuits of Figure 9 can be composed of resistance connected in parallel with a reactance of such magnitude as to produce the required test current at rated maximum voltage at a power factor between 5% and 10% lagging. Parallel reactance and resistance circuits present a more onerous interrupting duty than unloaded transformer magnetizing circuits. The ability to interrupt parallel reactance and resistance circuits can be used to ensure the ability to de-energize unloaded transformers; however, the inability to interrupt parallel reactance and resistance circuits does not imply the inability to de-energize unloaded transformers. The circuits of Figure 9, however, do not provide the proper inrush current for demonstrating making ability. If not switching an actual transformer, the ability to make unloaded transformer currents should be demonstrated utilizing a circuit shown in Figure 4 or Figure 5, where

a) The circuit voltage is the rated maximum voltage of the switch
b) X_s and R_s are adjusted to limit the current to 5000 times the rated unloaded transformer switching current for transformers rated 500 kVA or less, or 3000 times the rated unloaded transformer switching current for transformers rated above 500 kVA
c) The TRV is unimportant and may be other than that specified in Figure 6

NOTE—The inrush current peak is assumed to be approximately half of the short-circuit current of the transformer, which in turn can be as high as:

(rated unloaded transformer switching current) / (pu transformer impedance x pu transformer exciting current).

The factors of 5000 and 3000 above are based on a 0.5% exciting current and 2% impedance for transformers rated 500 kVA or less and a 0.2% exciting current and 8% impedance for transformers rated above 500 kVA.

Single-phase tests may be conducted at the voltage given in Table 3.

The switch shall close and interrupt the required current. Sufficient time shall be allowed after making the circuit to permit transients to subside. Current shall be measured after transients have subsided using an rms responding instrument. Twenty close/open operations shall be performed.

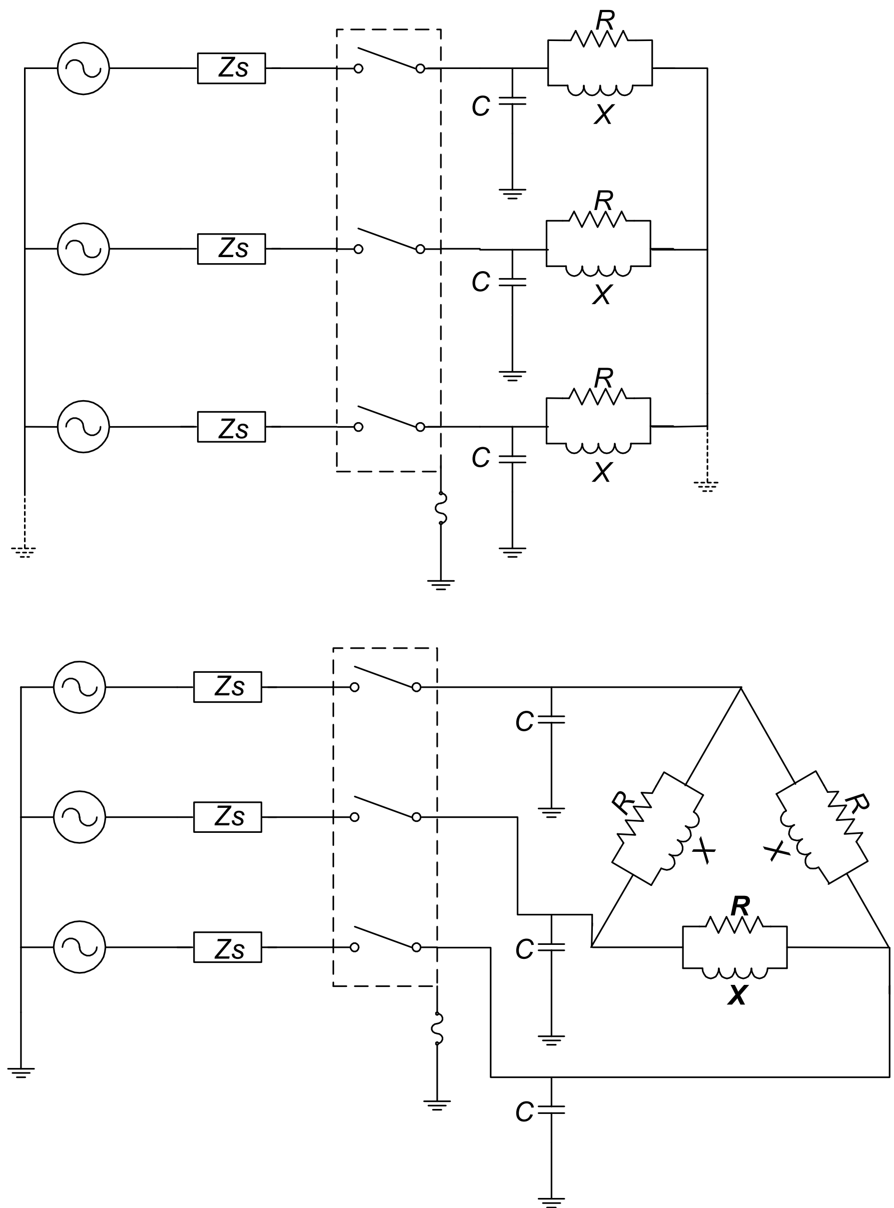


Figure 9—Three-phase alternate test circuits for unloaded transformer switching tests

Conditions applicable to Figure 9 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.

— 2. For rated maximum voltage rated less than 242 kV, either the neutral of the source or the neutral of the load may be grounded, but not both.

— 3. *X* is chosen to establish the current magnitude.

— 4. *C* is chosen to reduce the transient recovery voltage (TRV) frequency to less than 1 kHz (generally 2 nF or more are required). The capacitance, *C*, may be connected to ground as shown, or it may be connected across the inductance, *X*. Note that while a 1 kHz TRV is acceptable for conventional oil insulated transformers, there is some dry-type transformers that may have higher TRV requirements—the subject needs further study and will be addressed in a future revision to this document.

— 5. *R* is chosen to over-damp the TRV.

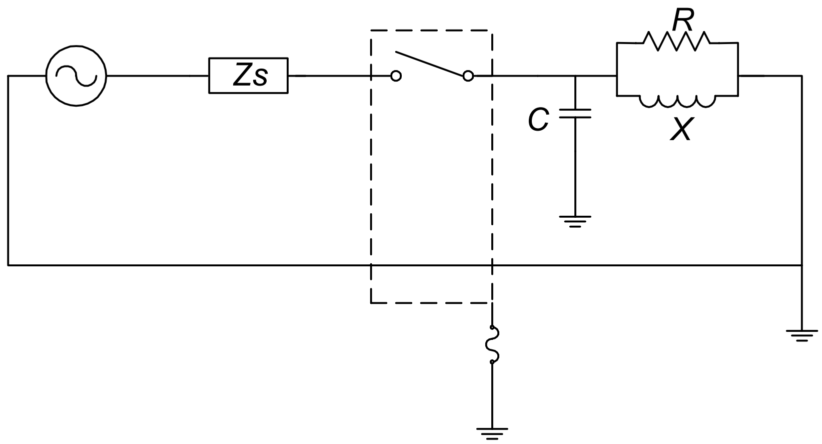


Figure 10—Single-phase alternate test circuit for unloaded transformer switching tests

Conditions applicable to Figure 10 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.

— 2. *X* is chosen to establish the current magnitude.

— 3. *C* is chosen to reduce the transient recovery voltage (TRV) frequency to less than 1 kHz (generally 2 nF or more are required). The capacitance, *C*, may be connected to ground as shown, or it may be connected across the inductance, *X*. Note that while a 1 kHz TRV is acceptable for conventional oil insulated transformers, there is some dry-type transformers that may have higher TRV requirements—the subject needs further study and will be addressed in a future revision to this document.

— 4. *R* is chosen to over-damp the TRV.

8.3.2.6 Shunt capacitor switching tests

8.3.2.6.1 Test circuit

Capacitive current switching tests shall be conducted to demonstrate the shunt capacitance switching current ratings of an interrupter switch. Tests shall be conducted on a single pole of the interrupter switch in a test circuit as shown in Figure 11 and as further described.

As an alternate to single-phase testing, three-phase testing may be conducted with a test circuit as described in Figure 12 at the minimum differential capacitance voltage at rated maximum voltage.

The same switch must be used for all tests without any maintenance or adjustment.

All making operations shall cause the circuit to become energized within 15 electrical degrees of a voltage crest.

Opening operations must be done in 30 degree windows every 30 electrical degrees, i.e., every 30 electrical degrees ±15 degrees. Random timing may be used as long as the required number of opening operations occur in each 30 degree window.

Table 9 lists the required tests.

