PC37.016 WG, Standard for AC High Voltage Circuit Switchers Rated 15.5 kV (HVCB)

April 17, 2023 – Clearwater, FL

Chair: Neil McCord (Consultant)
Vice Chair & Secretary: Luke Collette (Utility)

Meeting Minutes

1. **Call to order and introduction:**

   The PC37.016 WG IEEE Standard for AC High Voltage Circuit Switchers Rated 15.5 kV met on Monday, April 17, 2023, at 3:45 P.M. Neil McCord, Working Group Chair, presided over the meeting.
   The Copyright, Patent, and Behavior/Ethics slides were presented.
   Chair called for any potential Patent claims. No Patent claims identified.

2. **Agenda:**

   Chair presented the agenda. Attendance sheet was circulated.

3. **Introduction of Members and Guests**

   Roster distributed and attendance recorded (attendance sheet attached to MOM).
   34 in attendance with 7 of 13 members (54%) present. Quorum met, Note 2 of 15 existing members excused for this meeting (Neil Hutchins, Andy Keels).

4. **Previous Meeting Minutes**

   Chair presented the minutes from the last meeting.

   - Motion to Approve MOM: Pat Dilillo
   - 2nd to Motion: Chris Jarnigan

5. **Introduction of WG Leadership**

   Chair: Neil McCord (Consultant)
   Vice Chair & Secretary: Luke Collette (Utility)

6. **Presentation by Chair**

Chair reviewed the definition of a circuit switcher to kick-off the technical discussion.

Chair discussed removing primary bus fault from C37.016 and replacing with terminal fault language to be consistent with C37.04, C37.09, etc.

Chair reviewed the Normative References section of the existing C37.016 and suggested removing reference to IEC standards and replacing with relevant IEEE standards. A comment was made that normative references must be included if they are referred to in the text. Need to confirm we can remove the IEC references.

Chair discussed transformer-limited faults and the difference between dead tank circuit breakers with integrated current transformers vs circuit switchers which require the use of external current transformers to detect fault current.

Chair mentioned rated capacitive current switching requirements and how it doesn't apply to all circuit switchers. Suggested making it more clear that these are optional ratings.

Question was raised about required short-line fault ratings. There was discussion about the application of circuit switchers and how they should not be applied in situations in which they would be exposed to a short-line fault.

Chair reviewed proposed changes to C37.016 by going through a marked up version of the document (reference attached document).

A comment was made that the operating duty is different in C37.09, so we should not use C37.09 for a direct reference.

A question was raised about whether a T30 should be included as a test requirement in C37.016. There was a discussion but a conclusion was not reached.

7. **Next meeting:**

   Fall 2023 8-13 October 2023 Planned for Catamaran Resort, San Diego, CA

8. **Meeting Adjourned:** 5:33 PM

Submitted by:

Neil A. McCord
WG Chair, C37.016
Standard for AC High Voltage Circuit Switchers Rated 15.5 kV

IEEE STANDARDS ASSOCIATION

IEEE Standard for AC High Voltage Circuit Switchers Rated 15.5 kV through 245 kV

IEEE Power and Energy Society

Sponsored by the
Switchgear Committee

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

IEEE Std C37.016™-2018
(Revision of IEEE Std C37.016-2006)

IEEE Std C37.016™-2018
(Revision of IEEE Std C37.016-2006)

IEEE Standard for AC High Voltage Circuit Switchers Rated 15.5 kV through 245 kV

Sponsor

Switchgear Committee
of the
IEEE Power and Energy Society

Approved 5 December 2018

IEEE-SA Standards Board

Abstract: This standard is applicable to ac circuit switchers designed for outdoor installation and for rated power frequencies of 50 Hz and 60 Hz and rated maximum voltages of 15.5 kV through 245 kV. It is applicable only to three-pole circuit switchers for use in three-phase systems. This standard is also applicable to the operating devices of circuit switchers and to their auxiliary equipment. Included in this document are the normal and special service conditions under which the ratings are based and requirements for design and construction, which include those for interrupting media, stored energy systems, operating characteristics, mechanical loading and operation capabilities, electrical insulation, and auxiliary devices. The rating structure establishes the basis for all assigned ratings, including continuous current, dielectric withstand voltages, primary-bus fault breaking current, transformer-limited fault breaking current, short-circuit making current, transient recovery voltages, and capacitor switching, plus associated capabilities such as mechanical endurance and operation under high- and low-temperature environmental extremes. Routine (production) tests are defined and requirements for their execution documented.

Keywords: circuit switcher, coordinated disconnect, design tests, IEEE C37.016, interrupter, operating mechanism, primary-bus fault, production tests, ratings, service conditions, stored energy, transformer-limited fault, transient recovery voltage

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PDF: ISBN 978-1-5044-5445-2 STD23490
Print: ISBN 978-1-5044-5446-9 STDPD23490

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Participants

At the time this IEEE standard was completed, the C37.016 Working Group had the following membership:

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Don Steigerwalt
Jean-Marc Torres
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The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

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When the IEEE-SA Standards Board approved this standard on 5 December 2018, it had the following membership:

Introduction

This introduction is not part of IEEE Std C37.016-2018, IEEE Standard for AC High Voltage Circuit Switchers Rated 15.5 kV through 245 kV.

This standard is being revised to remove references to IEC documents and to, where appropriate, use references to IEEE documents. Since the first release of this standard in 2006, there have not been significant technical issues with the standard, so the technical content is intended to be consistent with the 2006 version.

Contents

IEEE Standard for AC High Voltage Circuit Switchers Rated 15.5 kV through 245 kV

1. Overview

1.1 Scope

This standard is applicable to ac circuit switchers designed for outdoor installation and for rated power frequencies of 50 Hz and 60 Hz and rated maximum voltages of 15.5 kV through 245 kV. It is applicable only to three-pole circuit switchers for use in three-phase systems. This standard is also applicable to the operating devices of circuit switchers and to their auxiliary equipment. It includes the basis of rating, preferred ratings and test procedures for circuit switchers.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~IEC 60507:2013, Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems.~~[1]

~~IEC 60815-1:2008, Selection and dimensioning of high-voltage insulators intended for use in polluted conditions—Part 1: Definitions, information and general principles.~~

IEEE Std 4™-2013, IEEE Standard for High-Voltage Testing Techniques.[2, 3]

IEEE Std C37.30.1™-2011, IEEE Standard Requirements for AC High-Voltage Air Switches Rated Above 1000 V.

[1] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA.
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IEEE Std C37.04™-2018, IEEE Standard for Ratings and Requirements for AC High Voltage Circuit Breakers with Rated Maximum Voltages above 1000 V.[4]

IEEE Std C37.09™-2018, IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage above 1000 V.

IEEE Std C37.100.1™-2018, IEEE Standard of Common Requirements for AC High-Voltage Power Switchgear Rated Above 1000 V.

IEEE Std C37.100.2™-2018, IEEE Standard for Common Requirements for Testing of AC Capacitance Current Switching Devices over 1000 V.

NEMA CC 1-2009 (R2015), Electric Power Connectors for Substations.[5]

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[6]

circuit switcher: A mechanical switching device with an integral interrupter, suitable for making, carrying, and interrupting currents under normal circuit conditions. It is also suitable for interrupting specified primary-bus fault current and transformer-limited fault current that may be less than its rated short-circuit making current and rated short-time withstand current.

circuit switcher with isolating disconnect: A circuit switcher with an integrally mounted, isolating disconnect to provide a visible air gap. The disconnect operation and open-close position may be independent of interrupter operation and position or coordinated with the interrupter operation and position.

NOTE—A circuit switcher with an isolating disconnect is considered an integrated device including the interrupter and the disconnect. It is referred to as a circuit switcher, and the rating and test apply to the entire device.

coordinated disconnect operation: A sequence of operation of a circuit switcher with an isolating disconnect where the disconnect automatically opens after the interrupter opens. Automatic closing of the disconnect may occur before or after the interrupter closes.

independent disconnect operation: A sequence of operation of a circuit switcher with an isolating disconnect where the disconnect operation and position are independent of the interrupter operation and position.

Remove PBF

primary-bus fault current (PBF): The fault current supplied by a system with single or multiple transmission lines connected between the source of the current and the interrupting device. Transformers may also be directly connected in parallel with the lines. See Figure 1.

NOTE—The significant system capacitances reduce the rate of rise of the transient recovery voltage (TRV) as compared to the rate of rise of the TRV related to the transformer-limited fault current rating.

[4]Numbers preceded by P are IEEE authorized standards projects that were not approved by The IEEE-SA Standards Board at the time this publication went to Sponsor ballot/press. For information about obtaining drafts, contact the IEEE.
[5]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).
[6]*IEEE Standards Dictionary Online* subscription is available at: http://ieeexplore.ieee.org/xpls/dictionary.jsp.

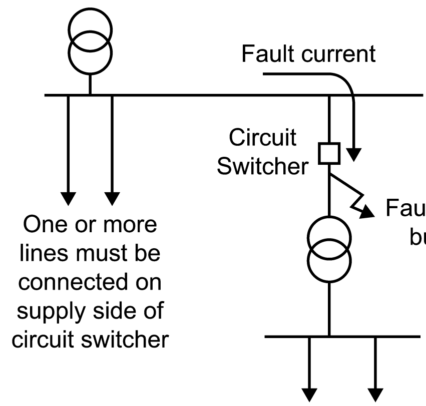


Figure 1—Diagram of primary-bus faults

transformer-limited fault current (TLF): The fault current supplied by or limited by a transformer directly connected to the interrupting device without transmission lines or cables connected in parallel with the transformer. See Figure 2.

NOTE—The minimal transformer capacitance results in a very high rate of rise of transient recovery voltage (TRV).

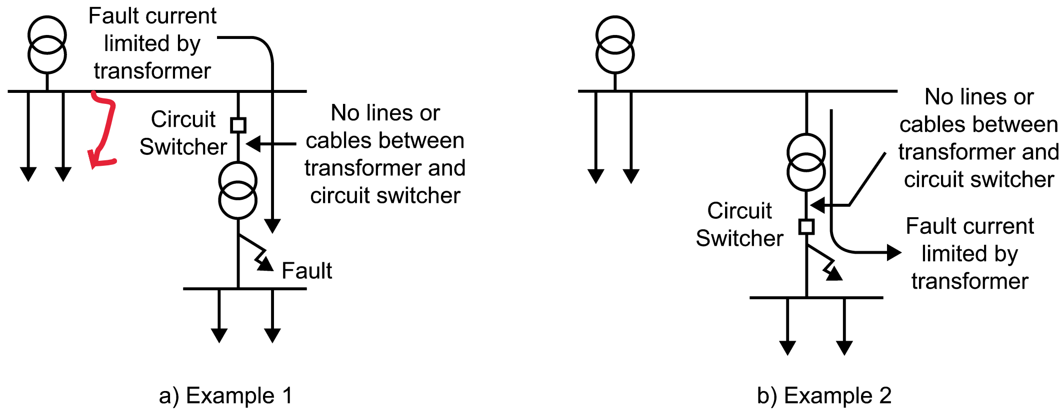


Figure 2—Diagrams of transformer-limited faults

4. Normal and special service conditions

4.1 Normal service conditions

Subclause 3.2.2 of IEEE Std C37.100.1-2018 is applicable with the following substitution for item e):

Ice coating does not exceed 9.5 mm.

4.2 Special service conditions

Subclause 3.3 of IEEE Std C37.100.1-2018 is applicable.

5. Ratings

5.1 General

The characteristics of a circuit switcher, including its operating devices and auxiliary equipment, that shall be used to determine the ratings are the following:

a) Rated characteristics to be given for all circuit switchers are as follows:

   1) Rated maximum voltage
   2) Rated insulation level
   3) Rated power frequency
   4) Rated continuous current
   5) Rated short-time withstand current
   6) Rated peak withstand current
   7) Rated duration of short circuit
   8) Rated control voltage of closing and opening devices and of auxiliary circuits
   9) Rated control frequency of closing and opening devices and of auxiliary circuits
   10) Rated pressures of compressed gas supply for insulation, operation, and/or interruption
   11) Rated primary bus fault breaking current
   12) Rated transient recovery voltage (TRV) for the rated primary bus fault breaking current
   13) Rated transformer-limited fault breaking current
   14) Rated TRV for the rated transformer-limited fault breaking current
   15) Rated short-circuit making current
   16) Rated operating sequence
   17) Rated time quantities
   18) Rated static terminal load

b) Rated characteristics to be given on request are as follows:

   1) Rated line-charging switching current

   NOTE—If a circuit-switcher is assigned a line-charging current switching rating and is to also be used to interrupt faults on the line, then a short-line fault rating should be assigned and tested for per applicable clauses of IEEE Std C37.04-2018, and IEEE Std C37.09-2018.

   2) Rated cable-charging switching current
   3) Rated shunt capacitor bank switching current
   4) Rated peak capacitive inrush current

5.2 Rated maximum voltage (U_r)

The rated maximum voltage indicates the upper limit of the highest power-frequency voltage of systems for which the circuit switcher is intended. Standard values of rated voltages are given in Table 1.

Why is Table 1 different from 100.1 Table 1a? Look at Table 1b.

Table 1—Preferred rated maximum voltages and rated insulation

Rated maximum voltage (kV, rms)	Rated power-frequency withstand voltage (kV, rms)[a]		Rated lightning impulse withstand voltage (kV, peak)		Chopped wave withstand voltage[c] (optional) (kV, peak)
	Common value	Across the isolating distance[b]	Common value	Across the isolating distance[b]	
15.5	30	33	95	105	125
	45	50	110	125	140
25.8	45	50	125	140	160
	60	66	150	165	195
38	60	66	150	165	195
	80	88	200	220	260
52	100	110	250	275	325
72.5	140	154	350	385	450
100	150	175	380	420	490
	185	205	450	495	580
123	185	205	450	495	580
	230	255	550	605	710
145	230	255	550	605	710
	275	305	650	715	840
170	275	305	650	715	840
	325	360	750	825	970
245	350	385	900	990	1160
	460	505	1050	1155	1350

[a]These values are to be used for both the wet and dry test.
[b]Test voltages for isolating distances are applicable to the disconnect blade only, not the interrupter.
[c]Minimum time to sparkover for the chopped wave is 2 µsec.

5.3 Rated insulation level

The preferred rated insulation levels of the circuit switcher are given at the standard atmospheric conditions specified in IEEE Std 4-2013.

And Table 6 in .04

The "common values" as used in Table 1 apply to phase-to-ground, between phases, and across the open circuit switcher interrupter. The withstand voltage values "across the isolating distance" are valid only for the disconnect blade of circuit switchers that incorporate a disconnect blade. The chopped wave withstand voltage rating is an optional rating and must be specified by the user, if desired.

5.4 Rated power frequency (f_r)

Subclause 5.4 of IEEE Std C37.100.1-2018 is applicable.

5.5 Rated continuous current (I_r)

Subclause 5.5 of IEEE Std C37.100.1-2018 is applicable.

NOTE—Circuit switchers can switch loads up to the rated continuous current. No testing is required by this standard since demonstrations of the fault interrupting rating are more severe and demonstrate this capability.

5.6 Rated short-time withstand current (I_k)

Subclause 5.6 of IEEE Std C37.100.1-2018 is applicable with the following addition:

The rated short-time withstand current shall be equal to or greater than the larger of the rated primary-bus fault breaking current or the corresponding symmetrical current associated with the rated short-circuit making current because of the way circuit switchers can be applied.

5.7 Rated peak withstand current (I_p)

Subclause 5.7 of IEEE Std C37.100.1-2018 is applicable.

5.8 Rated duration of short-circuit (t_k)

Subclause 5.8 of IEEE Std C37.100.1-2018 is applicable.

If this is a rating it should be on the nameplate

5.9 Rated control voltage of operating devices and of auxiliary and control circuits (U_a)

Subclause 6.7 of IEEE Std C37.04-2018 is applicable.

5.10 Rated control frequency of operating devices and auxiliary circuits

Subclause 5.10 of IEEE Std C37.100.1-2018 is applicable.

5.11 Rated pressures of compressed gas supply for insulation, operation, and/or interruption

19) Rated minimum operating temperature

Rated filling levels for insulation and/or operation, refers to the pressure in Pa (or density) or liquid mass assigned by the manufacturer referred to atmospheric air conditions of 20 °C and 101.3 kPa (absolute) at which the gas- or liquid-filled circuit switcher is filled before being put into service.

5.12 Rated primary-bus fault breaking current (I_{pbf})

Replace this with .04 T100 see 5.6

The rated primary-bus fault breaking current is the highest primary-bus fault current that the circuit switcher shall be capable of breaking under the conditions of use and behavior prescribed in this standard in a circuit having a power-frequency recovery voltage corresponding to the rated maximum voltage of the circuit switcher and having a TRV equal to the value specified in 5.13.

The rated primary-bus fault breaking current is characterized by two values:

- The rms value of its ac component
- The percentage dc component

Short circuit interrupting or breaking?

NOTE—If the dc component does not exceed 20%, the rated short-circuit breaking current is characterized only by the rms value of its ac component.

For determination of the ac and dc components, see Figure 3.

The circuit switcher shall be capable of breaking any primary-bus fault breaking current up to its rated primary-bus fault breaking current containing any ac component up to the rated value and, associated with it, any percentage dc component up to that specified under the conditions mentioned in the first paragraph of this subclause. At voltages below and equal to the rated maximum voltage, a standard circuit switcher shall be capable of breaking its rated primary-bus fault breaking current.

5.12.1 AC component of the rated primary-bus fault breaking current

The preferred values of the ac component of the rated primary-bus fault breaking current are selected from the R10 series.

5.12.2 DC component of the rated primary-bus fault breaking current

The percentage dc component shall correspond to a time interval equal to the minimum opening time of the first opening pole (T_{op}) of the circuit switcher plus an assumed relay time of one half-cycle of rated power frequency (T_r).

The minimum opening time mentioned in the previous paragraph is specified by the manufacturer.

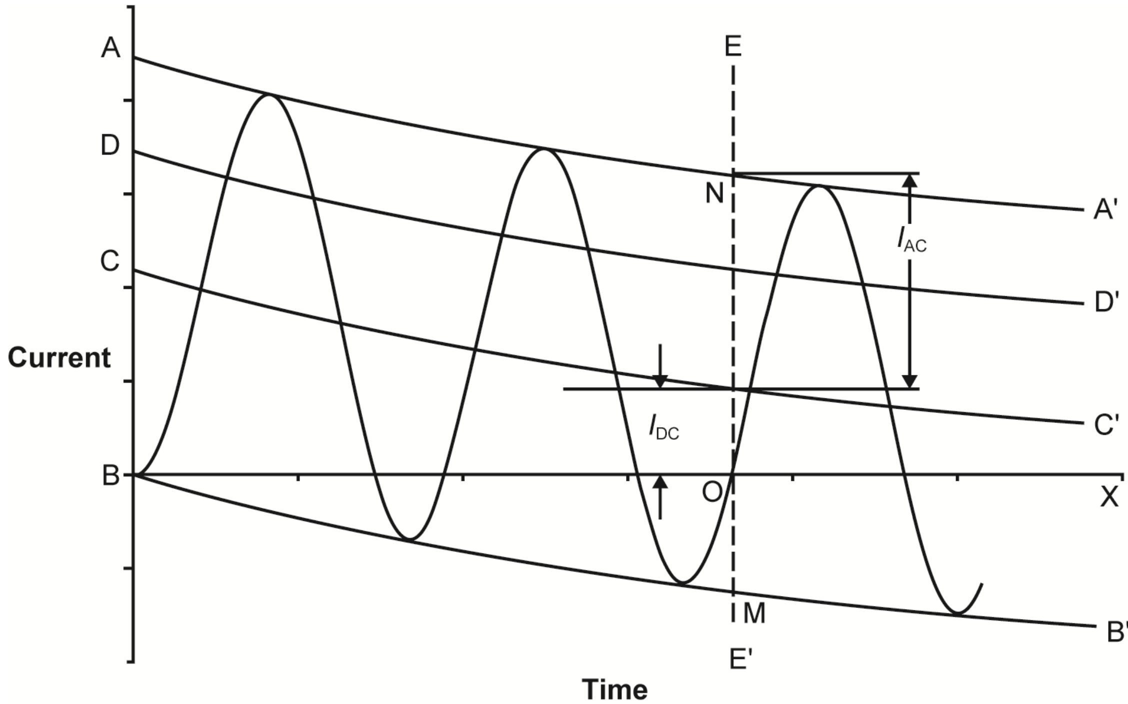
The percentage value of the dc component (% dc) can be derived from Figure 4 and is based on the time interval ($T_{op} + T_r$) and the time constant τ using the formula:

$$\%\ \mathrm{dc} = 100 \times e \frac{\left(T_{op} + T_r\right)}{\tau}$$

where

T_{op} is the minimum opening time of the first opening pole (ms)
T_r is the assumed relay time of one half-cycle of rated power frequency (ms)
τ is the time constant (ms)

The graphs of the dc component against time given in Figure 4 are based on a standard time constant of 45 ms.



AA', BB'	is envelope of current-wave
BX	is normal zero line
CC'	is displacement of current wave zero line at any instant
DD'	is rms value of the ac component of current at any instant, measured from CC'
EE'	is instant of contact separation (initiation of the arc)
I_{MC}	is making current
I_{AC}	is peak value of ac component of current at instant EE'
$I_{AC}/\sqrt{2}$	is rms value of the ac component of current at instant EE'
I_{DC}	is value of the dc component of current at instant EE'

$$\frac{I_{DC}}{I_{AC}}\cdot 100 = \frac{\overline{ON} - \overline{NM/2}}{\overline{NM/2}}\cdot 100 = \left(\frac{2.\overline{ON}}{NM} - 1\right)\cdot 100$$ is percentage value of the dc component

Figure 3—Determination of short-circuit making and breaking currents and of percentage dc component

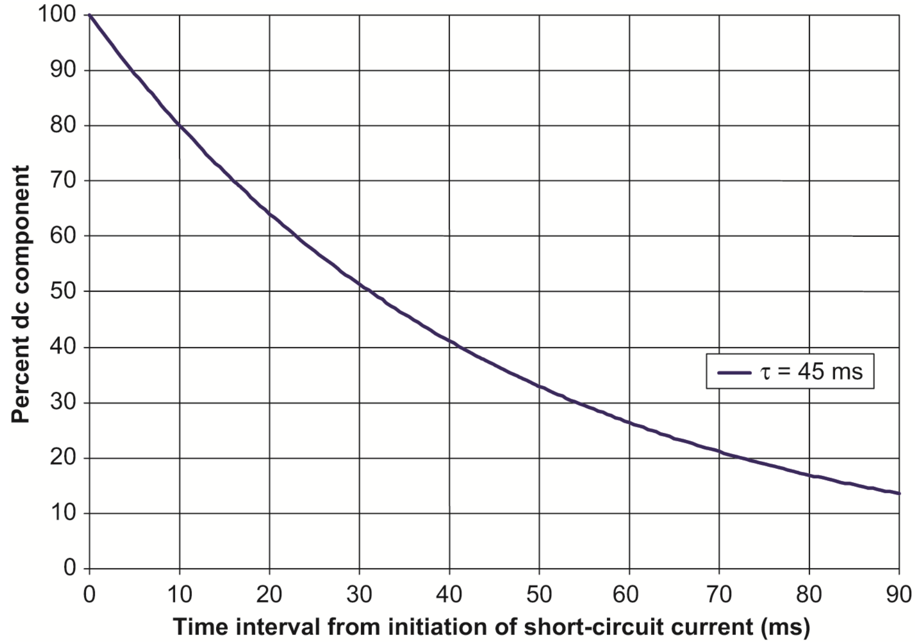


Figure 4—Percentage dc component in relation to time interval (T_{op} + T_r) for standard time constant τ = 45 ms

5.13 TRV related to the rated primary-bus fault breaking current

5.13.1 General

The TRV related to the rated primary-bus fault breaking current in accordance with 5.12 is the reference voltage that constitutes the limit of the prospective TRV of circuits that the circuit switcher shall be capable of withstanding under primary-bus fault conditions.

The waveform of TRVs varies according to the arrangement of actual circuits.

For primary-bus faults on systems with a voltage 100 kV and above and for system-fed fault currents that are relatively large in relation to the maximum primary-bus fault current at the point under consideration, the TRV contains first a period of high rate of rise, followed by a later period of lower rate of rise. This waveform is generally adequately represented by an envelope consisting of three line segments defined by means of four parameters.

For primary-bus faults on systems with a voltage less than 100 kV, the TRV approximates to a damped single-frequency oscillation. This waveform is adequately represented by an envelope consisting of two line segments defined by means of two parameters.

Such a representation in terms of two parameters is a special case of representation in terms of four parameters.

The influence of local capacitance on the source side of the circuit switcher produces a slower rate of rise of the voltage during the first few microseconds of the TRV. This is taken into account by introducing a time delay.

5.13.2 Representation of TRV

The following parameters are used for the representation of TRV:

a) Four-parameter reference line (see Figure 6): For voltages 100 kV and above

u_1 = first reference voltage (kV)
t_1 = time to reach u_1 (μs)
u_c = second reference voltage (TRV peak value) (kV)
t_2 = time to reach u_c (μs)

TRV parameters are defined as a function of the rated maximum voltage (U_r), the first pole-to-clear factor (k_{pp}), and the amplitude factor (k_{af}) as follows:

Only time RRRV is mentioned

$$u_1 = 0.75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$$

t_1 is derived from u_1 and the specified value of the rate of rise u_1/t_1 = RRRV. Is this statement of value?

$$u_c = k_{af} \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$$, where k_{af} is equal to 1.4 for primary-bus faults.

$t_2 = 4\ t_1$

b) Two-parameter reference line for rated maximum voltages below 100 kV (see Figure 5):

u_c = reference voltage (TRV peak value) (kV)
t_3 = time to reach u_c (μs)

TRV parameters are defined as a function of the rated maximum voltage (U_r), the first pole-to-clear factor (k_{pp}), and the amplitude factor (k_{af}) as follows:

$$u_c = k_{af} \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$$, where $k_{af} = 1.54$ and $k_{pp} = 1.5$

t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3 = RRRV. Is this statement of value?

c) Delay line of TRV (see Figure 5 and Figure 6):

t_d = time delay (μs)
u' = reference voltage (kV)
t' = time to reach u' (μs)

The delay line starts on the time axis at the specified time delay, runs parallel to the first section of the reference line of rated TRV, and terminates at the voltage u' (time coordinate t').

For rated maximum voltages below 100 kV:

$t_d = 0.05\ t_3$
$u' = u_c/3$ and
t' is derived from u', u_c/t_3, and t_d according to Figure 5.

For rated maximum voltages 100 kV and above:

t_d = 2 μs
u' = u_1/2 and
t' is derived from u', u_1/t_1, and t_d according to Figure 6.

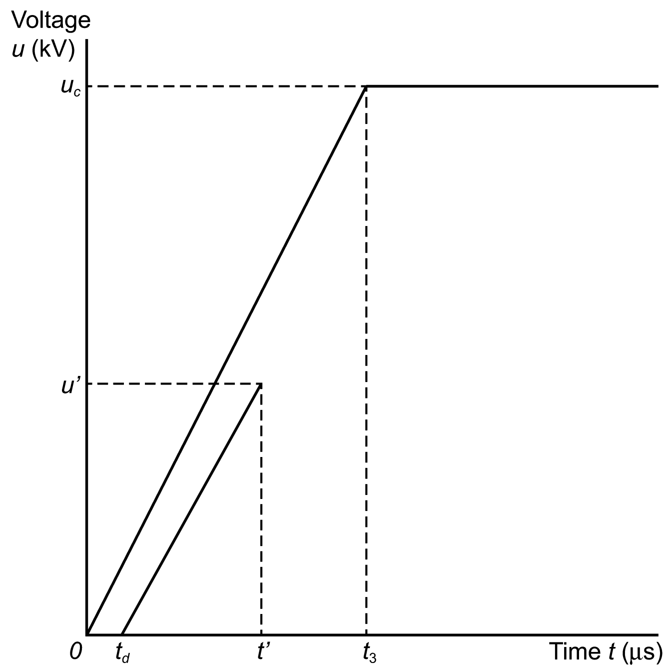


Figure 5—Representation of specified TRV by two-parameter reference and delay line

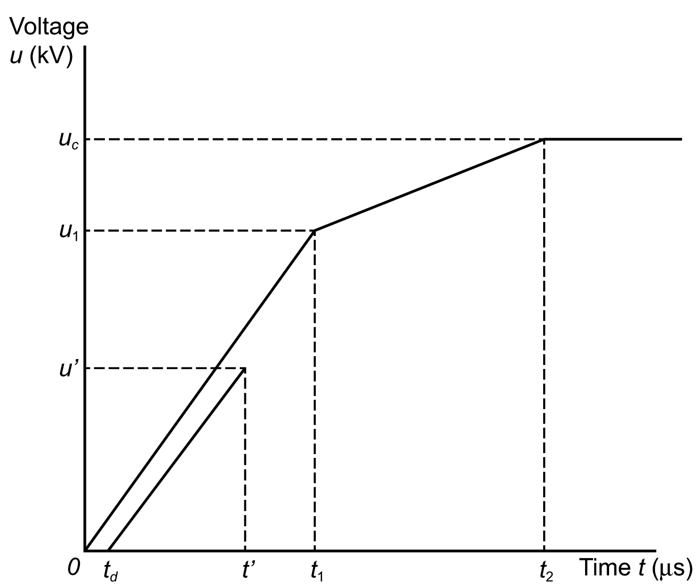


Figure 6—Representation of specified TRV by four-parameter reference and delay line

5.13.3 Standard values of TRV

Preferred values of TRV for three-pole circuit switchers of rated maximum voltages below 100 kV make use of two parameters. Values are given in Table 2.