Table 9—Required shunt capacitor switching tests

% rated capacitive switching current	Number of operations	Number of operations in each 30° window
100	12	1
50	12	1
10	12	1

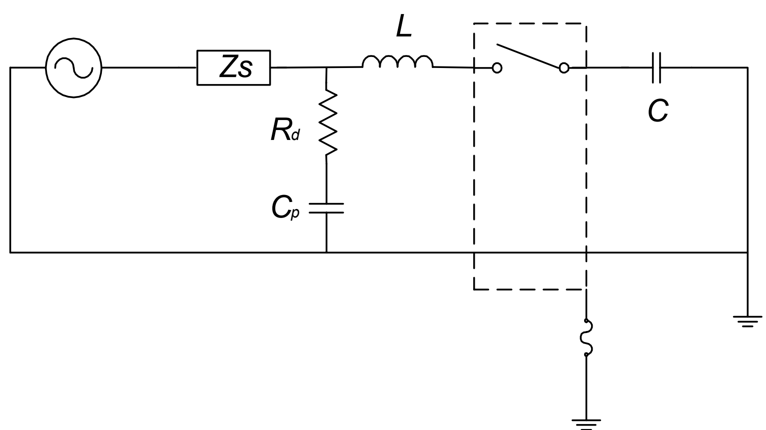


Figure 11—Single-phase test circuit for shunt capacitor switching tests

Conditions applicable to Figure 11 are shown below:

- 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.
- 2. *C* is selected to produce the rated capacitive current.
- 3. C_p is selected along with *L* to produce the rated peak inrush current when the switch closes at the crest with no current limiting elements. Current limiting elements integral to the switch, or controlled point on wave closing are allowed to control actual inrush currents below the prospective values.
- 4. R_d represents the circuit damping.
- 5. The full cycle damping in the circuit, without arc resistance, or circuit modifying switch components shall be no less than:
  - 0.84 if (rated peak capacitive inrush current)/ (rated capacitive switching current) is equal or less than 20, or
  - 0.91 if (rated peak capacitive inrush current)/ (rated capacitive switching current) is higher than 20
- 6. After adjusting the test circuit parameters as above, only the load capacitance may be adjusted for those tests requiring less than rated switched capacitance current.

— 7. The source TRV is unimportant except in determining restrike-free performance, in which case the differential capacitive voltage of the test circuit shall be less than 1%. See 8.3.2.6.3.

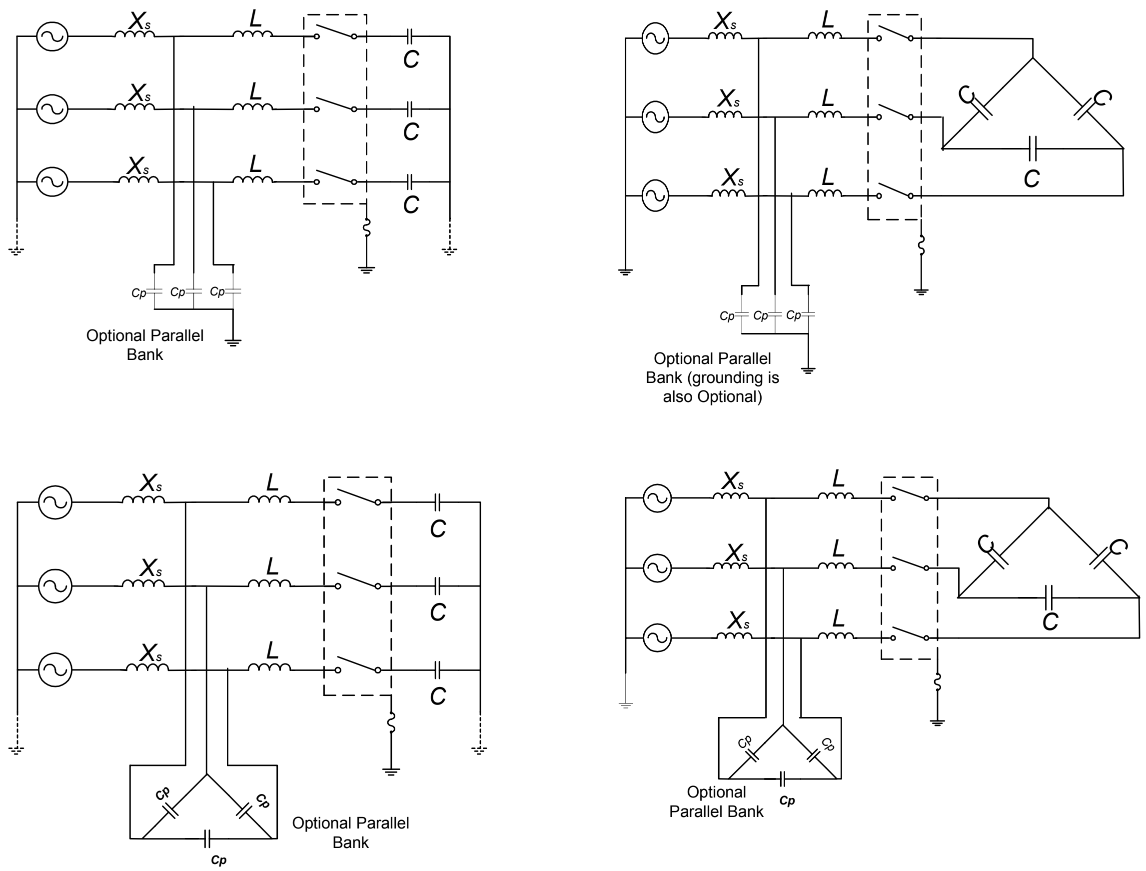


Figure 12—Three-phase test circuits for shunt capacitor switching tests

Conditions applicable to Figure 12 are shown below:

— 1. See 8.3.1.2 for grounding of the switch frame, base, or screens.

— 2. For rated maximum voltage less than 242 kV, either the neutral of the source or the neutral of the load may be grounded, but not both.

— 3. The grounding of the optional capacitance should match that of the load.

— 4. See items 2 through 7 below Figure 11.

8.3.2.6.2 Alternate test circuit for demonstrating the rated peak capacitive inrush current

The test circuits of Figure 11 and Figure 12 are the preferred circuits to be used to demonstrate both the making ratings (rated capacitor peak inrush current) as well as the interrupting related ratings (rated capacitive switching current). However, for a variety of reasons, particularly if the rated peak capacitive inrush current is very large, it may be difficult to demonstrate the rated capacitive current peak transient current inrush with the circuits of Figure 11 and Figure 12. The alternate circuit described by Figure 13 may be used to demonstrate the rated peak capacitive inrush current.

The number of operations for this alternate test circuit shall be 36 operations.

NOTE—If a switch is applied at its rated capacitive inrush current and a restrike occurs on opening, the peak inrush current could be exceeded by a factor of 2.0. Additionally, if the switch could interrupt on transient current zeros, escalating overvoltage and transient currents may lead to switch, capacitor, arrester, or system failure.

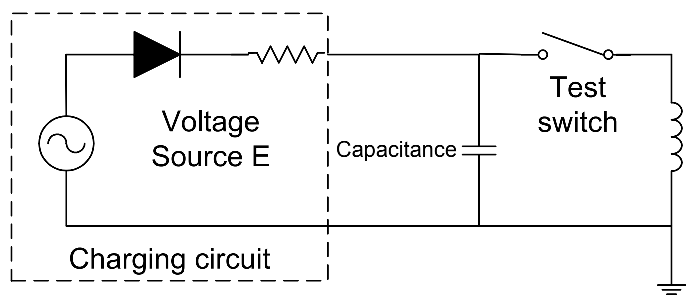


Figure 13—Alternate test circuit for shunt capacitor current making tests

The interrupter switch shall close into the fully charged capacitor through a suitably sized inductor. The capacitor shall be sized to draw the rated capacitance current at rated voltage and frequency. The inductor shall be sized relative to the capacitor to produce rated crest inrush current as follow:

$$L = 0.91 \times \frac{2}{3} \times \frac{E_{rated}}{I_{peak}^2} \times \frac{\sqrt{3} \times I_{rated}}{2 \times \pi \times Freq_{rated}}$$

where:

L is the total discharge inductance in mH,

E_{rated} is the rated voltage of the switch in kV,

I_{rated} is the rated capacitive switching current in A,

I_{peak} is the rated peak capacitive inrush current in kA.

8.3.2.6.3 Class of shunt capacitor bank switching current rating

The capacitive current switching ratings of cable-charging switching, line-charging switching, and shunt capacitor bank switching shall be designated with one of the Classes listed in 8.3.2.6.3.1 through 8.3.2.6.3.3.

The class of shunt capacitor bank switching current rating does not imply restrike-free performance. See Annex C for a treatment of restrike performance.