Table 2—Standard values of TRV for system-fed faults with rated maximum voltages below 100 kV with representation by two parameters

Rated maximum voltage U_r (kV)	First pole-to-clear factor k_{pp} (pu)	Amplitude factor k_{af} (pu)	TRV peak value u_c (kV)	Time t_3 (µs)	Time delay t_d (µs)	Voltage u' (kV)	Time t' (µs)	Rate of rise u_c/t_3 (kV/µs)
15.5	1.5	1.54	29.2	32	2	9.7	12	0.92
25.8	1.5	1.54	48.7	45	2	16.2	17	1.08
38	1.5	1.54	71.7	59	3	23.9	23	1.21
52	1.5	1.54	98.1	74	4	32.7	36	1.33
72.5	1.5	1.54	137	93	5	45.6	36	1.47

For rated maximum voltages of 100 kV and above, four parameters are used. Values are given in Table 3. For effectively grounded systems, a first pole-to-clear factor (k_{pp}) of 1.3 should be used. For ungrounded systems and for three-phase ungrounded faults on effectively grounded systems, a first pole-to-clear factor (k_{pp}) of 1.5 should be used.

Table 3—Standard values of TRV for system-fed faults with rated maximum voltages 100 kV and above with representation by four parameters

Rated maximum voltage U_r (kV)	First pole-to-clear factor k_{pp} (pu)	Amplitude factor k_{af} (pu)	First reference voltage U_1 (kV)	Time t_1 (µs)	TRV peak value u_c (kV)	Time t_2 (µs)	Time delay t_d (µs)	Voltage u' (kV)	Time t' (µs)	Rate of rise u_1/t_1 (kV/µs)
100	1.3	1.4	80	40	149	160	2	40	22	2
100	1.5	1.4	92	46	171	184	2	46	25	2
123	1.3	1.4	98	49	183	196	2	49	27	2
123	1.5	1.4	113	57	211	226	2	57	30	2
145	1.3	1.4	115	58	215	230	2	58	31	2
145	1.5	1.4	133	67	249	266	2	67	35	2
170	1.3	1.4	135	68	253	270	2	68	36	2
170	1.5	1.4	156	78	291	312	2	78	41	2
245	1.3	1.4	195	98	364	390	2	98	51	2
245	1.5	1.4	225	113	420	450	2	113	58	2

The TRV corresponding to the rated primary-bus fault breaking current on the occurrence of a terminal fault is used for testing at primary-bus fault breaking currents equal to the rated value. However, for testing at primary-bus fault breaking currents less than 100% of the rated value, other values of TRV are specified (see 5.13.4).

5.13.4 TRVs for currents below rated primary-bus fault breaking current

The circuit switcher shall be capable of withstanding a TRV envelope greater than the rated TRV when interrupting primary-bus fault currents are less than the rated primary-bus fault breaking current. The TRV parameters for currents below the rated primary-bus fault breaking current are defined as a function of the parameters for the 100% rated primary-bus fault breaking current case [designated by a (100) subscript] and appropriate multipliers:

For rated maximum voltages below 100 kV, two parameters are used.

- TRV peak value $u_c = K_u\, u_{c(100)}$ (see Figure 7).
- Rate of rise $u_c/t_3 = K_r\, u_{c(100)}/t_{3(100)}$ (see Figure 8).
- Voltage $u' = u_c/3$.
- Time delay $t_d = 0.05\, t_3$.
- Time t' is derived from u', u_c/t_3, and t_d according to Figure 5.

Dump this and replace with Tables 14, 19 and 20 from .04

Why not just $t_3 = u_c \cdot t_{3(100)}/(K_r * u_{c(100)})$

This was not in -2006

For rated maximum voltages 100 kV and above, the four parameters are used.

- First reference voltage $u_1 = K_u\, u_{1(100)}$ (see Figure 7).
- Rate of rise $u_1/t_1 = K_r\, u_{1(100)}/t_{1(100)}$ (see Figure 8).
- TRV peak value $u_c = K_u\, u_{c(100)}$ (see Figure 7).
- Time $t_2 = t_{2(100)}/K_t$ (see Figure 8).
- Voltage $u' = u_{c(100)}/2$.
- Time delay $t_d = 2$ μs.
- Time t' is derived from u', u_1/t_1, and t_d according to Figure 6.

What does Ku mean, K under?

Why not just $t_1 = u_1 * t_{1(100)}/(K_r * u_{1(100)})$

Is this equation correct??

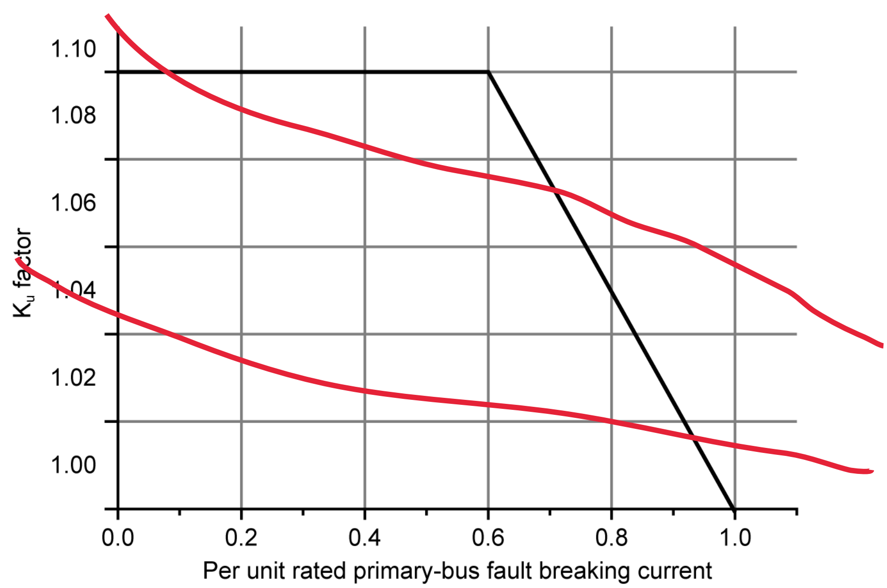


Figure 7— K_u factor

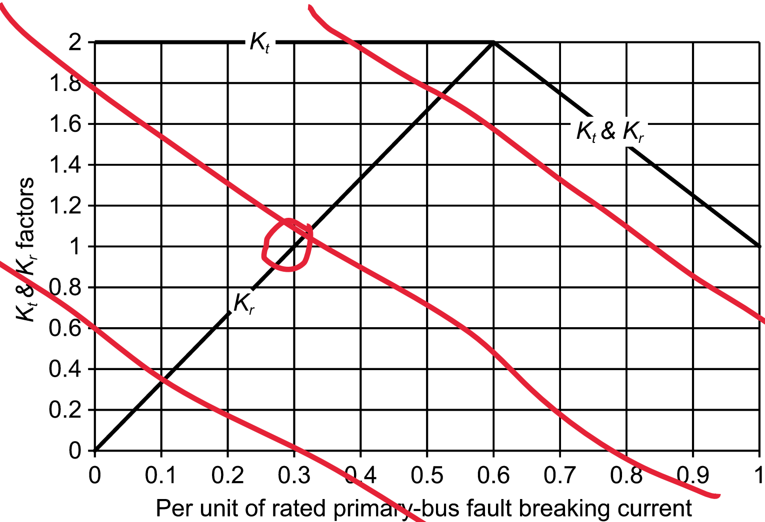


Figure 8—K_t and K_r factors

5.14 Rated transformer-limited fault breaking current (I_{tf})

The rated transformer-limited fault breaking current is the highest transformer-limited fault current that the circuit switcher shall be capable of breaking under the conditions of use and behavior prescribed in this standard in a circuit having a power-frequency recovery voltage corresponding to the rated maximum voltage of the circuit switcher and having a TRV equal to the value specified in 5.15. The preferred rated transformer-limited fault breaking currents are selected from the R10 series.

5.15 Rated TRV related to the transformer-limited fault breaking current

5.15.1 General

The TRV related to the rated transformer-limited fault breaking current in accordance with 5.14 is the reference voltage that constitutes the limit of the prospective TRV of circuits that the circuit switcher shall be capable of withstanding under transformer-limited fault currents.

The TRV can be approximated by a damped single-frequency oscillation for the transformer-limited fault because the fault is influenced by the transformer. This waveform is adequately represented by an envelope consisting of two line segments defined by means of two parameters.

5.15.2 Representation of TRV

The following parameters are used for the representation of TRV:

a) Two-parameter reference line (see Figure 5):

u_c = reference voltage (TRV peak value) (kV)
t_3 = time to reach u_c (µs)

TRV parameters are defined as follows as a function of the rated maximum voltage (U_r), the first pole-to-clear factor (k_{pp}), and the amplitude factor (k_{af}):

$$u_c = 0.9 k_{pp} k_{af} U_r \sqrt{\frac{2}{3}}$$

where k_{af} is equal to 1.8 (based on statistical measurements of transformers), k_{pp} is equal to 1.5 reflecting ungrounded transformer primary connections for transformer-limited faults, and the 0.9 factor accounts for the reduction of the TRV because of the voltage drop across the source impedance.

$$t_3 = 0.106 \sqrt{\frac{U_r C}{I_{tf}}}$$

where C is equal to the lumped equivalent terminal capacitance to ground of the transformer in picofarads, and I_{tf} is equal to the transformer-limited fault current in kiloamperes, as follows:

$C = 1480 + 89\ I_{tf}$ (pF) for rated maximum voltages less than 123 kV
$C = 1650 + 180\ I_{tf}$ (pF) for rated maximum voltages 123 kV and above

d) Delay line of TRV (see Figure 5)

t_d = time delay (μs)
u' = reference voltage (kV)
t' = time to reach u' (μs)

NOTE—The equations for t_3 and C given in item c) are based on the 90th percentile curves for three-phase power transformer TRV frequencies across the first pole to clear given in Annex B of IEEE Std C37.011 [B2].

The delay line starts on the time axis at the rated time delay, runs parallel to the first section of the reference line of rated TRV, and terminates at the voltage u' (time coordinate t').

For rated maximum voltages below 100 kV:

$t_d = 0.2\ t_3$
$u' = u_c/3$
t' is derived from u', u_c/t_3, and t_d according to Figure 5.

For rated maximum voltages from 100 kV to 245 kV:

$t_d = 0.123\ t_3$
$u' = u_c/3$
t' is derived from u', u_c/t_3, and t_d according to Figure 5.

5.15.3 Preferred values of TRV for rated transformer-limited fault breaking current

Preferred values of TRV for three-pole circuit switchers with rated transformer-limited fault breaking current are calculated from the equations given in 5.15.2.

NOTE—The following is an example of how to calculate the rated TRV for a typical transformer-limited fault application:

Circuit switcher ratings:

Rated maximum voltage U_r = 145 kV
First pole-to-clear factor k_{pp} = 1.5
Rated transformer-limited fault current I_{tf} = 4 kA

Calculated values for two-parameter representation of the TRV related to the rated transformer-limited fault current:

$u_c = 0.9 \times 1.5 \times 1.8 \times \sqrt{(2/3)} \times 145 = 288$ kV
$C = 1650 + 180 \times 4 = 2370$ pF
$t_3 = 0.106 \times \sqrt{(145 \times 2370/4)} = 31$ µs
$t_d = 0.123 \times 31 = 3.8$ µs
$u' = 288 / 3 = 96$ kV
$t' = 96 \times (31/288) + 3.8 = 14.1$ µs

5.15.4 TRV for transformer-limited fault currents less than the rated value

The circuit switcher shall be capable of withstanding a TRV calculated as shown in 5.15.2 when interrupting transformer-limited fault currents less than the rated transformer-limited fault breaking current.

5.16 Rated short-circuit making current (I_m)

The rated short-circuit making current is the maximum peak power-frequency current that a circuit switcher shall be required to make at its rated maximum voltage. The peak current is 2.5 times the symmetrical value at rated power frequency of 50 Hz and 2.6 times at a rated power frequency of 60 Hz.

When the rated short-circuit making current exceeds 2.5 times the rated primary-bus fault breaking current at 50 Hz or 2.6 times the rated primary-bus fault breaking current at 60 Hz, the circuit switcher shall be assigned a 1 or 2 times duty-cycle closing rating. The circuit switcher shall be able to switch and carry the rated continuous current after completion of all the duty-cycle closing operations. Additionally, the circuit switcher shall be able to interrupt its rated fault currents after the first closing operation when a 2 times duty-cycle closing rating is assigned.

5.17 Rated operating sequence

The rated operating sequence of a circuit switcher is close-open (CO), which represents a closing operation followed immediately (that is, without any intentional delay) by an opening operation.

5.18 Rated capacitive switching currents

5.18.1 General

Capacitive switching currents may comprise part or all of the operating duty of a circuit switcher, such as the charging current of an unloaded transmission line or cable or the load current of a shunt capacitor bank.

The rating of a circuit switcher for capacitive current switching shall include the following, where applicable:

a) Rated line charging breaking current
b) Rated cable charging breaking current
c) Rated capacitor bank breaking current
d) Rated back-to-back capacitor bank transient peak inrush making current
e) Tested back-to-back capacitor bank transient inrush making current frequency
f) Application grounding condition: grounded or ungrounded
g) Pole discrepancy: simultaneous or non-simultaneous operation

h) Breaking in the presence of ground faults

i) Restrike performance—Class C0, Class C1, or Class C2

Preferred values of rated capacitive switching currents are given in Table 4.

Table 4—Preferred values of rated capacitive switching currents

Rated maximum voltage U_r (kV, rms)	Rated line-charging switching current I_l (A, rms)	Rated cable-charging switching current I_c (A, rms)	Rated shunt capacitor bank switching current[a] I_b (A, rms)	Rated peak capacitive inrush current I_{bi} (kA)	Frequency of the inrush current F_{bi} (kHz)
15.5	10	25	600	20	5
25.8	10	31.5	600	20	5
38	10	50	600	20	5
52	10	80	600	20	5
72.5	20	125	600	20	5
100	20	125	600	20	5
123	50	140	600	20	5
145	80	160	600	20	5
170	100	160	600	20	5
245	160	250	600	20	5

[a]The preferred class of shunt capacitor bank switch current is class C2 per IEEE Std C37.100.2-2018.

The recovery voltage related to capacitive current switching depends on the following:

Compare this to 100.2 for example simultanaety is missing.

— The grounding of the system.

— The grounding of the capacitive load, for example screened cable, capacitor bank, transmission line.

— The mutual influence of adjacent phases of the capacitive load, for example belted cables, open air lines.

— The mutual influence of adjacent systems of overhead lines on the same route.

— The presence of single- or two-phase ground faults.

The following three classes of circuit switchers are defined according to their restrike performances:

— Class C0: unspecified probability of restrike during capacitance current breaking; up to one restrike per operation.

— Class C1: low probability of restrike during capacitance current breaking.

— Class C2: very low probability of restrike during capacitance current breaking.

Each capacitance current switching rating assigned must have an associated class (C0, C1, or C2) with it.

A circuit switcher can be of class C2 for one kind of application (for example in grounded neutral systems) and of class C1 for another kind of application where the recovery voltage stress is more severe (for example in systems other than grounded neutral systems).

5.18.2 Rated line-charging breaking current (LC)

The rated line-charging breaking current is the maximum line-charging current that the circuit switcher shall be capable of breaking at its rated voltage.

5.18.3 Rated cable-charging breaking current (CC)

The rated cable-charging breaking current is the maximum cable-charging current that the circuit switcher shall be capable of breaking at its rated voltage.

5.18.4 Rated single capacitor bank breaking current (BC)

The rated single capacitor bank breaking current is the maximum capacitor current that the circuit switcher shall be capable of breaking at its rated voltage. Rated single capacitor bank breaking current is applicable for both single bank and back-to-back bank applications.

5.18.5 Rated back-to-back capacitor bank transient peak inrush making current (I_{bb})

The rated back-to-back capacitor bank transient peak inrush making current is the peak value of the current that the circuit switcher shall be capable of making at its rated voltage and with a frequency of the inrush current appropriate to the service conditions.

5.19 Rated time quantities

5.19.1 General

Refer to Figure 9, Figure 10, and Figure 11.

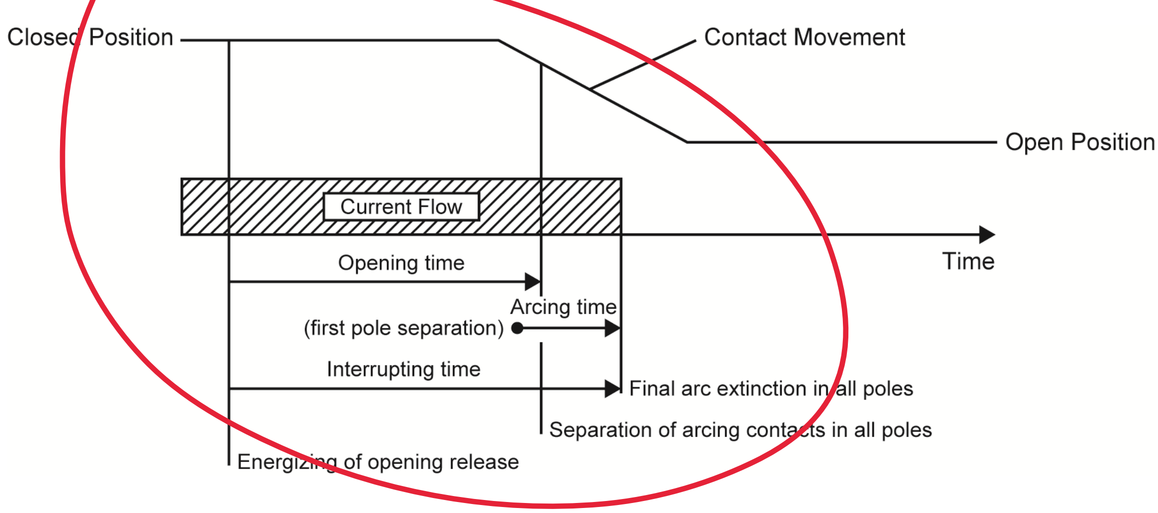


Figure 9—Opening time quantities

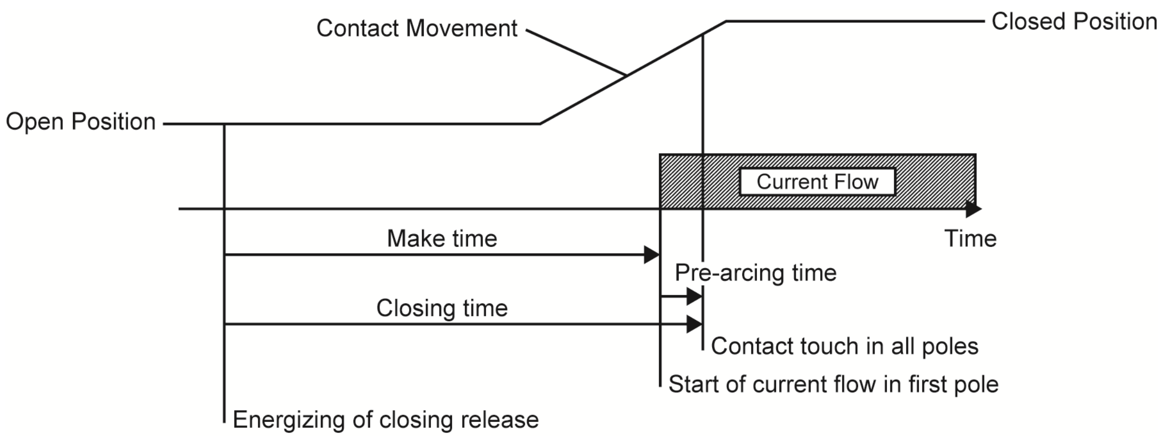


Figure 10—Closing time quantities

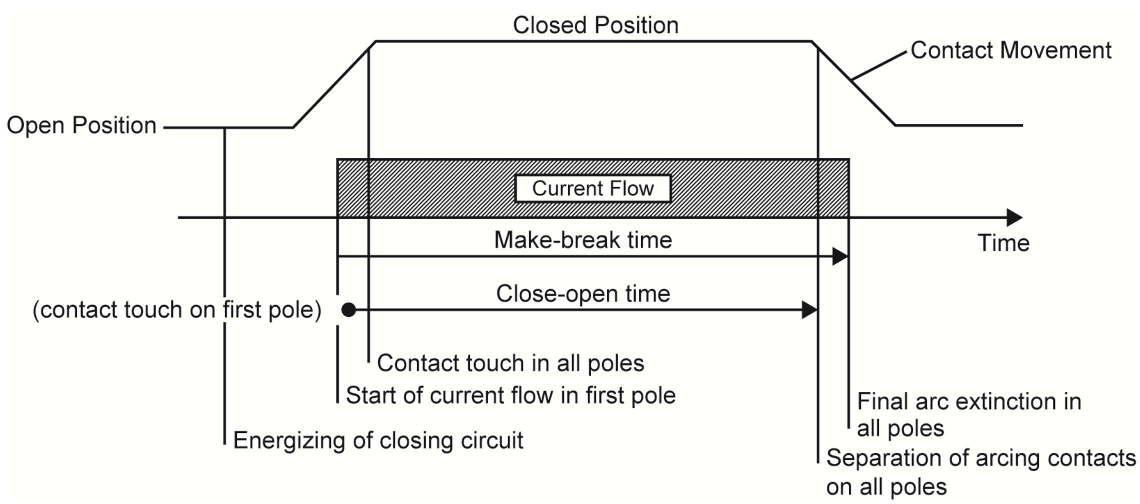


Figure 11—Close-open time quantities

Rated values may be assigned to the following time quantities:

— Opening time (no load)

— Interrupting time

— Closing time (no load)

NOTE 1—Although rated values may be assigned, they are not verified by the tests specified in this standard as the tests are not performed with rated conditions.

Rated time quantities are based on the following:

— Rated control voltages of closing and opening devices and of auxiliary circuits

— Rated control frequency of closing and opening devices and of auxiliary circuits' rated pressures of compressed gas supply for operation and for interruption, as applicable rated pressure of hydraulic supply for operation

— An ambient air temperature of 20 ± 5 °C

NOTE 2—Usually, it is not practical to assign a rated value of make time or of make-break time due to the variation of the pre-arcing time.

5.19.2 Rated interrupting time

C37.09-2018, 4.7?

The rated interrupting time of a circuit switcher is the maximum interval between energizing the trip circuit and interruption of the main circuit in all poles on an opening operation when interrupting a current within the assigned ratings at rated maximum voltage. If we do single phase tests how would we know this?

NOTE—Although a rated interrupting time may be assigned, it is not verified by the tests specified in this standard as the tests are not performed with rated conditions.

5.20 Mechanical operations endurance

A circuit switcher shall be able to perform the number of operations given in Table 5, taking into account the program of maintenance specified by the manufacturer.

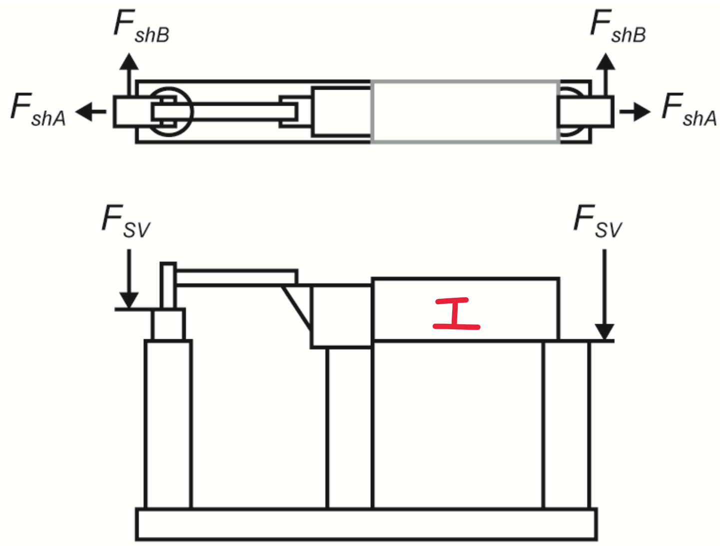
Table 5—Preferred rated mechanical endurance operations

Class	Endurance	Number of operating cycles
CSM1	Low mechanical endurance for applications such as transformer protection	1500
CSM2	Medium mechanical endurance for applications such as capacitor bank switching	5000
CSM3	High mechanical endurance for applications such as frequent capacitor bank switching	10 000

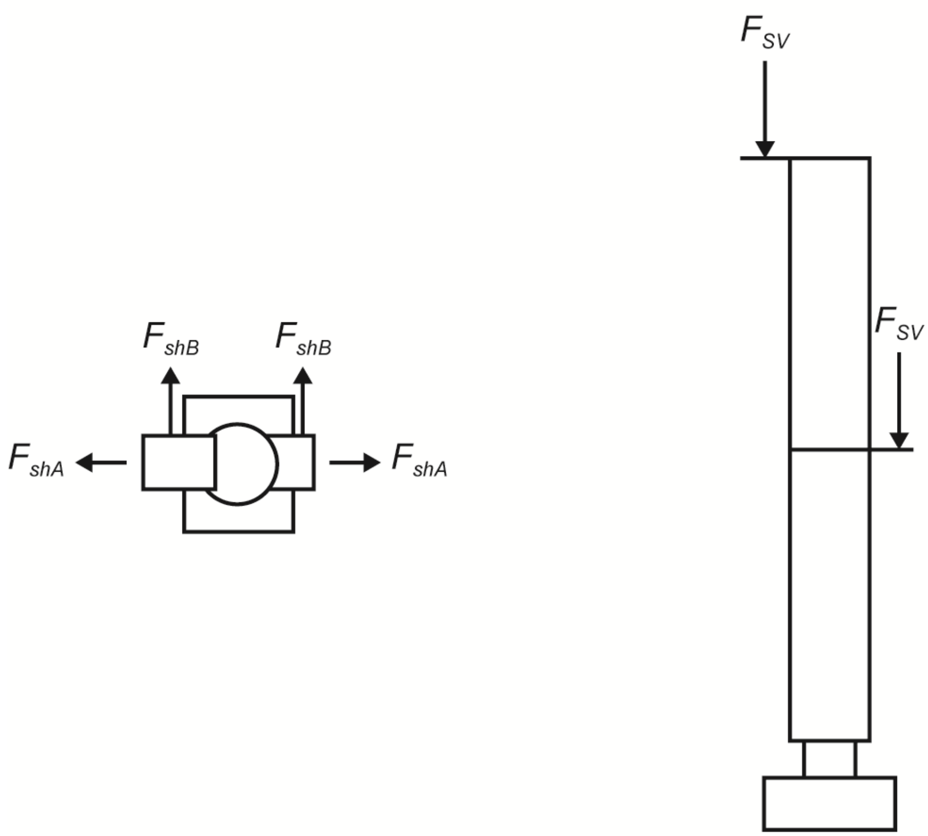
5.21 Rated static terminal load

The rated static terminal load is the highest static terminal load that may be applied to the circuit switcher terminals as shown in Figure 11.

The preferred rated static terminal loads are given in Table 6.



(a) Circuit switcher with isolating disconnect



(b) Circuit switcher without isolating disconnect

Figure 12—Examples of the application of rated static terminal loads

Table 6—Preferred values of rated static terminal loads

Preferred rated maximum voltage U_r (kV)	Rated continuous current	Static horizontal force F_{sh} Longitudinal F_{shA} (N)	Static horizontal force F_{sh} Transverse F_{shB} (N)	Static vertical force (vertical axis-upward and downward) F_{sv} (N)
Circuit switchers with isolating disconnects				
15.5–72.5	—	400	130	130
100–170	—	530	180	490
245	—	800	270	1670
Circuit switchers without isolating disconnects				
15.5–72.5	1250 A and below Above 1250 A	500 750	400 500	500 750
100–170 kV	2000 A and below Above 2000 A	1000 1250	750 750	750 1000
245 kV	All	1250	1000	1250

5.22 Rated ice-breaking ability

The rated ice-breaking ability is the maximum thickness of ice deposited on a device that will not interfere with its successful opening or closing.

The preferred values of rated ice-breaking ability are 9.5 mm and 19 mm.

6. Design and construction

6.1 Requirements for liquids in circuit switchers

Subclause 6.1 of IEEE Std C37.100.1-2018 is applicable.