8.3.2.6.3.1 Class A

A Class A shunt capacitor bank switching current rating requires the completion of one of the following tests, in addition to the capacitive current switching tests, without the switch restriking. The same switch used for the capacitive current switching tests must be used for the additional test (one of the following tests) without any maintenance or adjustment. The test circuit shall be that associated with the capacitive current switching test. The test voltage shall be that utilized by the capacitive current switching test. The differential capacitive voltage of the test circuit shall be less than 1%, and the test current shall be any convenient magnitude between 10% and 100% of the rated capacitive switching current rating. The tests are specified as follows:

a) 920 randomly timed breaking operations shall be performed.

b) The minimum arcing time (for one pole if utilizing a three-phase test) for both polarities of current prior to interruption by the switch shall be determined by a set of any 10 breaking operations, clustered within a 1 ms range of contact opening (relative to the current wave), five of which produce arcing times near the minimum and five of which produce arcing times near the maximum. The minimum arcing time of the set shall be designated the minimum arcing time. Additional breaking operations are performed to accumulate a total of 164 breaking operations each with an arcing time within 0.5 ms of the minimum arcing time. The 164 operations shall be divided evenly between both polarities of current prior to interruption.

8.3.2.6.3.2 Class B

A Class B shunt capacitor bank switching current rating requires the completion of one of the following tests, in addition to the capacitive current switching tests, without the switch restriking. The same switch used for the capacitive current switching tests must be used for the additional test (one of the following tests) without any maintenance or adjustment. The test circuit shall be that associated with the capacitive current switching test. The test voltage shall be that utilized by the capacitive current switching test. The differential capacitive voltage of the test circuit shall be less than 1%, and the test current shall be any convenient magnitude between 10% and 100% of the rated capacitive switching current rating. The tests are specified as follows:

a) 92 timed breaking operations shall be performed.

b) The minimum arcing time (for one pole if utilizing a three-phase test) for both polarities of current prior to interruption by the switch shall be determined by a set of any 10 breaking operations, clustered within a 1 ms range of contact opening (relative to the current wave), five of which produce arcing times near the minimum and five of which produce arcing times near the maximum. The minimum arcing time of the set shall be designated the minimum arcing time. Additional breaking operations are performed to accumulate a total of 16 breaking operations each with an arcing time within 0.5 ms of the minimum arcing time. The 16 operations shall be divided evenly between both polarities of current prior to interruption.

c) Alternately, the test specified in 4.13 of IEEE Std C37.09 may be used.

8.3.2.6.3.3 Class C

A Class C shunt capacitor bank switching current rating is given to switches that do not undergo additional capacitive current switching beyond the testing specified in the capacitive current switching tests.

8.3.3 Condition of the switch during the switching tests

During operation, the switch shall neither show signs of excessive distress nor endanger the operator.

There shall be no outward emission of flame from liquid-filled switches and the gases produced together with the liquid carried with the gases shall be allowed to escape in such a way as not to cause electrical breakdown.

For other types of switches, flame or metallic particles that might impair the insulation level of the switch shall not be projected beyond the boundaries specified by the manufacturer.

8.3.4 Condition of the switch after the switching tests

The switch shall meet the conditions outlined in 8.6.

8.4 Short-time withstand current tests

Short-time withstand current tests are performed to confirm the switch's ability to withstand the magnetic forces (peak current) and the thermal duty (current duration) imposed by a short circuit. If a single test circuit can provide both the rated peak withstand current and the rated short-time (symmetrical) withstand current for the rated short-time (symmetrical) withstand current duration, both tests may be combined. However, the combined test is not a requirement.

8.4.1 Test conditions

The switch to be tested shall be new, or in good condition, and mounted on a rigid supporting structure in the usual service position for which it is designed.

The test may be three-phase or single-phase. However the following standards may require three-phase testing:

- IEEE Std C37.20.2
- IEEE Std C37.20.3
- IEEE Std C37.20.4
- IEEE Std PC37.74

Single-phase testing may be done on two adjacent phases with minimum phase-spacing or on one phase with return conductor located at a distance equal to the minimum phase-spacing; other configurations of conductors, which result in an equivalent force on the switch, may be used.

The conductor connecting the switch to the test circuit shall be representative of the expected service condition. Unless support means for the conductors normally connected to the switch are specified by the manufacturer, the conductors shall be unsupported for a distance of at least the open gap distance of the switch, or the interrupter length, if the switch has no open gap. The terminal connections shall not impose any unrealistic stress on the switch terminals.

The switch phases or phase shall be locked closed in a manner that realistically simulates the controls and locking mechanisms of the switch as it is intended to be used.

8.4.2 Peak withstand current tests

Peak withstand current tests are performed to confirm the ability of the switch to carry its rated peak withstand current.

8.4.2.1 Test procedure

The test shall be made at the rated power frequency + 10% at any voltage that provides the desired current for the required time. Testing at a more onerous frequency, still within a + 20% range, is permissible to establish a rating at more than one rated frequency.

The peak current shall not be less than the rated peak withstand current. The test duration shall not be less than ten cycles. The rms symmetrical component of the current at the tenth cycle shall not be less than the rated peak current divided by 2.6.

For three-phase tests, the symmetrical current in any phase shall not vary from the average of the symmetrical currents in the three-phases by more than 10% of the average.

8.4.2.2 Condition of the switch after the peak withstand current test

The switch shall meet the conditions outlined in 8.6.

8.4.3 Short-time (symmetrical) withstand current test

Short-time (symmetrical) withstand current tests are performed to confirm the ability of the switch to carry its rated short-time (symmetrical) withstand current for a time equal to its rated short-time (symmetrical) withstand current duration (seconds).

8.4.3.1 Test procedure

The test shall be made at the rated power frequency ±10% at any voltage that provides the desired current for the required time.

For practical purposes, the current magnitude and current duration may be adjusted together to provide an integrated heating equivalent to that of the rated short-time (symmetrical) withstand current for the rated short-time (symmetrical) withstand current duration. The test duration, however, shall not be greater than 6 seconds.

8.4.3.1.1 Current magnitude

The rms current shall be not less than the rated short-time (symmetrical) withstand current.

For three-phase tests, the current in any phase shall not vary from the average of the currents in the three phases by more than 10% of the average.

8.4.3.1.2 Current duration

The test current shall be applied for a time not less than the rated short-time (symmetrical) withstand current duration.

8.4.3.2 Condition of the switch after the short-time (symmetrical) withstand current test

The switch shall meet the conditions outlined in 8.6.

8.5 Fault-making current test

Fault-making current tests are performed to confirm the ability of the switch to close and carry a short-time withstand current driven by a voltage up to its rated maximum voltage.

8.5.1 General

The fault-making current ability of a switch shall be stated in terms of the following:

- Applied voltage
- rms symmetrical current
- Speed of operation

8.5.2 Test conditions

The switch shall be mounted in the usual service position for which it is designed. The base, or other normally grounded metal parts, shall be grounded, except as explained for switch to be rated for use in enclosures (see 5th paragraph). The switch operating device shall be operated in the manner specified and in particular, if it is electrically, hydraulically, or pneumatically operated, operations shall be made at minimum voltage or fluid pressure and at maximum voltage or fluid pressure.

Switches with manual operation may be operated by remote control or power operating means, provided that an operating speed equivalent to that of the manual operator is obtained. (See 5.4.3.)

Due consideration shall be given to the choice of source side connections. When the switch is intended for power supply from both sides and the physical arrangement of one side differs from that of the other side, the live side of the test circuit shall be connected to the side that represents the most onerous conditions. In case of doubt, some of the operations shall be carried out with supply connected to one side and the remaining operations with the supply connected to the other side.

Fault-making current tests may be made three-phase (unless otherwise specified) or single-phase. Fault-making current tests on three-pole switches, where the pole-to-pole electromagnetic forces are expected to challenge the mechanical strength of the switch supports (generally switches rated 38 kV or less, or non-air insulated switches at higher voltages), and the poles of which are operated simultaneously, shall be made three-phase.

If the switch is to be rated for use in enclosures, the tests shall be made in the smallest enclosure for which the switch is intended to be used, or the tests shall be made with metallic screens placed in the vicinity of the live parts and separated from them by a minimum clearance specified by the manufacturer. The enclosure, or screens, as well as the frame and other normally grounded parts, shall be insulated from ground but connected thereto through a suitable device to indicate any significant current to ground. A fuse consisting of a 5 cm (2 in) long #38 AWG copper wire is sufficient to detect significant current to ground.

8.5.3 Conditioning of the test sample

The switch shall be conditioned prior to performing the fault-making current test. This shall consist of 10 close/open operations of the switching duty for which the switch has the highest rated current as outlined in 8.3, or the switch may be subjected to the total test sequence as outlined in 8.3.

If it is evident or if it can be proven that the fault-making current is not influenced by conditioning, for testing convenience, the fault-making current test may be made on a new switch of the same type.