6.2 Requirements for gases in circuit switchers

Subclause 6.2 of IEEE Std C37.100.1-2018 is applicable.

6.3 Grounding of circuit switchers

Subclause 6.3 of IEEE Std C37.100.1-2018 is applicable with the following addition:

The diameter of the clamping screw or bolt shall be at least 12 mm. A standard 2-hole NEMA pad as defined in NEMA CC 1-2009 should be provided when specified. Other terminals pads may also be specified and supplied.

6.4 Auxiliary and control equipment and circuits

Users shall specify the auxiliary equipment requirements necessary for their applications.

6.5 Dependent power operation

Subclause 6.5 of IEEE Std C37.100.1-2018 is applicable with the following addition:

A circuit switcher arranged for dependent power closing with external energy supply shall also be capable of opening immediately following the closing operation with the rated primary-bus fault breaking current.

6.6 Stored energy closing

6.6.1 General

A circuit switcher arranged for stored energy closing shall also be capable of opening immediately following the closing operation with the rated primary-bus fault breaking current when the energy store is suitably charged in accordance with 6.6.2 or 6.6.3. If maximum closing and opening times are stated by the manufacturer, these maximums shall not be exceeded.

Except for slow operation during maintenance, the main contacts shall move only under the action of the drive mechanism and in the designed manner and not in the case of reapplication of the energy supply after a loss of energy.

6.6.2 Energy storage in gas receivers or hydraulic accumulators

When the energy store is a gas receiver or hydraulic accumulator, the requirements of 6.6.1 apply at operating pressures between the following:

a) External pneumatic or hydraulic supply
   - Unless otherwise specified by the manufacturer, the limits of the operating pressure are between 85% and 110% of rated pressure.
   - These limits do not apply where receivers also store compressed gas for interruption.

b) Compressor or pump integral with the circuit switcher or the operating device
   - The limits of operating pressure shall be stated by the manufacturer.

6.6.3 Energy storage in springs (or weights)

When the energy store is a spring (or weight), the requirements of 6.6.1 apply when the spring is charged (or the weight lifted). It shall not be possible for the moving contacts to move from the open position unless the charge is sufficient for satisfactory completion of the closing operation.

6.7 Manually operated releases

Circuit switchers shall be equipped with a manually operated release to OPEN the circuit switcher and may optionally be equipped with a manually operated release to CLOSE the circuit switcher. These releases shall be clearly labeled such that an operator can easily identify and operate them.

6.8 Operation of releases

Subclause 7.4.4 of IEEE Std C37.04-2018 is applicable.

6.9 Nameplates

The nameplates of a circuit switcher and its operating devices shall be marked in accordance with Table 7.

The nameplate shall be visible in the position of normal service and installation.

Table 7—Nameplate information

Information	Abbreviation[a]	Unit	Circuit switcher	Operating device	Condition: Marking required only if
Manufacturer			X	X	
Type designation and serial number			X	X	
Instruction book number			X	X	
Rated maximum voltage	U_r	kV	X		
Rated lightning impulse withstand voltage	U_p	kV	X		
Rated power frequency	f_r	Hz	X*		
Rated continuous current	I_r	A	X		
Rated short-time withstand current	I_k	kA	X		
Rated duration of short circuit	t_k	s	y		different from 1 s
Rated primary-bus fault breaking current	I_{pbf}	kA	X		
DC component of the rated primary-bus fault breaking current	% dc	%	y		more than 20%
Rated interrupting time for fault currents		ms	X		
Rated operating sequence			X		
Rated transformer-limited fault breaking current	I_{tf}	kA	X		
Rated short-circuit making current	I_m	kA	X		
Rated line-charging switching current	I_l	A	(X)		
Rated cable-charging switching current	I_c	A	(X)		
Rated shunt capacitor bank switching current	I_b	A	(X)		
Rated peak capacitive inrush current	I_{bi}	kA	(X)		
Rated filling pressure for operation	p_{rm}	MPa		(X)	
Rated filling pressure for interruption	p_{re}	MPa	(X)		
Rated control voltage of closing and opening devices		V		(X)	
Rated supply frequency of closing and opening devices		Hz		(X)	
Rated control voltage of auxiliary circuits	U_a	V		(X)	
Rated control frequency of auxiliary circuits		Hz		(X)	
Mass of circuit switcher	M	kg	y	y	more than 300 kg
Mass of interrupting medium (measured mass shipped)	m	kg	y		if gas or fluid used for interruption
Year of manufacture			X		

X = the marking of these values is mandatory; blanks indicate the value zero.
(X) = the marking of these values is optional or when specified by the user. y = the marking of these values is to the conditions in column (6).
* = device rated for both 50 Hz and 60 Hz shall be marked 50/60 Hz.

[a]The abbreviation in the second column may be used instead of the terms in the first column. When terms in the first column are used, the word "rated" need not appear.

We need a temperature rating for SF6 or such. See McCord Power Point

6.10 Locking devices

Circuit switchers with isolating disconnects shall be provided with locking facilities as specified to the manufacturer (e.g., provision of padlocks).

6.11 Position indication

Subclause 6.12 of IEEE Std C37.100.1-2018 is applicable.

6.12 Degrees of protection provided by enclosures

Subclause 6.13 of IEEE Std C37.100.1-2018 is applicable.

6.13 Creepage distances for outdoor insulators

Subclause 6.14 of IEEE Std C37.100.1-2018 is applicable.

6.14 Gas and vacuum tightness

Subclause 7.11 of IEEE Std C37.04-2018 is applicable.

6.15 Tightness for liquid systems

Subclause 6.16 of IEEE Std C37.100.1-2018 is applicable.

6.16 Flammability

The materials should be chosen and the parts designed in such a way that they retard the propagation of any flame resulting from accidental overheating in the switchgear and controlgear and reduce harmful effects on the local environment. In cases where product performance requires the use of flammable materials, product design should take flame retardation into account, if applicable.

— IEEE Std C37.20.2 [B3] provides guidance on flame resistance tests for insulation.

— IEC 60695-1-10 [B1] provides guidance for assessing the fire hazard of electrotechnical products.

— IEC 60695-1-10 [B1] provides guidance on the minimization of toxic hazards due to fires involving electrotechnical products.

6.17 Electromagnetic compatibility (EMC)

Subclause 6.18 of IEEE Std C37.100.1-2018 is applicable.

6.18 X-ray emission

Subclause 6.19 of IEEE Std C37.100.1-2018 is applicable.

6.19 Pressurized components

Subclause 7.19 of IEEE Std C37.04-2018 is applicable.

6.20 Pressurized systems

Subclause 7.20 of IEEE Std C37.04-2018 is applicable.

6.21 Low- and high-pressure interlocking and monitoring devices

All circuit switchers having energy storage in gas receivers or hydraulic accumulators and all circuit switchers, except sealed pressure devices, using compressed gas for interruption shall be fitted with a low-pressure interlocking device, and can also be fitted with a high-pressure interlocking device, set to operate at, or within, the appropriate limits of pressure stated by the manufacturer. Sealed systems shall be fitted with a low gas pressure indicator set to the appropriate limits stated by the manufacturer.

6.22 Disconnect operation

6.22.1 Operating requirements for coordinated disconnect operation

Circuit switchers with coordinated disconnect operation shall have power-operated disconnects and integral control circuits to open the disconnect immediately after the interrupter opens and to close the disconnect in sequence with the interrupter to close the circuit switcher. Energization of the circuit may be done with the disconnect. The disconnect will operate every time the interrupter operates. Means shall be provided to decouple the disconnect drive from the power source and to lock the disconnect in the open position to provide secure isolation of the circuit.

6.22.2 Operating requirements for independent disconnect operation

Circuit switchers with independent disconnect operation have no requirement for the disconnect operation or position relative to the interrupter. Disconnect operation may be manual or power-operated, and these may be completely independent of the interrupter mechanism, position, or control scheme. For power-operated disconnects, means shall be provided to decouple the disconnect drive from the power source and to lock the disconnect in the open position to provide secure isolation of the circuit. For manually operated disconnects, means shall be provided to lock the disconnect in the open position. Requirements for interlocking shall be user specified.

7. Design (type) tests

7.1 General

7.1.1 Introduction

Each test specimen shall fully conform to drawings and be fully representative of its type and shall be subjected to one or more type tests.

Each individual type test shall be made in principle on a complete circuit switcher in the condition as required for service, on their operating devices and auxiliary equipment, all of which in principle shall be in, or restored to, a new and clean condition at the beginning of each type test.

7.1.2 Information for identification of specimens

Subclause 7.2.2 of IEEE Std C37.100.1-2018 is applicable.

7.1.3 Information to be included in design test (type test) reports

Subclause 7.2.3 of IEEE Std C37.100.1-2018 is applicable.

7.2 Dielectric tests

Change to 7.3.1 of .100.1 in a future version

7.2.1 General

Dielectric tests of the switchgear shall be performed in compliance with IEEE Std 4 unless otherwise specified in this standard.

The tolerance for test value of the impulse voltage tests is +3%/−0%.

If correction factors are applied due to atmospheric conditions at the time of the test, it may be necessary to perform separate tests on equipment with non-atmospheric insulation paths in accordance with 7.3.13 of IEEE Std C37.100.1-2018.

7.2.2 Ambient air conditions during tests

Subclause 7.3.2 of IEEE Std C37.100.1-2018 is applicable.

7.2.3 Wet test procedure

Subclause 7.3.3 of IEEE Std C37.100.1-2018 is applicable with the following addition:

For dead tank circuit switchers when the bushings have been previously wet tested, these tests can be omitted.

7.2.4 Arrangement of the equipment

Conditions of switchgear during dielectric tests

Subclause 7.3.4 of IEEE Std C37.100.1-2018 is applicable.

7.2.5 Criteria to pass the test

Subclause 7.3.5 of IEEE Std C37.100.1-2018 is applicable.

7.2.6 Application of test voltage and test conditions

7.2.6.1 General

Change to 7.3.6.1 of .100.1 in a future version

Distinction must be made between the general case, where the three test voltage applications (phase-to-ground, between phases, and across open switching device) are the same, and the special cases of the isolating distance and of insulation between phases higher than phase to ground.

Some insulating materials retain a charge after an impulse test and, for these cases, care should be taken when reversing the polarity. To allow the discharge of insulating materials, the use of appropriate methods, such as the application of three impulses at about 80% of the test voltage in the reverse polarity before the test, is recommended.

7.2.6.2 General case

7.2.6.2.1 Circuit switchers with interrupters only

Subclause 7.3.6.2 of IEEE Std C37.100.1-2018 is applicable.

7.2.6.2.2 Circuit switchers with disconnects

With reference to Figure 13, which shows a diagram of the connection of a three-pole circuit switcher, the test voltage shall be applied according to Table 8 as applicable.

Does this apply to both PF and LIWV?

Table 8—Test voltage application locations for circuit switcher with disconnect

Test condition	Interrupter position	Disconnect position	Voltage applied to	Ground connected to
1[a]	Closed	Closed	Aax	BCbcyzF
2	Closed	Closed	Bby	ACacxzF
3[b]	Closed	Closed	Ccz	ABabxyF
4[c,a,d]	Closed	Open	A	BCabcxyzF
5[c,d]	Closed	Open	B	ACabcxyzF
6[b,c,d]	Closed	Open	C	ABabcxyzF
7[c,a,d]	Closed	Open	ax	ABCbcyzF
8[c,d]	Closed	Open	by	ABCacxzF
9[b,c,d]	Closed	Open	cz	ABCabxyF
10[a,d,e,f]	Open	Closed	Ax	BCabcyzF
11[d,e,f]	Open	Closed	By	ACabcxzF
12[b,d,e,f]	Open	Closed	Cz	ABabcxyF
13[a,d,e,f]	Open	Closed	a	ABCbcxyzF
14[d,e,f]	Open	Closed	b	ABCacxyzF
15[b,d,e,f]	Open	Closed	c	ABCabxyzF

[a]When the circuit switcher has separately mounted poles, only test 1, 4, 7, 10, and 13 need be done with at least one adjacent grounded pole or equivalent ground plane mounted at the minimum recommended phase distance.

[b]Test conditions 3, 6, 9, 12, and 15 may be omitted if the poles are symmetric with respect to the center pole and ground.

[c]The interrupter shall be shorted out if necessary to achieve test conditions 4 to 9.

[d]Test conditions 4 to 15 do not necessarily confirm that the open device will always flashover to ground instead of across the open gap.

[e]Test conditions 10 to 15 not required for circuit switcher with coordinated disconnect operation.

[f]If the optional chopped wave test is to be performed, it should be performed on test conditions 10 to 15.

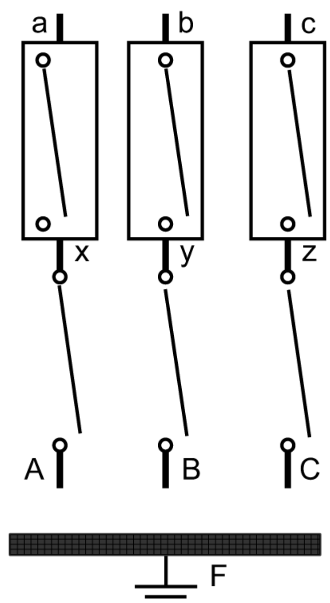


Figure 13—Dielectric test arrangement for circuit switcher with disconnect

7.2.6.3 Special case (when the test voltage across the open circuit switcher is higher than the phase-to-ground withstand voltage)

Subclause 7.3.6.3 of IEEE Std C37.100.1-2018 is applicable with the following addition:

When testing circuit switchers with disconnects, substitute Table 9 below for Table 11 or Table 12 in IEEE Std C37.100.1-2018.

Table 9—Impulse test conditions for longitudinal insulation for circuit switchers with disconnects[a,b]

Test condition	Interrupter position	Disconnect position	Voltage applied to		Ground connected to
			Main part	Complementary part	
1[c,d]	Closed	Open	A	ax	BCbcyzF
2[c]	Closed	Open	B	by	ACacxzF
3[c,e]	Closed	Open	C	cz	ABabxyF
4[c,d]	Closed	Open	ax	A	BCbcyzF
5[c]	Closed	Open	by	B	ACacxzF
6[c,e]	Closed	Open	cz	C	ABabxyF

[a]Figure 13 applies.
[b]These test conditions do not necessarily confirm that the open device will always flashover to ground instead of across the open gap.
[c]The interrupter shall be shorted out if necessary to achieve test conditions 1 to 6.
[d]When the circuit switcher has separately mounted poles, only test 1 and 4 need be done with at least one adjacent grounded pole or equivalent ground plane mounted at the minimum recommended phase distance.
[e]Test conditions 3 and 6 may be omitted if the poles are symmetric with respect to the center pole and ground.

7.2.7 Tests of circuit switchers

7.2.7.1 General

The tests shall be performed with the test values equal to the withstand values given in Table 1.

7.2.7.2 Power-frequency voltage tests

Subclause 7.3.7.2 of IEEE Std C37.100.1-2018 is applicable with the following addition:

In the case of circuit switchers enclosed in a metal tank where the bushings have been previously tested according to the relevant standards, tests under wet conditions can be omitted.

7.2.7.3 Lightning impulse voltage test

Subclause 7.3.7.3 of IEEE Std C37.100.1-2018 is applicable.

7.2.7.4 Chopped wave (optional)

Subclause 4.5.7 of IEEE Std C37.09-2018 is applicable with the following revision:

The magnitudes of the test voltages are given in Table 1 of this standard.

7.2.8 Artificial pollution tests

Artificial pollution tests are not required for insulators having creepage distances that comply with 6.13. If the creepage distances do not comply with the requirements of the 6.13, artificial pollution tests shall be performed according to IEC 60507:2013, using the rated voltage and the application factors given in IEC 60815-1:2008.

7.2.9 Partial discharge tests

Subclause 7.3.10 of IEEE Std C37.100.1-2018 is applicable with the following addition:

Partial discharge tests are not normally required to be performed on the complete circuit switcher. However, in the case of circuit switchers using components for which a relevant IEEE standard exists, including partial discharge measurements evidence shall be produced by the manufacturer showing that those components have passed the partial discharge tests as laid down in the relevant IEEE standard.

7.2.10 Dielectric tests on auxiliary and control circuits

Subclause 5.16 of IEEE Std C37.09-2018 is applicable.

7.2.11 Voltage test as a condition check

Subclause 7.3.12 of IEEE Std C37.100.1-2018 is applicable.

7.3 Radio interference voltage (R.I.V.) tests

Subclause 7.4 of IEEE Std C37.100.1-2018 is applicable with the following addition:

The circuit switcher shall be considered to have passed the test if the radio interference level at 1.1 $U_r/\sqrt{3}$ does not exceed 500 µV.

7.4 Resistance measurement

Subclause 7.5 of IEEE Std C37.100.1-2018 is applicable.

7.5 Continuous current tests

Subclause 7.6 of IEEE Std C37.100.1-2018 is applicable.

(STC)

7.6 Short-time withstand current and peak withstand current tests

Subclause 7.7 of IEEE Std C37.100.1-2018 is applicable with the following addition:

For a three-phase peak withstand current test, the maximum peak current shall occur in an outside pole.

7.7 Verification of the protection provided by enclosures

Subclause 7.8 of IEEE Std C37.100.1-2018 is applicable.

7.8 Tightness tests

Subclause 7.9 of IEEE Std C37.100.1-2018 is applicable.

7.9 Electromagnetic compatibility tests

Subclause 7.10 of IEEE Std C37.100.1-2018 is applicable.

7.10 X-radiation procedure for vacuum interrupters

Subclause 7.12 of IEEE Std C37.100.1-2018 is applicable.

7.11 Mechanical and environmental tests

7.11.1 General

Subclause 4.13.1 of IEEE Std C37.09-2018 is applicable.

Why list both and not just one 4.13

7.11.2 Mechanical endurance test object and conditions

~~Subclause 4.13.2 of IEEE Std C37.09-2018~~ is applicable.

7.11.3 Circuit switcher operational characteristics

Performance characteristics describe the data taken before, during, and after the mechanical endurance and environmental tests. These characteristics are grouped into datasets 1, 2, and 3, which are defined in Table 10.

Table 10 —Mechanical endurance and environmental test operational characteristic dataset

Item	Characteristic[a]	Dataset 1	Dataset 2	Dataset 3	Reference clause
a	Closing time		X	X	
b	Opening time		X	X	
c	Contact Δt within one phase (if applicable)		X	X	
d	Contact Δt between phases (if applicable)		X	X	
e	Time-travel curve		X	X	
f	Current trace of open signal		X	X	
g	Current trace of close signal		X	X	
h	Recharge time		X	X	
i	Monitor density switch contacts (if applicable)			X	
j	Resistance test of the main circuit	X			8.3
k	Tightness test (if applicable)	X			8.4
l	Vacuum integrity test (if applicable)	X			8.9
m	Auxiliary and control circuit inspection and test	X			8.2

[a]Not all characteristics are applicable for each type of circuit switcher. The manufacturer shall determine which characteristics are applicable.

7.11.4 Mechanical endurance test at ambient air temperature

7.11.4.1 Mechanical endurance CSM1, CSM2, and CSM3 test items and sequences

Follow the corresponding number of operating cycles and test items for CSM1, CSM2, or CSM3 shown in Table 11.

Table 11 —Test sequence for mechanical endurance

Step	Description	Operating sequence	Dataset (see Table 10)	Supply voltage	Operating energy	Number of operating sequences CSM1	CSM2	CSM3
1	Pre-test checks	—	1	—	—	—	—	—
2	Pre-test operations	O,C,CO	2	Minimum	Minimum	1	1	1
				Rated	Rated	1	1	1
				Maximum	Maximum	1	1	1
3	Test operation sequence[a]	C–t_a–O–t_a	3	Maximum	Rated	100	200	400
		C–t_a–O–t_a	3	Minimum	Rated	100	200	400
		C–t_a–O–t_a	3	Rated	Rated	1200	4400	8800
		CO–t_a	3	Rated	Rated	100	200	400
4	Post-test operations	O,C,CO	2	Minimum	Minimum	1	1	1
				Rated	Rated	1	1	1
				Maximum	Maximum	1	1	1
5	Post-test checks	—	1	—	—	—	—	—
Total number of accumulated test operations [b,c]						1500	5000	10,000

[a] Where t_a is the intentional test delay between successive operations determined by the manufacturer.
[b] One operation consists of one O and one C.
[c] During the test operation sequence, lubrication is permitted in accordance with the manufacturer's instructions. For CSM1, neither adjustment nor replacement of components and/or sub-assemblies is permitted. For CSM2 and CSM3, adjustment and replacement of defined routine-maintenance items is permitted. The manufacturer shall define routine maintenance in both the test report and instruction book.

7.11.4.2 Mechanical endurance qualification criteria

The mechanical endurance qualification criteria is as follows:

a) The circuit switcher shall be inspected to verify that all parts, including contacts, shall be in good condition and shall not show undue wear, and that the circuit switcher is in operable condition and meets the requirements set forth in this standard.

b) The characteristics of a representative number of test operations shall be within their respective tolerances as defined by the manufacturer.

c) During steps 2 through 4, the circuit switcher operates on command and does not operate without command.

d) The resistance of the main circuit shall conform to the limits defined by the manufacturer.

e) The insulating properties of the circuit switcher in the open position shall be in essentially the same condition as before the tests. Visual inspection of the circuit switcher after the tests is usually sufficient for verification of the insulating properties.

f) Control and auxiliary circuits shall function as intended and successfully complete the power frequency voltage withstand tests.

g) Gas tightness (if applicable) shall conform to the manufacturer's permitted leakage rate, F_P.

7.11.4.3 Mechanical endurance test report requirements

7.11.4.3.1 Information for identification of specimens

Subclause 7.2.2 of IEEE Std C37.100.1-2018 is applicable.

7.11.4.3.2 Information to be included in design-test (type-test) reports

Subclause 7.2.3 of IEEE Std C37.100.1-2018 is applicable.

7.11.5 Low and high temperature tests

7.11.5.1 Test object and conditions

Subclause 4.13.7 of IEEE Std C37.09-2018 is applicable with the exception that all items are applicable for both low and high temperature tests.

7.11.5.2 Low temperature test data and sequence

The low temperature test sequence is provided in Table 12 and a diagram of the application of the test sequence items is provided in Figure 14.

Table 12—Test sequence for low temperature test

<table>
<tr><th>Item</th><th>Description</th><th>Operating sequence</th><th>Dataset (see Table 10)</th><th>Supply voltage</th><th>Operating energy</th><th>Number of operating sequences</th></tr>
<tr><td>a</td><td>Pre-test checks</td><td>—</td><td>1</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td rowspan="3">b</td><td rowspan="3">Pre-test operations</td><td rowspan="3">O, C, CO</td><td rowspan="3">2</td><td>Minimum</td><td>Rated</td><td>2</td></tr>
<tr><td>Maximum</td><td>Rated</td><td>2</td></tr>
<tr><td>Rated</td><td>Rated</td><td>2</td></tr>
<tr><td>c</td><td colspan="6">Circuit switcher CLOSED – cool down</td></tr>
<tr><td>d</td><td colspan="6">Tightness test (see subclause 7.8)</td></tr>
<tr><td>e</td><td>Low temperature operations</td><td>O, C, CO</td><td>3</td><td>Rated</td><td>Rated</td><td>Variable[a]</td></tr>
<tr><td rowspan="3">f [b]</td><td colspan="6">Auxiliary heaters OFF</td></tr>
<tr><td>Minimum density operation [c]</td><td>O</td><td>3</td><td>Rated</td><td>Rated</td><td>0.5</td></tr>
<tr><td colspan="6">Auxiliary heaters ON</td></tr>
<tr><td>g</td><td colspan="6">Circuit switcher OPEN</td></tr>
<tr><td>h</td><td colspan="6">Tightness test (see subclause 7.8)</td></tr>
<tr><td rowspan="3">i</td><td rowspan="3">Low temperature operations[d]</td><td>C–3 min–O</td><td rowspan="3">3</td><td>Rated</td><td>Rated</td><td>1</td></tr>
<tr><td>CO–3 min</td><td>Rated</td><td>Rated</td><td>3</td></tr>
<tr><td>C–t_a–O–t_a</td><td>Rated</td><td>Rated</td><td>46</td></tr>
<tr><td>j</td><td>Increasing temperature operations</td><td>C–t_a–O–t_a–C–30 min–O–t_a–C–t_a–O–30 min</td><td>3</td><td>Rated</td><td>Rated</td><td>Variable</td></tr>
<tr><td rowspan="3">j</td><td rowspan="3">Post-test operations</td><td rowspan="3">O, C, CO</td><td rowspan="3">2</td><td>Minimum</td><td>Rated</td><td>2</td></tr>
<tr><td>Maximum</td><td>Rated</td><td>2</td></tr>
<tr><td>Rated</td><td>Rated</td><td>2</td></tr>
<tr><td>k</td><td>Post-test checks</td><td>—</td><td>1</td><td>—</td><td>—</td><td>—</td></tr>
</table>

[a] Manufacturer shall determine the number of operations necessary to demonstrate low temperature operating characteristics.
[b] For circuit switchers whose gas densities can be controlled by auxiliary heaters, perform this item. For circuit switchers that have no control of gas density, this item shall be skipped.
[c] This operation is performed as the test object approaches the minimum functional density. The intent is to demonstrate acceptable travel characteristics as close as practical to the minimum functional density.
[d] t_a is the intentional test delay between successive operations determined by the manufacturer.

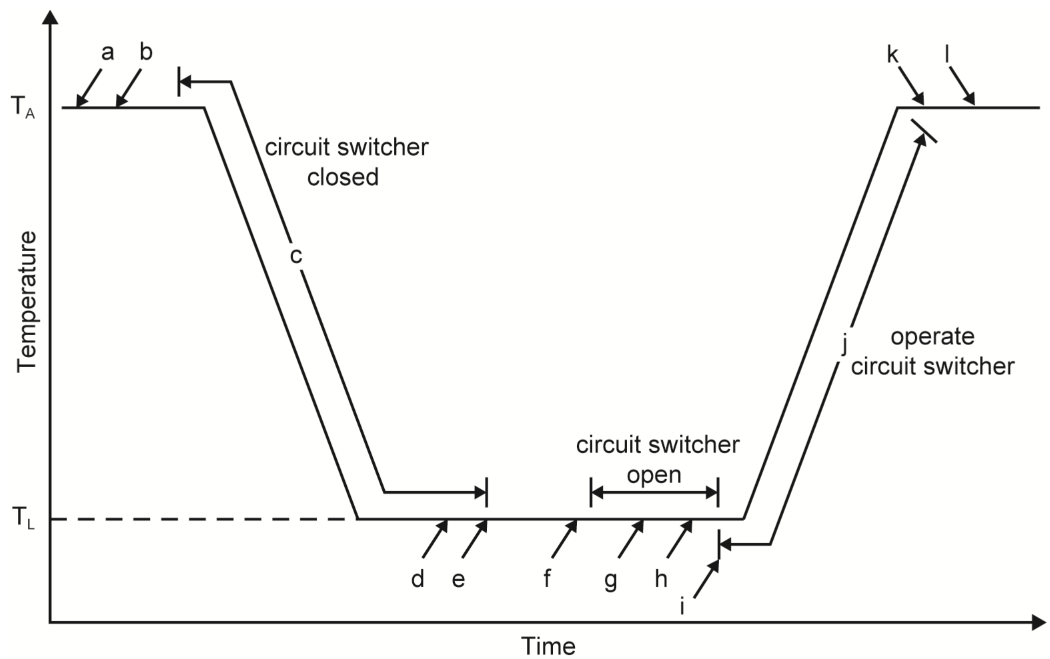


Figure 14—Test sequence for low temperature test

a) Pre-test checks of the assembly shall be made. The tightness test (if applicable) shall determine the initial leak rate, *F*.

b) Pre-test operational characteristics shall be measured and evaluated against the manufacturer's published data. These tests are performed at ambient temperature (T_A) between 15 and 25 °C.

c) With the circuit switcher in the closed position and all heater circuits energized, the test cell temperature shall be decreased to the minimum test temperature (T_L). The circuit switcher shall remain in the closed position for 24 hours after the test cell temperature has stabilized at T_L.

d) During the final 8 hours of the 24-hour soak at T_L, a tightness test shall be performed (if applicable).

e) After 24 hours at T_L, low temperature operations shall be performed as specified in row e of Table 12.

f) For circuit switchers whose gas densities can be controlled by auxiliary heaters, perform this item. For circuit switchers that have no control of gas density, this item shall be skipped. With all test object thermocouples and density monitors stabilized, all auxiliary heater circuits are de-energized for two hours. As the test object approaches minimum functional density, perform a single O operation. Record the occurrence of alarm and block operation conditions (if applicable). Record temperature conditions within the mechanism and control enclosures. Re-energize all heater circuits. Record the recovery from block operation and alarm conditions (if applicable). Record the temperature recovery within mechanism and control enclosures.

g) The circuit switcher shall remain in the open position for 24 hours at T_L.

h) During the final 8 hours of the 24-hour soak at T_L, a tightness test shall be performed (if applicable).

i) After 24 hours at T_L, low temperature operations shall be performed.

j) After completion of the low temperature operations, the test cell temperature shall be increased to ambient temperature at approximately 10 °C per hour. During this time, alternating C–t_a–O–t_a–C–30 min–O–t_a–C–t_a–O–30 min operations shall be performed.

k) After the circuit switcher has stabilized thermally at ambient temperature, post-test operational characteristics shall be measured and evaluated against the manufacturer's published data as well as the pre-test data.

l) Post-test checks of the assembly shall be made. The tightness test (if applicable) shall determine the final and overall leak rate, *F*.