8.5.4 Test procedure

8.5.4.1 Frequency

The frequency of the applied voltage shall be the rated power frequency of switch being tested ±2%.

8.5.4.2 Applied voltage for fault-making current test

The applied voltage for the fault-making current test is the rms value of the rated maximum voltage immediately before current flow.

In the case of three-phase tests, the average value of the applied voltages shall not be less than the rated voltage and shall not exceed this value by more than 10%.

The difference between the average value and the applied voltages of each phase shall not exceed 5% of the average value.

For single-phase or three-phase non-gang-operated switches, the applied test voltage shall not be less than the rated voltage of the switch.

8.5.4.3 Current magnitude

The peak fault-making current shall be no less than 2.6 times the rated rms symmetrical fault-making current, and shall appear in an outside pole of a three-pole device when tested with a three-phase circuit. When testing a three-pole device with a single-phase circuit, the return current path shall be positioned such that forces equivalent to those produced with a three-phase circuit are generated in an outside pole.

8.5.4.4 Degree of asymmetry

For three-phase testing, at least one phase shall have peak current of the first major current loop equal to 2.6 times the rated rms symmetrical fault-making current, except as noted below. For single-phase or three-phase non-gang-operated switches, the tests shall be repeated on separate phases until at least one phase experiences a peak current of the first major current loop equal to 2.6 times the rated rms symmetrical fault-making current, except as noted below.

Due to pre-arcing it is not always possible to reach the peak current value; in this case, the current shall be considered satisfactory if the prospective peak current of the test circuit is equal to or greater than 2.6 times the rated rms symmetrical fault-making current.

8.5.4.5 Duration of current flow

The duration of the current flow shall be no less than 10 cycles.

8.5.5 Condition of the switch after the fault-making current test

The switch shall meet the conditions outlined in 8.6.

8.6 Condition of the switch after each test of 8.3, 8.4, and 8.5

During the test, the switch shall have functioned without failure and without maintenance or replacement of parts.

After performing the specified making and breaking test duties, the mechanical function and the insulators of the used switch shall be practically in the same condition as before the tests. The arcing contacts or any other specified renewable parts may be worn. The quality of the oil, used for arc extinction in oil switches, may be impaired and its quantity reduced from the normal level. There may be deposits on insulators caused by the decomposition of the arc extinguishing medium.

The switch shall be capable of operating normally, carrying its rated continuous current without experiencing a thermal run-away. Unless the current tests have consumed the switch’s life, as defined by the switch manufacturer, the switch shall be capable of performing its rated switching duties. The power-frequency dry withstand voltage withstand ability of the used switch shall not be reduced below 80% of the rated power-frequency dry withstand voltage, by deterioration of insulating parts. Visual inspection and no-load operation of the used switch after tests are usually sufficient for checking these requirements. For switches having contact structures not readily visible, a contact resistance check shall be made to determine the switch’s current carrying ability, with a current of at least 10 amperes, dc. The value of contact resistance shall be less than 200% of that before the test.

If there is any doubt as to whether or not the switch has passed the electrical test with respect to any of the above criteria, further testing of the capability that is in doubt shall be made. The additional tests are as follows:

a) A continuous current test with no thermal runaway shall be performed. Thermal runaway means that the temperature does not stabilize and continues to increase as a trend.

b) A suitable interrupting test shall be performed.

c) A rated power-frequency dry withstand voltage test shall be performed at 80% of the rated power-frequency dry withstand voltage to evaluate the insulating ability.

There shall be no indication of significant current to the grounded structure, or screens when fitted, during the tests.

8.7 Ice loading test

Ice loading tests are design tests performed to determine the rated ice breaking ability of outdoor switching equipment.

Under certain circumstances, an ice storm can cause a deposit of ice of such thickness that overhead lines fail, and operation of specific switching equipment is impaired.

The ice loading test is used to demonstrate that the equipment will operate successfully under iced conditions. The procedure for producing controlled coatings of ice (comparable with those encountered in nature) is defined in 8.7.2.4.1.

8.7.1 Ice formations

Ice is produced naturally in two general categories:

a) *Clear ice.* Clear ice results from rain falling through air with a temperature between 0 °C (+32 °F) and –10 °C (+14 °F)

b) *Rime ice.* Rime ice is characterized by a white appearance from the air entrapped during ice formation, forms from rain falling through air with a temperature below –10 °C (+14 °F), or from condensation of atmospheric moisture on cold surfaces

The ice loading test shall be performed with clear ice, which represents the most difficult operating conditions. Since these coatings may form during a period of rain with initial temperatures above freezing, moving parts may be filled with water, which may subsequently freeze.

8.7.2 Test program

One of the following test methods is acceptable:

a) Controlled environment test (indoor laboratory test)

b) Natural environment test (outdoor test)

The type of laboratory must be stated in the test report. Three-pole, group-operated interrupter switches must be tested as complete three-pole assemblies; however, single-pole operated interrupter switches may be tested as complete single-pole assemblies.

8.7.2.1 Switch surface condition

External surfaces shall be free from all traces of oil or grease, since even a thin film of oil or grease will prevent ice from adhering directly to the surface and will affect the test results.

8.7.2.2 Test arrangement

The test for the ice breaking rating shall be performed for both making and breaking operations. The switching equipment shall be tested with representative operating mechanism components, as required for a typical installation in the field. For switches with outdoor insulators, a minimum of one insulator per stack shall be used for the test. In the indoor laboratory, reductions may be made in switch mounting height, insulator height, and phase spacing. Reductions shall be made so that the validity of the test performance is not compromised. In an outdoor environment, reductions may be made in switch mounting height and phase spacing. For EHV switch tests, when the available water spray cannot wet all three-phases at the same time, appropriate modifications of the test conditions are permitted. However, the water spray must be capable of covering at least one entire pole of the switch during the wetting and freezing period.

8.7.2.3 Ice thickness measurement

Test bars, (metal rods or tubes) approximately 2.5 cm (1 in) in diameter and 60 cm (24 in) in length, shall be mounted at each end of the test specimen—with their longitudinal axes horizontal—and placed to receive the same general wetting as the switch under test. For switches with main contacts not at the end of the specimen, additional test bars shall be placed near the contacts. The number of test bars shall provide a fair evaluation of the ice thickness over all parts of the switch, and in no case shall less than one test bar per pole be used. Visual inspection of the ice build-up on the switch shall be consistent with the test bar measurements.

The thickness of the ice shall be determined on the top surface of the test bars by measurement of the depth of saw cuts or drilled holes 15 cm (6 in) from each end of the test bar. The average of the ice thickness shall be equal to or greater than the rated ice breaking ability of the interrupter switch. No measurement shall be less than 83% of this rating.

8.7.2.4 Test conditions

8.7.2.4.1 Controlled environment (indoor laboratory)

The switch shall be completely assembled in a chamber that can be cooled to a temperature of –6 °C (+21°F). The chamber shall be equipped with sprinklers to provide a fine water spray to the entire assembly with general wetting from above.

The water used in the spray shall be cooled to a temperature between 0 °C (32 °F) and 3 °C (37 °F).

During a 1 h wetting period, the chamber ambient temperature shall be held between +1 °C (+33 °F) and +3 °C (+37 °F).

Following the 1 h spray period, the ambient temperature shall be lowered to the range of –10 °C (+14 °F) to –3 °C (+27 °F). The spray shall be continued until the rated ice thickness is measured on the top surface of the test bars.

The ice coating shall then cure with the chamber ambient temperature in the range of –10 °C (+14 °F) to –3 °C (+27 °F) for a minimum of 2 h after spray is discontinued. The switch shall be operated following this curing period.

8.7.2.4.2 Natural environment (outdoor)

Outdoor tests can be performed when the ambient temperature is between –3 °C (+27 °F) and –15 °C (+5 °F) and the wind velocity is below 25 km/h (15 mph). The completely assembled switch shall be tested in an area equipped with adequate spray equipment to provide even coverage of the interrupter switch under test.

With the ambient temperature above freezing, the switch shall be given a 1 h wetting period, which will coat the surface with a fine spray deposit. The wetting shall precede the spray for ice buildup by not more than 4 h.

To obtain uniform coverage, the spray equipment may require adjustment due to wind conditions, or the spray may be interrupted frequently to permit ice formation. The spray procedure shall be continued until the rated ice thickness is measured on the top surface of the test bars.

The ice coating shall cure for a minimum of 2 h prior to operation of the interrupter switch. Further temperature decrease during the curing period will not appreciably affect the test results. The operation test must be completed before the temperature rises above –3 °C (+27 °F) and before the radiant heat of the sun changes the characteristics of the ice.