7.11.5.3 High temperature test data and sequence

The high temperature test sequence is provided in Table 13 and a diagram of the application of the test sequence items is provided in Figure 15.

Table 13—Test sequence for high temperature test

Item	Description	Operating sequence	Dataset (see Table 10)	Supply voltage	Operating energy	Number of operating sequences
m	Pre-test checks	—	1	—	—	—
n	Pre-test operations	O,C,CO	2	Minimum	Rated	2
				Maximum	Rated	2
				Rated	Rated	2
o	Circuit switcher CLOSED – warm up					
p	Tightness test (see subclause 7.8)					
q	High temperature operations	O,C,CO	3	Rated	Rated	Variable[a]
r	Circuit switcher OPEN					
s	Tightness test (see subclause 7.8)					
t	High temperature operations[b]	C—3 min—O	3	Rated	Rated	1
		CO–3min	3	Rated	Rated	3
		C—t_a—O—t_a	3	Rated	Rated	46
u	Decreasing temperature operations	C—t_a—O—t_a—C—30 min—O—t_a—C—t_a—O—30 min	3	Rated	Rated	Variable
v	Post-test operations	O,C,CO	2	Minimum	Rated	2
				Maximum	Rated	2
				Rated	Rated	2
w	Post-test checks	—	1	—	—	—

[a] Manufacturer shall determine the number of operations necessary to demonstrate high temperature operating characteristics.
[b] t_a is the intentional test delay between successive operations determined by the manufacturer.

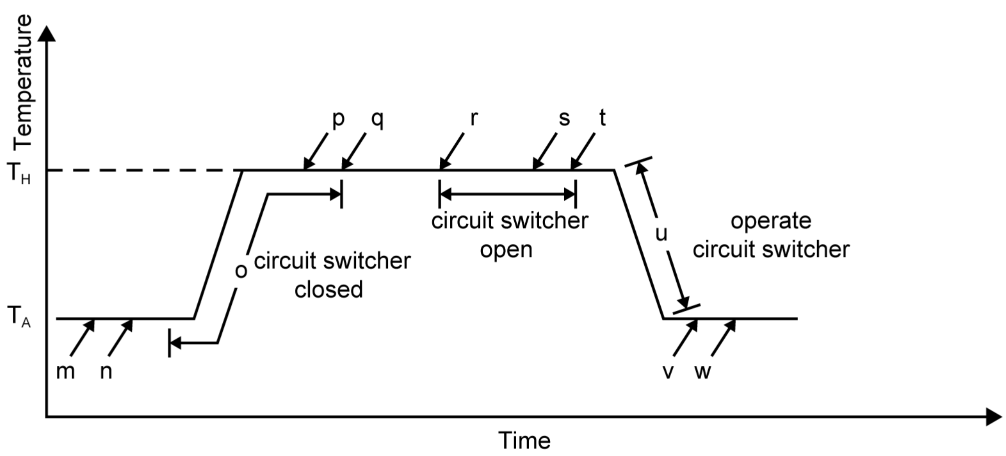


Figure 15—Test sequence for high temperature test

a) Pre-test checks of the assembly shall be made. The tightness test (if applicable) shall determine the initial leak rate, *F*.

b) Pre-test operational characteristics shall be measured and evaluated against the manufacturer's published data. These tests are performed at ambient temperature (T_A) between 15 and 25 °C.

c) With the circuit switcher in the closed position, the test cell temperature shall be increased to the maximum test temperature (T_H). The circuit switcher shall remain in the closed position for 24 hours after the test cell temperature has stabilized at T_H.

d) During the final 8 hours of the 24-hour soak at T_H, a tightness test shall be performed (if applicable).

e) After 24 hours at T_H, high temperature operations shall be performed as specified in row q of Table 13.

f) The circuit switcher shall remain in the open position for 24 hours at T_H.

g) During the final 8 hours of the 24-hour soak at T_H, a tightness test shall be performed (if applicable).

h) After 24 hours at T_H, high temperature operations shall be performed as specified in row t of Table 13.

i) After completion of the high temperature operations, the test cell temperature shall be decreased to ambient temperature at approximately 10 °C per hour. During this time, alternating C−t_a−O−t_a−C−30 min−O−t_a−C−t_a−O−30 min operations shall be performed.

j) After the circuit switcher has stabilized thermally at ambient temperature, post-test operational characteristics shall be measured and evaluated against the manufacturer's published data as well as the pre-test data.

k) Post-test checks of the assembly shall be made. The tightness test (if applicable) shall determine the final and overall leak rate, F.

7.11.5.4 Low and high temperature qualification criteria

The low and high temperature qualification criteria is as follows:

a) The characteristics of all test operations shall be within their respective tolerances as defined by the manufacturer.

b) During the tests, the circuit switcher operates on command and does not operate without command.

c) The resistance of the main circuit shall conform to the limits defined by the manufacturer.

d) Control and auxiliary circuits shall function as intended and successfully complete the power frequency voltage withstand test.

e) Gas tightness (if applicable) shall conform to the manufacturer's permitted leakage rate, F_P.

— The low temperature leakage rate shall be less than or equal to 3 × F_P for circuit switchers tested as low as −40 °C and shall be less than or equal to 6 × F_P for circuit switchers tested between −40 °C and −50 °C.

— The high temperature leakage rate shall be less than or equal to 3 × F_P.

f) At low temperature, auxiliary heaters (if applicable) are sufficient to enable operation of the circuit switcher when uninterrupted auxiliary power is available.

g) At low temperature, after two hours of auxiliary power interruption, resumption of auxiliary power enables unrestricted operation of the circuit switcher after recovery.

7.12 Ice-loading test

Subclause 8.5 of IEEE Std C37.30.1-2011 is applicable with the following revisions:

— The test under ice loading conditions is applicable only to outdoor circuit switchers that have moving external parts.

— Opening and closing shall perform successfully on each attempted operation since circuit switchers have a short-circuit making and breaking rating.

— Operations shall be performed under power operation using the rated values of control voltages and operating mechanism pressures.

7.13 Static terminal load test

7.13.1 General

C37.30?

The static terminal load test is performed to demonstrate that the circuit switcher operates correctly when loaded by stresses resulting from ice, wind, and connected conductors. Preferred rated static terminal pad loads are given in Table 6.

The tensile force due to the connected conductors is assumed to act at the center of the bolt hole pattern on the terminal pad or the center of the terminal stud.

7.13.2 Tests

The tests shall be made on at least one complete pole of the circuit switcher.

Tests shall be made separately for F_{shA} and F_{shB} and F_{sv} according to the ratings assigned. See Figure 12.

— F_{shA} shall be applied to each terminal pad simultaneously. The test shall be repeated with the direction of the force reversed.

— F_{shB} shall be applied to each terminal pad simultaneously. The test shall be repeated with the direction of the force reversed.

— F_{sv} shall be applied to each terminal pad simultaneously.

Two operating cycles shall be performed for each of the specified terminal load tests above in this subclause. Measurements shall be taken to demonstrate proper mechanical operation as specified in Table 10 dataset 2. The condition of the circuit switcher after the test shall be as specified in 7.11.4.2 a). The circuit switcher shall open and close fully within the mechanical operating tolerance set by the manufacturer.

7.14 Short-circuit current making and breaking tests

C37.09?

7.14.1 General

The short-circuit current interrupting rating of a circuit switcher is demonstrated by a series of tests. These tests demonstrate the rated short-circuit current and the related required capabilities of the circuit switcher for applications in either effectively and non-effectively grounded systems.

The test duties used to demonstrate the performance of a circuit switcher are listed in Table 1, where the test parameters are identified as follows:

a) For test voltage for all duties   Test voltage E for all test duties

E

$$E = \frac{k_{pp}}{\sqrt{3}} \times U_r$$, for single-phase tests in substitution for three-phase tests, or (1)

E = U_r, the applied phase-to-phase voltage during three-phase making tests on a three-pole circuit switcher (2)

$$E = \frac{U_r}{\sqrt{3}}$$, ~~for three-phase test:~~ the applied voltage during single-phase making tests on a three-pole circuit breaker (2)

where

k_{pp} is the first pole to clear factor

U_r is the rated maximum voltage.

See the corrigenda.

b) Test current is equal to either the rated primary-bus fault breaking current (I_{pbf}) or the rated transformer-limited fault breaking current (I_{tf}), depending on the test duty.

c) Making current peak factor, F, is equal to 2.6 for 60 Hz or 2.5 for 50 Hz.

Table 14—Single-phase or three-phase test duties for short-circuit current tests

Test duty	Operating duty	Test voltage (kV)	Making current (kA peak)	Short-circuit current (kA)	% Asymmetry at contact part
30 — TLF	Three Os	E		I_{tf}	< 20
PBF60	Three Os	E		0.6 I_{pbf}	< 20
PBF100s	Three COs	E	F × I_{pbf}	I_{pbf}	< 20
PBF100s(a)	Two Cs	E	F × I_{pbf}		< 20
PBF100s(b)	Three Os	E		I_{pbf}	< 20
PBF100a[a]	Three Os	E		See 7.14.4.5	> 20
Single-phase fault tests					
T100s 1ph[b]	O	$U_r/\sqrt{3}$		I_{pbf}	< 20
T100a 1ph[b]	O	$U_r/\sqrt{3}$		See 7.14.4.6	> 20

[a] Only if required. See 7.14.4.5.
[b] Only if required. See 7.14.4.6.

7.14.2 Test conditions

7.14.2.1 Power factor

Subclause 4.8.2.1 of IEEE Std C37.09-2018 is applicable.

7.14.2.2 Frequency of test circuit

Subclause 4.8.2.2 of IEEE Std C37.09-2018 is applicable.

7.14.2.3 Demonstration of arcing time

Subclause 4.8.2.3 of IEEE Std C37.09-2018 is applicable for circuit switcher test duties TLF, PBF60, PBF100s, and PBF100a by substituting the circuit switcher test duties for the circuit breaker test duties.

7.14.2.4 Recovery voltage

Subclause 4.8.2.4 of IEEE Std C37.09-2018 is applicable by substituting the text in paragraph b) with the following:

b) TRV: The inherent TRV of the test circuit shall meet or exceed the rated envelopes as defined in 5.13 and 5.15. The rated envelopes are required for rated symmetrical short-circuit currents. For short-circuit currents other than rated, the envelope shall be adjusted to establish the capabilities as stated in 5.13.4.

7.14.2.5 Initial TRV test conditions

Subclause 4.8.2.6 of IEEE Std C37.09-2018 is applicable.

7.14.2.6 Control voltage

Subclause 4.8.2.7 of IEEE Std C37.09-2018 is applicable.

7.14.2.7 Operating conditions

Subclause 4.8.2.8 of IEEE Std C37.09-2018 is applicable.

7.14.2.8 Conditions during single-pole tests and unit tests

Subclause 4.8.2.9 of IEEE Std C37.09-2018 is applicable.

Does this require three phase open tests?

7.14.2.9 Grounding of the circuit switcher and test circuit

Subclause 4.8.2.10 of IEEE Std C37.09-2018 is applicable.

7.14.2.10 Reversal of test connections

Subclause 4.8.2.11 of IEEE Std C37.09-2018 is applicable.

7.14.3 Test methods

Subclause 4.8.3 of IEEE Std C37.09-2018 is applicable with the exception that Table 14 of this standard be substituted for Table 1 of IEEE Std C37.09-2018.

7.14.4 Test duties

7.14.4.1 General

The basic short-circuit test series shall consist of tests for rated transformer-limited fault current (test duty TLF) and for rated primary-bus fault breaking current (test duties PBF60, PBF100s, and PBF100a). See Table 14 for list of test duties and requirements.

7.14.4.2 Test duty TLF

Test duty TLF consists of three opening operations at the rated transformer-limited fault current with a dc component of less than 20% and a TRV as specified in 5.15.

7.14.4.3 Test duty PBF60

Test duty PBF60 consists of three opening operations at 60% of the rated primary-bus fault breaking current with a dc component of less than 20% and a TRV as specified in 5.13. If the PBF60 current is less than 1.5 times the rated transformer-limited fault current, then the test duty may be omitted.

7.14.4.4 Test duty PBF100s

Test duty PBF100s consists of three CO operating sequences at 100% of the rated primary-bus fault breaking current with a dc component of less than 20% and a TRV as specified in 5.13. The minimum time between the operating sequences shall be specified by the manufacturer and noted in the test report. When the rated short-circuit making current is greater than the rated primary-bus fault breaking current, then the making current for test duty PBF100s shall be based on the rated primary-bus fault breaking current taking the peak current ratios as given in 5.7.

7.14.4.5 Test duty PBF100a

Clarify the sentence

Test duty PBF100a shall be applied only to circuit switchers that have a time interval equal to the minimum opening time T_{op} of the circuit switcher, as stated by the manufacturer, plus one half-cycle of rated power frequency T_r such that the dc component at the instant of contact separation is greater than 20% (see 5.12.2).

Test duty PBF100a consists of three opening operations at 100% of the rated primary-bus fault breaking current with a percentage dc component equal to the appropriate rated value and the related prospective transient and power-frequency recovery voltages. The minimum time between the operating sequences shall be specified by the manufacturer and noted in the test report.

.09a These single-phase test duties are not required if test duties T100s and T100a are performed by single-phase tests in substitution for three-phase tests (see 4.8.2.3.5).

7.14.4.6 Single-phase tests

Subclause 4.8.4.5 of IEEE Std C37.09-2018 is applicable with the exception that Table 14 of this standard shall be substituted for Table 1 of IEEE Std C37.09-2018.

7.14.5 Short-circuit making current

7.14.5.1 General

The ability of the circuit switcher to make the rated short-circuit making current is proven in test duty PBF100s (see 7.14.4.4) when the rms symmetrical value of the rated short-circuit making current is equal to the rated primary-bus fault breaking current. When the rms symmetrical value of the rated short-circuit making current exceeds the rated primary-bus fault breaking current, the following apply:

— The closing operations in test duty PBF100s shall be performed at the rated primary-bus fault breaking current.