8.7.2.5 Operation procedure

Interrupter switches shall be operated by a person using a standard operating mechanism. On switches without fault-making or load, loop, fault, or capacitor bank switching ratings, chopping on opening or closing (jerking back and forth on the manual operating mechanism) is an acceptable means of loosening the ice. Chopping is not permitted on switches with fault-making or load, loop, fault, or capacitor bank switching ratings, because these switches are likely to be in a position to carry significant current when closed, and multiple unsuccessful attempts at opening or closing are likely to result in significant current arcs being drawn in air.

Power-operated interrupter switches shall perform successfully on the first power-operated opening or closing attempt.

8.7.3 Acceptance criteria

The ice test shall be completed when the interrupter switch has been operated from its iced fully-open position to its fully-closed position, (with proper engagement of the contact surfaces and proper engagement of the interrupter) and has been operated from its iced fully-closed position to its fully-open position (with proper operation of the interrupter). The equipment must sustain no damage that will interfere with normal operation. The order of close-to-open and open-to-close icing and operation is optional.

The equipment shall be capable of circuit interruption during successful opening of the switch. Following the successful closing of an iced switch, the equipment must be capable of circuit interruption during a subsequent opening operation. During the test, no damage shall be sustained that would impair the current interruption ability. A physical examination of linkages, components, and alignments shall be made to assure that proper interruption operation and sequencing has been preserved.

The contact forces or resistance shall be measured before and after the tests to verify that no significant damage has occurred to the switch.

If there is doubt about the successful performance of the interrupter switch, a temperature-rise test, a short-time withstand current test, or a switching test, as applicable, shall be conducted to verify acceptable performance.

8.8 Mechanical operation tests

The purpose of the mechanical operations tests for interrupter switches is to demonstrate the ability of a completely assembled interrupter switch to operate satisfactorily during its mechanical operating life expectancy.

8.8.1 Test arrangement

A complete interrupter switch shall be tested with a full complement of its rated strength insulators, representative operating mechanisms, and associated components, (levers, bell cranks, pin joints, bearings, etc.,) as is required for a typical installation in the field. Modifications shall be limited to operating pipe lengths.

8.8.2 Test procedure

This test series does not require that voltage or current be applied to the main circuits.

8.8.2.1 Number of operations

The rated number of mechanical operations shall be performed on the interrupter switch.

Outdoor interrupter switches shall have mechanical loading of the terminals in accordance with the interrupter switch's ratings for 10% of the rated number of mechanical operations per 8.8.2.2.

Interrupter switches designed to be used in enclosed equipment shall have interlock tests performed per 8.8.2.3.

8.8.2.2 Terminal loading

On outdoor interrupter switches, the rated mechanical terminal load for each of the four loading conditions shall be applied to each of the terminals of one pole simultaneously as follows:

a) In a plane parallel to the plane of the mounting base and in the direction of the mounting base toward the switch for one-fourth of the terminal loaded operations (Figure 14[a])

b) In a plane parallel to the plane of the mounting base and in the direction of the mounting base away from the switch for one-fourth of the terminal loaded operations (Figure 14[b])

c) In a plane parallel to the plane of the mounting base and 90° to the direction of the mounting base for one-fourth of the terminal loaded operations (Figure 14[c])

d) In a plane perpendicular to the plane of the mounting base and toward the mounting base for one-fourth of the terminal loaded operations (Figure 14[d])

There are no terminal loading requirements specified for indoor switches and enclosed switches.

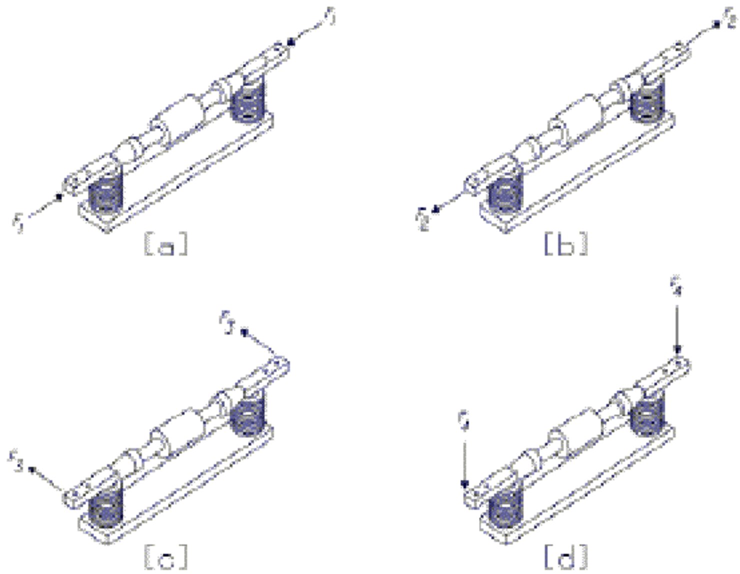


Figure 14—Terminal loading

8.8.2.3 Enclosed switches with integral interlocks

On interrupter switches to be used in enclosed equipment and employing integrated interlocks, during the last 50 mechanical close/open operating tests, the proper sequential operation and satisfactory functioning of Stored energy mechanism interlocks, as applicable, and door, key, and other interlocks, as applicable, shall be demonstrated.

In addition, if the interrupter switch is of a draw-out design with integrated interlocks, 50 mechanical endurance test cycles between disconnected and connected positions shall be performed. These tests shall be performed to demonstrate proper sequential operation and satisfactory functioning of

— Separable primary contacts
— Separable control contacts, as applicable
— Interrupter switch removable element position interlocks, as applicable
— Stored energy mechanism interlocks, as applicable

8.8.2.4 Power- or stored-energy-operated switches

Power- or stored-energy-operated switches shall be tested, performing 90% of rated no-load mechanical operations at rated control voltage, pressure, or force; 5% of rated no-load mechanical operations at minimum control voltage, pressure, or force; and 5% of rated no-load mechanical operations at maximum control voltage, pressure, or force. Control voltage shall be measured at the user terminals to the motor operator. Pressure or force shall be measured at a convenient point as close to the switch as practical.

8.8.2.5 Switch maintenance during the test

During testing, no components shall be repaired or replaced and no maintenance shall be performed.

8.8.3 Criteria for acceptance

The mechanical operations tests shall be satisfactorily completed if all parts, including contact surfaces, are in good condition and do not show undue wear or any mechanical misalignment.

The contact forces or electrical resistance shall be determined before beginning and after completing the test to verify that no significant change (a factor of 2) has occurred in the condition of the main switch and interrupter contacts.

Timing tests shall verify that operating speeds of interrupting switches employing power-operated or stored-energy operating mechanisms are within manufacturer's specifications for

- Opening and closing speeds of main switch and interrupter contacts
- Pole closing and opening non-simultaneity of main switch and interrupter contacts

Dielectric withstand tests shall consist of the standard required production hi-pot tests of the main insulation and interrupter circuit elements.

8.9 Corona tests

Corona tests shall consist of the application of voltage, followed by the detection of visible corona plumes and spikes produced at the external surface extremities of the device being tested. When a switch is a component part of an assembly to be tested, the test voltage shall be based on the lowest rated maximum voltage of any component part.

8.9.1 Switches requiring corona tests

Non-enclosed outdoor-switches applied at 121 kV and above, and all switches that use organic materials as a primary insulation system, shall be subjected to corona tests.

8.9.2 Test equipment

The equipment shall consist of a test transformer sufficiently void of corona so that it will not interfere with proper observance of the tested device. The tests shall be performed in a dark area, wherein corona plumes and spikes are visible to unaided eyes (after the eyes become accustomed to the general light level in the test area).

8.9.3 Method for conducting tests

Outdoor gang-operated and single-pole switches shall be tested utilizing a single-pole switch in the following manner:

a) With the switch in the closed position and the base grounded, energize the live parts by a connection to either terminal.

b) With the switch in the open position and the base and one terminal grounded, energize the other terminal. Repeat the test with the energized and grounded terminals reversed.

The height of energized live parts shall be no higher above the ground plane than the values listed in Table 10. These values are based upon the minimum vertical clearances for ungrounded parts as per the National Electrical Safety Code ® (NESC®).

Table 10 —Recommended ground clearances

BIL (kV)	Recommended clearance between energized live parts and grounded parts for corona testing
350	3.00 m (9’–10″)
450	3.18 m (10’–5″)
550	3.53 (11’–7″)
650	3.71 m (12’–2″)
750	3.91 m (12’–10″)
900	4.52 m (14’–10″)
1050	4.72 m (15’-6″)
1300	5.23 m (17’-2″)
1550	5.74 m (18’-10″)
1800	6.25 m (20’-6″)
2050	6.83 m (22’-5″)

8.9.4 Proximity of other objects

No grounded or ungrounded objects or structures, except a mounting structure when required, shall be nearer to any part of the switch than 1.5 times its length-of-break distance, with a minimum spacing of 0.9 m (3 ft). When space requirements do not permit the above clearance to be maintained, the test will be considered satisfactory if the limits for corona-free voltage are equal to or higher than those specified for the switch. In such cases, it is desirable that a record be made of the objects, structures, etc. and their distances from the switch under test. These data may be useful for future reference in determining the proximity effect.