— The test procedures for the closing operations described in PBF100s shall be separately performed at the rated short-circuit making current on a test sample that has been preconditioned by performing the opening operations described in PBF60. If it is evident or if it can be proven that the short-circuit making current is not influenced by conditioning, the short-circuit making test may be performed on a new sample.

The circuit switcher shall be able to make the current with the prestrike of the arc occurring at any point on the voltage wave consistent with its prestrike characteristics. Two extreme cases are specified as follows:

— Making at the peak of the voltage wave, leading to a symmetrical short-circuit current and the longest prestriking arc

— Without prestriking, for circuit switchers capable of closing at the zero of the voltage wave leading to a fully asymmetrical short-circuit current

145 kV/ 1.732
or 145 x 0.577

7.14.5.2 Applied voltage before short-circuit making tests

For short-circuit making tests the applied voltage shall be as follows:

a) For three-phase tests on a three-pole circuit switcher, the average value of the applied voltages shall not be less than the rated maximum voltage $U_r/\sqrt{3}$ and shall not exceed this value by more than 5% without the consent of the manufacturer.

Ur Per C37.09 4.8.1

b) The differences between the average value and the applied voltages of each pole shall not exceed 5%.

c) For single-phase tests on a three-pole circuit switcher, the applied voltage shall not be less than the phase-to-ground value $U_r/\sqrt{3}$ and shall not exceed this value by more than 10% without the consent of the manufacturer.

NOTE—With the manufacturer's consent, it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-ground voltage and the first pole-to-clear factor (1.3 or 1.5) of the circuit switcher.

7.14.5.3 Test procedure

The test procedure as outlined in 7.14.5.3.1 and 7.14.5.3.2 aims to demonstrate the ability of the circuit switcher to fulfill the following two requirements:

a) The circuit switcher can close against a symmetrical current as a result of the pre-arcing commencing at a peak of the applied voltage. This current shall be the symmetrical component of the rated short-circuit making current (see 5.16).

b) The circuit switcher consistent with its prestrike characteristics can close against a circuit with an available fully asymmetrical short-circuit current equal to the related peak of the rated short-circuit making current (see 5.16).

A circuit switcher shall be able to operate below its rated maximum voltage at voltages that may reduce the prestrike and allow fully asymmetrical current. The lower limit of voltage, if any, shall be stated by the manufacturer.

7.14.5.3.1 Three-phase tests

7.14.5.3.1.1 Requirements when rms symmetrical value of the short-circuit making current is equal to rated primary-bus fault breaking current

For three-phase tests on a three-pole circuit switcher, it is assumed that the requirements outlined in requirements a) and b) in 7.14.5.3 are adequately demonstrated during test duty PBF100s when the rated short-circuit making current is equal to the rated primary-bus fault breaking current.

When the prestrike characteristics of the circuit switcher permits zero voltage closing, the control of the timing shall be such that, in at least one of the three CO operations of test duty PBF100s, the related peak of the rated short-circuit making current or rated primary-bus fault breaking current is obtained.

Where a circuit switcher exhibits pre-arcing to such an extent that the related peak of the rated short-circuit making current or rated primary-bus fault breaking current is not attained during the three CO operations of test duty PBF100s, a fourth closing operation shall be carried out at reduced voltage. Before this operation, the circuit switcher may be reconditioned.

In some cases, due to the prestriking characteristics of the circuit switcher, it is not always possible to reach the peak current value. In such cases, the current shall be considered satisfactory if the prospective peak current of the test circuit is equal to or greater than the related peak of the rated short-circuit making current or rated primary-bus fault breaking current.

7.14.5.3.1.2 Requirements when rms symmetrical value of the short-circuit making current is greater than rated primary-bus fault breaking current

When the rated short-circuit making current is greater than the rated primary-bus fault breaking current, the circuit switcher must adequately demonstrate the requirements outlined in requirements a) and b) in 7.14.5.3. Since the circuit switcher can be assigned a one-time duty-cycle closing rating and the requirements in 7.14.5.3 may not be met with one operation, additional closing operations on a reconditioned circuit switcher may be necessary.

7.14.5.3.2 Single-phase tests

7.14.5.3.2.1 Requirements when rms symmetrical value of the short-circuit making current is equal to rated primary-bus fault breaking current

For single-phase tests, test duty PBF100s shall be carried out in such a way that requirement a) in 7.14.5.3 is met on two of the operations and requirement b) is met on the third closing operation. The sequence of these operations is not specified. If during test duty PBF100s, one of the requirements a) and b) has not been adequately demonstrated, an additional closing operation is necessary. It may be made with a reconditioned circuit switcher.

This seems to say that the third shot in PBF100s should be asymmetrical? I suspect the reason this is a mess is most circuit switchers have a higher fault closing than the PBF100 so this was not thoroughly vetted.

The additional closing operation shall, depending on the results obtained during the normal test duty PBF100s, demonstrate either of the following:

- Requirement a) or b) in 7.14.5.3 has been met.
- Evidence that the short-circuit making currents attained are representative of the conditions to be met in service due to the pre-arcing characteristics of the circuit switcher.

KERI thinks this means 2 sym and one asym

If, during test duty PBF100s, the rated short-circuit making current has not been attained due to the characteristics of the circuit switcher, the additional closing test may be made at a lower applied voltage.

If, during test duty PBF100s, no symmetrical current has been obtained, as in requirement a) in 7.14.5.3, the additional closing test may be made at an applied voltage within the margins stated in 7.14.5.2.

7.14.5.3.2.2 Requirements when rms symmetrical value of the short-circuit making current is greater than rated primary-bus fault breaking current

When the rated short-circuit making current is greater than the rated primary-bus fault breaking current, the circuit switcher must adequately demonstrate the requirements outlined in requirements a) and b) in 7.14.5.2. Since the circuit switcher can be assigned a one-time duty-cycle closing rating and the requirements in 7.14.5.2 may not be met with one operation, additional closing operations on a reconditioned circuit switcher may be necessary.

7.14.6 Condition of circuit switcher tested

7.14.6.1 General

Subclause 4.8.6.1 of IEEE Std C37.09-2018 is applicable.

add .09 4.8.6.2 also

7.14.6.2 Circuit switcher operating characteristics prior to test initiation

Subclause 4.8.6.3 of IEEE Std C37.09-2018 is applicable.

7.14.6.3 Reconditioning of circuit switcher during testing

The expendable parts of a circuit switcher may be replaced during a test series. The manufacturer shall provide a statement to the testing laboratory of the parts that may be replaced during the tests.

7.14.6.4 Circuit switcher operating characteristics after test

Subclause 4.8.6.5 of IEEE Std C37.09-2018 is applicable.

7.14.6.5 Condition of circuit switcher after test

Subclause 4.8.6.6 of IEEE Std C37.09-2018 is applicable with the exception that item c) in IEEE Std C37.09-2018 shall be replaced with the following:

c) The circuit switcher shall be checked dielectrically using the voltage condition-checking test according to subclause 7.2.11.

7.15 Capacitor switching

7.15.1 Characteristics of the capacitive circuit to be switched

Subclause 4.4 of IEEE Std C37.100.2-2018, is applicable.

7.15.2 Characteristics of supply circuits

Subclause 4.5 of IEEE Std C37.100.2-2018, is applicable.

7.15.3 Test current

Subclause 4.6 of IEEE Std C37.100.2-2018, is applicable.

7.15.4 Preconditioning for Class C2

Subclause 4.7 of IEEE Std C37.100.2-2018, is applicable.

7.15.5 Test programs

For circuit switchers where the parting of the interrupting contacts can be controlled, subclause 4.8 of IEEE Std C37.100.2-2018, is applicable. For circuit switchers where parting of the interrupter contacts is random, subclause 4.9 of IEEE Std C37.100.2-2018, is applicable.

7.15.6 Common criteria to pass the capacitance switching tests

Subclause 4.10 of IEEE Std C37.100.2-2018, is applicable.

7.16 Design tests on pressurized components

Subclause 4.17 of IEEE Std C37.09-2018 is applicable.

8. Production tests

8.1 General

Production tests are normally made by the manufacturer at the factory as part of the process of producing the circuit switcher. If the circuit switcher is completely assembled prior to shipment, some of the production tests are made after final assembly, but other tests can often be made more effectively on components and subassemblies during or after manufacture. If the circuit switcher is not completely assembled at the factory prior to shipment, appropriate tests on component parts shall be made to check the quality of workmanship and uniformity of material used and to ensure satisfactory performance when properly assembled at its destination. This performance may be verified by making tests after delivery.

Production tests shall be made and shall include the following as appropriate for the type of circuit switcher concerned:

a) Dielectric test on the main circuit in accordance with 8.2

b) Inspection and testing of auxiliary and control circuits in accordance with 8.3

c) Measurement of the resistance of the main circuit in accordance with 8.4

d) Tightness test in accordance with 8.5

e) Design and visual checks in accordance with 8.6

f) Mechanical operations test in accordance with 8.7

g) Timing tests in accordance with 8.8

h) Gas system pressure tests in accordance with 8.9

i) Vacuum integrity tests in accordance with 8.10

Test reports of the routine tests are normally not necessary unless otherwise agreed upon between manufacturer and user.

8.2 Dielectric test on the main circuit

Power-frequency withstand voltage tests shall be made for one minute at the voltages specified in Table 1 in compliance with 7.2.1. Tests shall be performed on the main circuit of completely assembled circuit switchers. Insulation formed by solid core insulators or by air at ambient pressure, such as air-insulated disconnect gaps, does not need to be tested.

8.3 Inspection and testing of auxiliary and control circuits

8.3.1 Resistors, heaters, and coils check tests

Subclause 5.8 of IEEE Std C37.09-2018 is applicable.

8.3.2 Auxiliary and control circuit check tests

Subclause 5.9 of IEEE Std C37.09-2018 is applicable.

8.3.3 Dielectric test on auxiliary and control circuits

Subclause 5.16 of IEEE Std C37.09-2018 is applicable.

8.4 Measurement of resistance of main circuit

Subclause 8.4 of IEEE Std C37.100.1-2018 is applicable.

8.5 Tightness test

Subclause 8.5 of IEEE Std C37.100.1-2018 is applicable.

8.6 Design and visual checks

Namplate check?

Subclause 8.6 of IEEE Std C37.100.1-2018, and subclause 5.5 of IEEE Std C37.09-2018 are applicable.

The switchgear shall be checked to verify its compliance with the purchase specifications.

8.7 Mechanical operation tests

Subclause 5.11 of IEEE Std C37.09-2018 is applicable.

8.8 Timing tests

Subclause 5.12 of IEEE Std C37.09-2018 is applicable.

8.9 Gas system pressure tests

Subclause 5.4 of IEEE Std C37.09-2018 is applicable.

8.10 Vacuum integrity tests

Subclause 5.7 of IEEE Std C37.09-2018 is applicable.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] IEC 60695-1-10, Fire hazard testing—Part 1-10: Guidance for assessing the fire hazard of electrotechnical products—General guidelines.

[B2] IEEE Std C37.011™, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers.

[B3] IEEE Std C37.20.2™, IEEE Standard for Metal-Clad Switchgear.

Consensus

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IEEE PES Switchgear Committee
HVCB C37.016 - Meeting Roster

Place / Date of meeting: **Sheraton Sand Key Resort, Clearwater Beach, FL / April 17, 2023**

Initial to denote attendance	Last name	First name	Company name	Role	Request Membership
X	Allinghan	Edward	Hydro One	Guest	New
X	Andreyo	Joe	Southern States	Guest	New
	Ashtekar	Koustubh	JST Power Eq	Guest	
X	Beckel	Andy	Xcel Energy	Guest	New
X	Bolar	Sankey	Oncor	Guest	New
	Bray	Elizabeth	Southern Company	Guest	
X	Bryant	Craig	Duke Energy	Guest	X
	Bui	Ngoc	SDG&E	Guest	
	Cary	Stephen	2 Phase Solutions	Member	
X	Chovanec	Andrew	G&W	Guest	
X	Collette	Lucas	Duquesne Light Co.	Vice Chair	
X	Cunningham	Jason	Southern States	Guest	
	Diallo	Boubacar	Southern States	Guest	
X	Dilillo	Pat	Con Ed	Member	
X	Dragan	Tabakovic	Hubbell	Guest	New
X	Eastman	Maxwell	Black & Veatch	Guest	New
X	Falkingham	Leslie	VIL & S&C	Guest	New - X
	Fennell	Bruce	Nashville Electric Services	Guest	
	Hanna	Robert	JST Power Eq	Guest	
	Hurst	Bill	GE	Guest	
	Hutchins	Neil	Georgia Power	Excused Member	
X	Irwin	Todd	GE Grid Solutions	Member	
	Jagadeesan	Bharat	Southern States	Guest	
X	Jarnigan	Chris	Southern Company Services	Member	
X	Kechroud	Riyad	GE Grid Solutions	Guest	New
	Keels	Andy	KE Electric	Excused Member	
	Lopez	Leo	WIKA	Guest	
X	Mapp	Peter	GE	Guest	New
X	Marshall	Vincent	Southern Company	Guest	
X	Marzec	Pete	S&C Electric Co.	Member	
X	May	Steve	Southern Company	Guest	X
X	McCord	Neil	KEC Precision LLC	Chair	
	Meyer	Peter	S&C Electric Co.	Guest	
X	Mitchell	David	Southern States	Member	
	Monroe	Andrew	Southern Company	Guest	
X	Ordein	Fernando	Dominion Energy	Guest	New - X
X	Owen	John	Powertech Labs	Guest	New
	Pellerito	Tom	DTE Energy	Guest	
X	Peterson	Mark	Xcel Energy	Guest	New
X	Roberts	Brian	Southern States	Guest	New - X
	Santulli	Jen	IEEE SA	Guest	
	Schiffbauer	Dan	Toshiba International	Guest	
	Schuetz	Carl	ATC	Member	
X	Scott	Jeff	Ameren	Guest	
	Skidmore	Mike	AEP	Member	
X	Steigerwalt	Don	Duke Energy	Guest	X
X	Toups	Vernon	Siemens Energy	Guest	X
	Trichon	Francois	Schneider Electric	Member	
	Usner	Joe	AEP	Guest	
X	Voyles	Adam	Ameren	Member	
	Ward	Jeff	Doble Engineering	Member	
X	Weeks	Casey	Siemens Energy	Guest	New
X	Weisker	Jan	Siemens Energy	Guest	X
X	Yongwoo	Lee	KERI	Guest	New
	Young	Marcus	MEPPI	Guest	
X	Yunseorg	Kim	KERI	Guest	New
	Zhang	Wei	Southern Company	Member	
X	Zia	Danish	UI Solutions	Guest	New