Smaller horizontal clearances to live parts than those specified in the NESC shall be considered special.

8.9.5 Rated voltage

In some cases, it may be found that the visible corona disappears after the rated voltage has been applied for a short time. In such cases, before proceeding with the tests, it is permissible to pre-excite the test piece at a higher voltage to eliminate the effects of dust particles, etc.

8.9.6 Test voltage application

The switch under test shall be stressed with an applied test voltage that will establish visible corona at several different locations. The test voltage need not exceed the corona-free test voltage in 8.9.7 by more than 10%. The test voltage shall then be lowered gradually and noted as the visible corona plumes and spikes disappear from each location. The test voltage at which visible corona plumes and spikes disappear from the last external surface location is the corona-free test voltage.

Adverse weather conditions and contamination may result in corona extinction at a voltage lower than the corona-free voltage.

8.9.7 Corona-free voltage requirement

The visible corona-free test voltage shall not be lower than 1.10 times the line-to-neutral value of the rated maximum voltage. The rated maximum voltages are given in ANSI C37.32.

8.9.8 Criteria for acceptance

The air switch shall be free of visible plumes or spikes at the voltage specified in 8.9.7. If it is questionable whether a switch part is corona-free at a specific test voltage, a suitable photographic method may be used to judge the test results.

8.10 Radio-influence tests

Radio-influence tests are tests that consist of the application of voltage and the measurement of the corresponding radio-influence units produced by the device being tested.

8.10.1 Test equipment

The meter used in making radio-influence measurements shall be in accordance with ANSI C63.2. (American National Standards on methods of measurement of radio-influence voltages on high-voltage equipment have not been established as of this date.)

8.10.2 Methods for conducting tests

8.10.2.1 Outdoor group-operated switches and single-pole switches

A single-pole switch shall be tested. Tests shall be made with the switch closed and additionally on each terminal with the switch open. The base and unenergized terminals shall be grounded.

8.10.2.2 Multi-pole housed apparatus

The apparatus housing shall be grounded. Tests shall be made on each pole with the switch closed and on each terminal with the switch open. Two measurements shall be made for each test: one with the unenergized terminals grounded, and one with the unenergized terminals ungrounded.

8.10.3 Proximity of other objects

No grounded or ungrounded object or structure, except mounting structure when required, shall be nearer any part of the apparatus or its terminals undergoing test than three times the longest overall dimension of the test piece, with a minimum allowable spacing of 1 m (3 ft).

Where space requirements under test conditions do not permit the above clearance to be maintained, the test will be considered satisfactory if the limits of radio-influence voltage obtained are equal to or less than those specified for the apparatus. In such cases, it is desirable that a record be made of the object, structures, etc. and their distance from the device under test. The data may be useful in determining the proximity effect.

8.10.4 Ambient radio noise

Tests may be made under the conditions prevailing at the time and place of the test. However, it is recommended that tests be avoided when the measured radio-influence voltage of the test equipment along with irrelevant electrical devices, but with the apparatus under test disconnected, exceeds 25% of the radio-influence voltage of the apparatus to be tested.

8.10.5 Frequency and waveshape of test voltage

Test voltage shall be sinusoidal at the rated power frequency of the device tested.

8.10.6 Atmospheric conditions

Tests shall be conducted under atmospheric conditions prevailing at the time and place of the test. It is recommended that tests be avoided when the vapor pressure is below 700 Pa (0.2 in of mercury) or above 2 kPa (0.6 in of mercury). Since the effects of humidity and air density upon radio-influence voltage are not definitely known, no correction factors are recommended at the present time. However, it is recommended that barometric pressure and dry and wet bulb thermometer readings be recorded so that if suitable correction factors should be determined, they can be applied to previous measurements.

8.10.7 Electrical connections

Conductors of the largest size intended for use with the test piece may be connected to each terminal. The length of the conductors, when used, shall be equal to or greater than the longest overall dimension of the test piece (except that the length need not exceed 2 m). The free end of any such conductor shall terminate in a sphere having a diameter two times the diameter of the conductor ±10%, or shall be shielded in some other suitable manner, to eliminate the effect of the end of the conductor as a source of radio-influence voltage.

8.10.8 Test on assembled equipment

In the case of assembled equipment, the test shall be made without removing any component part, and the test voltage shall be based on the lowest rated voltage of any component part. The limiting radio-influence voltage shall be identical with the highest value specified for any of the component parts that determine the test voltage.

8.10.9 Precautions

The temperature of the device should be approximately the same as that of the room in which the test is made. The device should be dry and clean, and should not be subjected to dielectric tests for two hours prior to the radio-influence voltage test.

In some cases, it may be found that the radio-influence voltage falls off rapidly after the rated power-frequency voltage has been applied for a short time. In such cases, before proceeding with the tests, it is permissible to pre-excite the test piece, at normal operating voltage, for a period of not more than five minutes.

8.11 Partial discharge test

Under consideration.

8.12 Production tests

Unless otherwise specified, all production tests shall be made by the manufacturer on the completed switch assembly.

NOTE—Other standards may specify production tests.

8.12.1 Mechanical operation test (for switches with maximum rated voltage < 48 kV)

Mechanical operation tests shall be performed to assure the proper functioning of the switch. Ten close/open operations of the switch shall be performed.

8.12.2 Power operation and control wiring test (for power-operated switches only)

8.12.2.1 Control wiring continuity

The correctness of the control wiring shall be verified by either or both of the following:

a) Actual electrical operation of the component control devices
b) Individual circuit continuity checks by electrical circuit testers

8.12.2.2 Control wiring insulation test

A power-frequency test voltage shall be applied after all circuit grounds have been disconnected. Either 1500 V for one minute or 1800 V for one second may be utilized. All wires shall be tested either individually or in groups.

Annex A

(informative)

Altitude correction factors

Altitude correction factors have been removed from this standard due to the current controversy regarding their use. This standard will adopt the recommendations of the Common Clause Working Group when the recommendations become an IEEE standard. The following paragraphs consist of background information on the subject.

Altitude correction factors consist of current and voltage factors that relate expected performance at various altitudes. Specific factors appear in IEEE Std 97-1969 [B7]. Over the years, there have been minor deviations in the factors, probably due to round-off errors made by standards developers who may have referenced other IEEE C37 standards, rather than IEEE Std 97-1969 [B7].

IEEE Std 97-1969 [B7] suggests voltage factors, however, they do not conform to actual relative air density (RAD) based on measurements by the U.S. Commerce Department in high altitude areas on earth (e.g., Flagstaff, AZ). IEEE Std 3-1982 [B6] bases its RAD on the U.S. Standard Atmosphere, which, in turn, is based on the International Civil Aviation Organization (ICAO) standard atmosphere. The ICAO RAD falls less rapidly than that of IEEE Std 97-1969 [B7], and also does not conform to actual conditions on earth, primarily due to temperature effects. The ICAO atmosphere is based on a steadily decreasing air temperature, as experienced above the earth. The temperature in high altitude areas on earth is much warmer than the ICAO atmosphere would predict. The curve for voltage factors, plotted in Figure A.1, is based on the physical measurements of air density and air pressure, (at sea level and displaced by 1000 m) and very closely matches weather data (also plotted in Figure A.1) from the U.S. Commerce Department (also displaced by 1000 m).

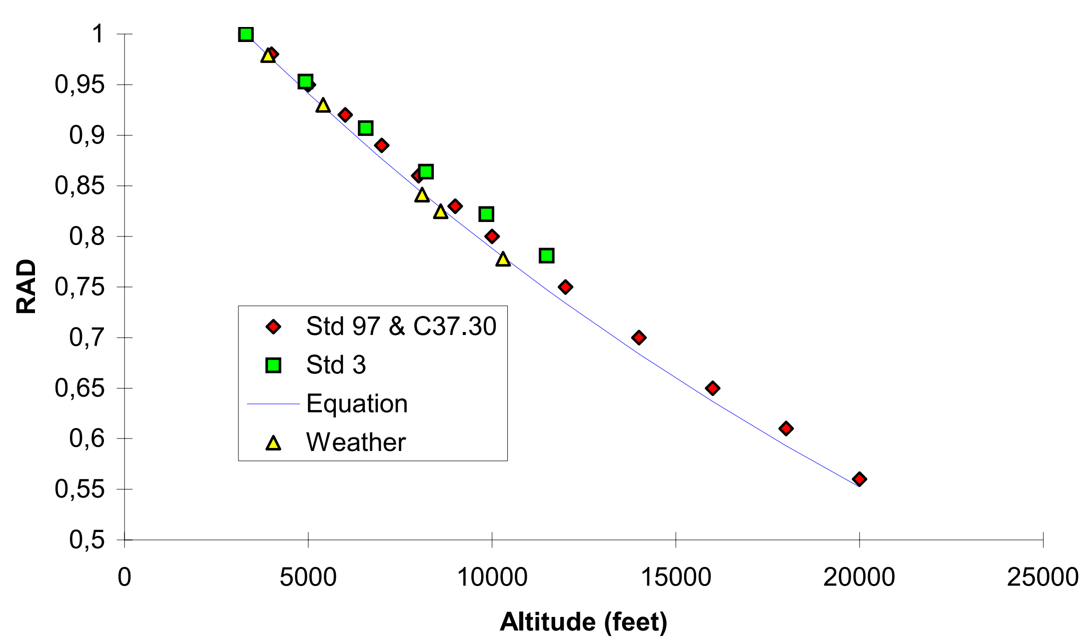


Figure A.1—RAD as a function of displaced altitude

Annex B

(informative)

Load-switching TRV

The Electromagnetic Transient Program (EMTP) study illustrates the effect that the power factor of a load has on the TRV associated with load-switching. The study is based on the TRV parameters for 27 kV load-switching, but the trend thus illustrated is applicable to all voltage classes. The TRVs shown below were generated utilizing the EMTP to model the circuit of Figure B.1 utilizing parameters in Table B.1.

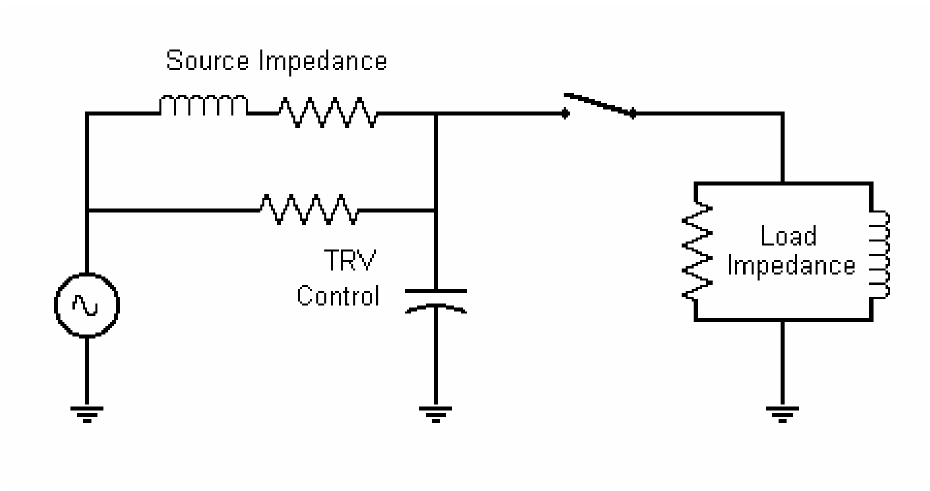


Figure B.1—Circuit diagram used for switching simulation

The TRVs generated by the EMTP program are shown in Figure B.2. Note that the initial portion of the TRV is virtually the same for power factors between 1.0 and 0.8. The initial recovery peak is substantially higher for unity power factor, making it the most severe TRV of the lot.

Table B.1—Values used to compute EMTP circuit elements[12]

Load power factor	Source	Load	TRV resistor	TRV capacitor
Unity	0.00583 + j 0.0991	0.991	8.53	–j 136.4
97% lag	0.00569 + j 0.0968	0.939 + j 0.235	8.33	–j 133.2
92% lag	0.00561 + j 0.0954	0.878 + j 0.374	8.216	–j 131.4
80% lag	0.00551 + j 0.0937	0.749 + j 0.562	8.06	–j 128.9

[12] Per unit impedance values of components.

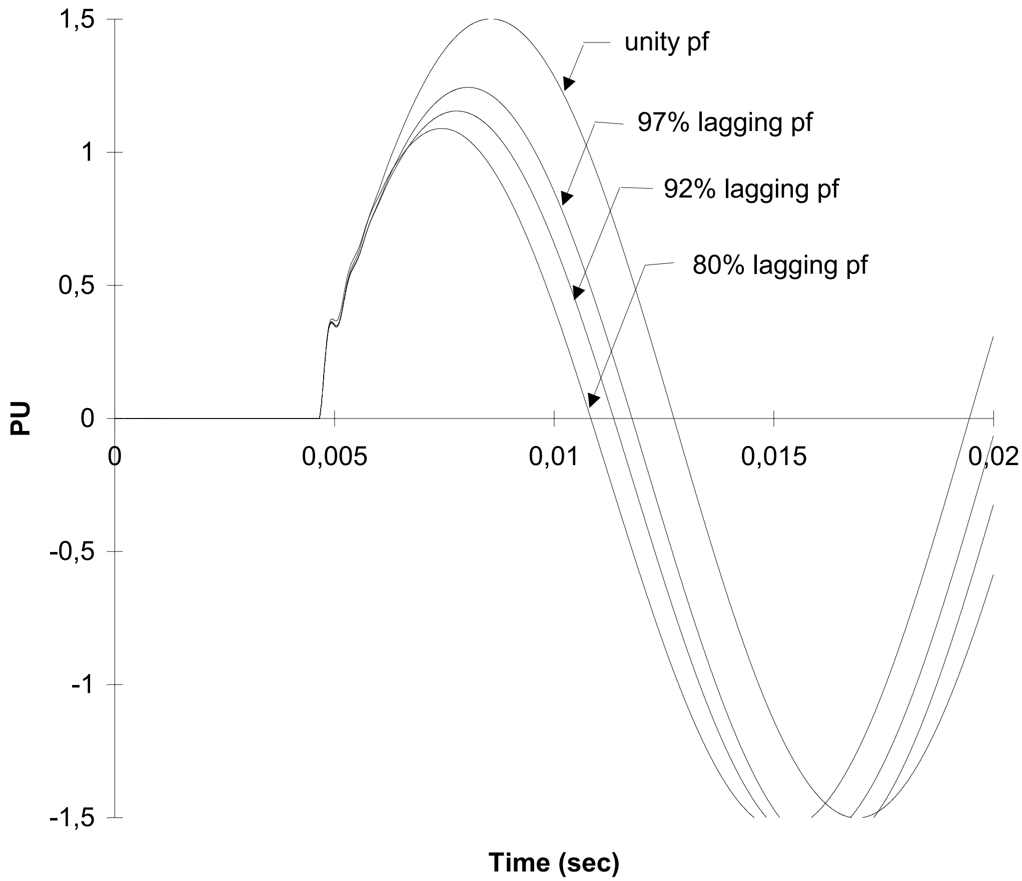


Figure B.2—Switch recovery voltage for various load power factors

Annex C

(informative)

Restrike-free performance

C.1 General

General points about restrike-free performance are as follows:

a) Restrike-free performance is not easy to define and is easily misunderstood.

b) Restrike-free performance is not universally needed, for example, it is not needed for unloaded-line switching at distribution voltages.

c) In the majority of applications, breakers tested to current ANSI breaker standards (specifically 4.13 of IEEE Std C37.09) provide acceptable performance and do not require a higher level of restrike performance.

d) In some applications, especially shunt capacitor bank switching, a higher level of restrike performance may be required.

C.2 Recommendations

Recommendations for restrike-free performance are as follows:

a) The term restrike-free should not be used in standards, to underscore concept that the probability of restrike is not zero.

b) There is a need for three levels of restrike performance:

   1) Moderate to high probability of restrike (designated as Class C)

   2) Low probability of restrike (about 2% probability) (designated as Class B)

   3) Very low probability of restrike (about 0.2% probability) (designated as Class A)

c) The levels of restrike performance should be designated as the class of the shunt capacitor bank switching current rating ratings such as Class A, B, or C.

d) Class C devices with moderate to high probability of restrike should only require interrupting tests, without regard to restrikes, for any capacitive current ratings they might have.

e) Devices tested to 4.13 of IEEE Std C37.09 should be designated as Class B. Tests for Class B device should be similar to 4.13 of IEEE Std C37.09.

f) Tests for a Class A device should be more stringent than 4.13 of IEEE Std C37.09. The essence of the restrike performance aspect of the test should require no restrikes in an additional series of capacitive current interrupting tests, the number of which should be defined to assure an upper limit of probability of restrike of about 0.2%.

C.3 Means to determine the number of operations for the Class A, shunt capacitor bank switching current rating

One means to ensure that the probability of restrike is below 0.2% is to interrupt an appropriate three-phase circuit a large number of times with no restrikes allowed (brute-force method). An alternate method is offered as an attempt to reduce the testing burden by more prudently selecting the interrupting test parameters. The methods are as follows:

- Brute force method. The probability of a series of n non-restriking operations occurring, each one of which has a probability $P_{restrike}$ of restriking, is $(1 - P_{restrike})^n$

If the probability of accepting a marginal design is made to be low, for example minus one standard deviation or 15.9% (meaning a marginal design has a 15.9% chance of passing the test) then:

$(1 - P_{restrike})^n = 15.9\%$; or,
$n = \ln(0.159) / \ln(1 - P_{restrike})$

For $P_{restrike} = 0.2\%$, n = 919, which should be taken with random contact parting.

- *Alternate method.* If a switching device does not have a high probability of restriking, it will only restrike when interruption occurs near its minimum arcing time, because greater arcing times allow the device to establish larger interrupter gaps by the time the recovery voltage is high enough to promote a restrike and because restrikes are highly sensitive to the interrupter gap. It is therefore follows that only operations that have contact parting, resulting in close to minimum arcing times, will challenge the device with respect to restrike performance. To define "close" to minimum arcing time, an arbitrarily definition of critical contact parting is offered as: contact parting which results in an arcing time no more than 1/2 ms greater than the minimum arcing time. Since restrikes will generally occur between 1/4 to 1/2 cycle (4.2 to 8.3 ms for 60 Hz) after interruption this definition essentially limits the interrupter gap (associated with critical contact parting, and in the restrike range) to less than about 12% (1/2 ms out of 4.2 ms) more than the minimum possible gap. A means to measure the minimum arcing time needs to be defined.

In the field, the switching device is assumed to contact part randomly with respect to the voltage wave. There are six (three phases and two per phase) 1/2 ms critical contact parting periods (3 ms total) per cycle of the power frequency. Therefore, single phase testing with critical contact parting provides a test that is approximately 6.7 (50 Hz) to 5.6 (60 Hz) times more effective in provoking restrikes than the three-phase field application (e.g., 16.67 ms/3 ms for 60 Hz)

Now referencing the "brute force method" above, the $P_{restrike}$ in the field is 0.2% but the $P_{restrike}$ for the test with critical contact parting at 60 Hz is 5.6 times greater or 1.12%. Then $n = \ln(0.159) / \ln(1 - 5.6 \times P_{restrike})$ and for $P_{restrike} = 0.2\%$, n = 164, which should be split between positive and negative recovery voltages.

The alternate method can also be used to support the suitability of using 4.13 of IEEE Std C37.09 to verify a 2% probability of restrike. If $n = \ln(0.159) / \ln(1 - 5.6 \times P_{restrike})$ and $P_{restrike} = 2\%$, then n = 16, which corresponds to the number of critical contact parting operations associated with 4.13 of IEEE Std C37.09, which calls for 12 operations "around the clock"; two of which will be near critical; plus 6 additional operations around the near-critical operation of the first 12 operations; for a total of 8 near-critical operations. An additional 8 near-critical operations are obtained in the second test circuit, for a grand total of 16 near-critical operations.

Annex D

(informative)

Capacitive current switching

D.1 Explanation of capacitor switching rating structure (steady state)

Under steady state conditions, the ultimate limitation will be the thermal rating of the switch. Items that need to be considered in application are harmonic content, overvoltage, and over-capacitance. The IEEE C37.010 (see [B9]) circuit breaker application guide recommends allowing a factor of 1.25 on the nominal capacitance current for an ungrounded capacitor bank and 1.35 on the nominal current for a grounded wye capacitor bank. These factors are to allow for an over-capacitance of 15%, an overvoltage of 10%, and a total harmonic distortion of 10%.

D.2 Difficulties with capacitor switching (interruption)

The basic problem with capacitor interruption is that the currents are low. The initial transient recovery voltage (ITRV) is also very low and the interruption initially takes place very easily; however, due to trapped charge on the capacitor, the final recovery voltage tends toward two plus per unit for a grounded capacitor and possibly as much as three plus per unit for an ungrounded capacitor. As a result, for many switching devices, restrikes are possible and likely during capacitor interruption. Certain devices have been used to limit trapped charge such as opening resistors or metal oxide varistors, which discharge the trapped charge into the source. In cases where these are used, the test circuit should be designed with the prospective recovery voltage as if such a device was not present. It may be of interest to develop ratings (if possible) for the switching device without resistors or metal oxide varistors across portions or all of the interrupter. The upper limit for capacitance switching of some interrupters may be determined by the maximum differential capacitance voltage which determines the ITRV. Examples include air switches and whips. Other interrupters with good ITRV ability may be limited by the propensity for an escalating overvoltage. An example would be an oil switch that has a very good ITRV ability but a poor delayed recovery voltage ability, particularly with low currents. However, when the capacitance current is high enough, the natural frequency will drop to the point that if a restrike occurs, the interrupter may be able to interrupt on transient current zeros, and thus develop even higher trapped charges with the likelihood of additional restrikes and escalating overvoltages to the point of failure. This leads to an upper limit for oil interrupters.

The standard as proposed uses the concept of a differential capacitance voltage, which is the steady-state voltage difference between the system with and without the capacitor. This voltage is what drives the ITRV. For switches that have difficulty with ITRV, (e.g., air switches with whip-type attachments) the maximum value of differential capacitance voltage will be problematic. However, with interrupting devices that generate more "interrupting effort", the minimum differential capacitance voltage may be a problem. The ITRV is so small that interruption can take place with a very small or almost no contact separation. Less than one-half cycle later, when the recovery voltage is approaching the maximum value of almost two per unit, the switch has a tendency to restrike. Thus, both the minimum and maximum differential capacitance voltages are important, but each for different types of switching devices. This concept could have been incorporated by specifying a range of minimum and maximum source impedance, but it is believed that the concept of differential capacitance voltage relates directly to the actual concern.

D.3 Capacitor closing with parallel-connected capacitors

The inrush that occurs when switching parallel-connected capacitors can result in very large transient currents with high transient frequencies. Either or both of these concerns may be a problem in switching parallel-connected capacitors. The inrush current magnitude and frequency may give rise to contact welding or, in some cases, shock waves within the interrupting chamber, which can lead to the destruction of the interrupting chamber. The duties of switching single or parallel-connected capacitors can be covered with an inrush current rating. This eliminates the old terminology of single versus parallel-connected capacitor switching. An application clause should be written to allow users to calculate their inrush current rating requirement.

D.4 Restrike probing

A search must be made for the minimum arcing time to determine the likelihood of a switch to restrike. Minimum arcing time shall be determined by a series of tests where arcing time is lessened in increments of about 0.5 millisecond for the particular value of capacitance being switched. In certain cases it may be desirable to use less than the maximum capacitance switching current allowed. Also, the minimum arcing time will be smaller if the differential capacitance voltage is small. These tests must be made with the minimum differential capacitance voltage rating. Several hundred interruptions with minimum arcing time and maximum recovery voltage are needed to demonstrate a low probability of restrike.

D.5 Determining the discharge inductance for the test circuit of Figure 13

The total inductance calculated includes the lead inductance of the switch, capacitor, and inductor. Thus, the lumped inductance of the discharge inductor must be reduced by subtracting the stray inductance from the calculated value. The discharge circuit is intended to be used for peak inrush currents greater than 20 times rated capacitance current. A full cycle damping factor of 0.91, or less, is required. A smaller inductor will be required to obtain the required discharge current than would be calculated from a loss-less circuit model.

Annex E

(informative)

Bibliography

[B1] ANSI C37.57-1990 (Reaff 1996), Switchgear - Metal-Enclosed Interrupter Switchgear Assemblies - Conformance Testing.

[B2] ANSI C37.58-1990 (Reaff 1996), Conformance Test Procedures for Indoor AC Medium Voltage Switches for Use in Metal-Enclosed Switchgear.

[B3] Harner, R. H. and Rodriguez, J., "TRVs Associated with Power System, Three-Phase Secondary Faults", T-PAS, pp. 1887-1896, Sept/Oct 1972.

[B4] IEC 265-2 (1988-03), High-voltage switches. Part 2: High-voltage switches for rated voltages of 52 kV and above.

[B5] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition.

[B6] IEEE Std 3-1982 (withdrawn), IEEE Recommended Practice in the Selection of Reference Ambient Conditions for Test Measurements of Electrical Apparatus.[13]

[B7] IEEE Std 97-1969 (withdrawn), IEEE Recommended Practice for Specifying Service Conditions in Electrical Standards.[14]

[B8] IEEE Std 386-1995, IEEE Standard for Separable Insulated Connectors System for Power Distribution Systems Above 600 V.

[B9] IEEE Std C37.010-1979 (Reaff 1988), IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[B10] IEEE Std C37.41-1994, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches and Accessories.

[13] IEEE Std 3-1982 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).
[14] IEEE Std 97-1969 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).