



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

IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

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

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Switchgear Committee
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Approved 6 December 2006

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.

Keywords: ac circuit switcher, three-pole circuit switcher

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Introduction

This introduction is not part of IEEE Std C37.016-2006, IEEE Standard for AC High-Voltage Circuit Switchers Rated 15.5 kV Through 245 kV.

This standard was written to cover a class and type of equipment that has been manufactured by a few manufacturers for over 30 years, yet did not have an international standard. More manufacturers and users have started using and manufacturing this class of equipment, and a standard has become necessary.

The IEC community has expressed interest in this type of device and has expressed interest in using this standard for its purposes. With that in mind, the Circuit Switcher Working Group has tried to reach out to both the IEEE and IEC communities. Therefore, the reader will find references to both IEEE and IEC standards within this standard. Where references to both standards are made, users are responsible for specifying the standard they desire, and manufacturers are responsible for specifying the standard they used for their design and testing.

Where there is a clear need for different requirements in different applications, diverging standards are appropriate.

This standard was written to provide the basic standard for circuit switchers. As such, an attempt was made to encompass as many different types of circuit switchers as practical.

Although this standard will be published before the work on IEEE Std C37.100.1 (Common Clauses) is finished, it is the intention of the Circuit Switcher Working Group to adopt or reference common clauses as they become available.

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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.

1.2 Normative references

The following referenced documents are indispensable for the application of this standard (i.e., they must be understood and used; therefore, each referenced document is cited in text and its relationship to this standard 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.

Where references to both standards are made, users are responsible for specifying the standard they desire, and manufacturers are responsible for specifying the standard they used for their design and testing.

ANSI C37.06, AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.¹

ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels.²

¹ ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

² ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (<http://www.asme.org/>).

- ASTM D 2472, ASTM Standard Specification for Sulfur Hexafluoride.³
- IEC 60050-441, International electrotechnical vocabulary — Switchgear, controlgear and fuses.⁴
- IEC 60060-1:1989, High-voltage test techniques — Part 1: General definitions and test requirements.
- IEC 60376, Specification of technical grade sulfur hexafluoride (SF₆) for use in electrical equipment.
- IEC 60427, Synthetic testing of high-voltage alternating current circuit-breakers.
- IEC 60694:2002, Common specifications for high-voltage switchgear and controlgear standards.
- IEC 60815, Guide for the selection of insulators in respect of polluted conditions.
- IEC 62271-100:2006, High-voltage switchgear and controlgear — Part 100: High-voltage alternating-current circuit-breakers.
- IEEE Std C37.04™-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit-Breakers.^{5, 6}
- IEEE Std C37.09™-1999, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.
- IEEE Std C37.081™, IEEE Guide for Synthetic Fault Testing of AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.
- IEEE Std C37.083™, IEEE Guide for Synthetic Capacitive Current Switching Tests of AC High-Voltage Circuit Breakers.
- IEEE Std C37.60™-2003, IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems up to 38 kV.
- IEEE Std C37.90.1™, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.
- IEEE Std C37.100™, IEEE Standard Definitions for Power Switchgear.
- IEEE Std 4™, IEEE Standard Techniques for High-Voltage Testing.
- IEEE Std 693™, IEEE Recommended Practice for Seismic Design of Substations.
- IEEE Std 1247™-2005, IEEE Standard for Interrupter Switches for Alternating Current, Rated Above 1000 V.

³ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

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

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

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NEMA 250, Enclosures for Electrical Equipment (1000 Volts Maximum).⁷

NEMA CC 1, Electric Power Connectors for Substations.

NOTE—IEEE Std 1247-2005 was intended to be a general reference for all devices related to interrupter switches; and although IEEE Std 1247-2005 excludes circuit switchers, some sections are applicable and referenced in this standard.⁸

2. Usual and unusual service conditions

2.1 Usual service conditions

Circuit switchers conforming to this standard shall be suitable for operating at their ratings when

- a) The maximum ambient air temperature is 40 °C, and the minimum ambient air temperature is −30 °C.
- b) The altitude does not exceed 1000 m.
- c) The wind velocity does not exceed 40 m/s.
- d) The seismic performance level does not exceed the low performance level defined in IEEE Std 693.⁹

2.2 Unusual service conditions

Circuit switchers may be used in service conditions different from the usual service conditions in 2.1. The user requirements may be developed from the following guidelines:

- a) For altitudes above 1000 m, refer to Section 2.2.1 of IEC 60694:2002 or Annex E of IEEE Std C37.60-2003.
- b) For seismic performance levels exceeding the low performance level, refer to IEEE Std 693.
- c) For areas with requirements for operating under ice formation, the user shall specify the ice thickness requirements per 4.22.
- d) For installation in polluted ambient air, refer to IEC 60815 or IEEE Std C37.010.
- e) For blowing dust and sand and for corrosive gas environments, special considerations should be given to the construction and to any special local regulations or standards.

⁷ NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

⁸ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

⁹ Information on references can be found in 1.2.

3. Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE Std C37.100, *The Authoritative Dictionary of IEEE Standards Terms* [B3]¹⁰, or IEC 60050-441 should be referenced for terms not defined in this clause.

NOTE—The term *interrupting* may be substituted for *breaking* in the breaking current definitions and ratings.

3.1 General definitions

3.1.1 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.

3.1.2 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.

3.1.3 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.

3.1.4 dependent power operation: An operation, by means of energy other than manual, where the completion of the operation is dependent upon the continuity of the power supply (e.g., to solenoids, electric or pneumatic motors).

3.1.5 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.

3.1.6 minimum functional pressure for interruption and insulation: For closed pressure systems, the standard atmospheric air conditions of +20 °C and 102 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a circuit switcher are maintained and below which a replenishment of the interrupting and/or insulating medium becomes necessary. For sealed systems, the standard atmospheric air conditions of +20 °C and 102 kPa, which may be expressed in relative or absolute terms, at which the rated characteristics of the circuit switcher are maintained considering the pressure drop at the end of the expected operating life.

3.1.7 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.

¹⁰ Numbers in brackets correspond to the numbers in the bibliography in Annex A.

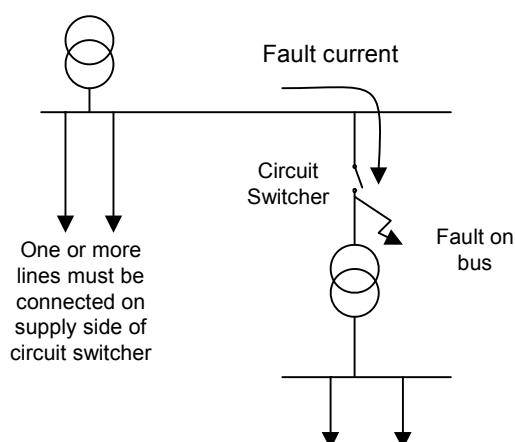


Figure 1—Diagram of primary-bus faults

3.1.8 R10 series: A series of numbers 1.0–1.25–1.6–2.0–2.5–3.15–4.0–5.0–6.3–8.0 and their products by powers of 10 as defined in IEC 60059. For example: 1000-1250-1600-2000-2500-3150-4000-5000-6300.

3.1.9 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).

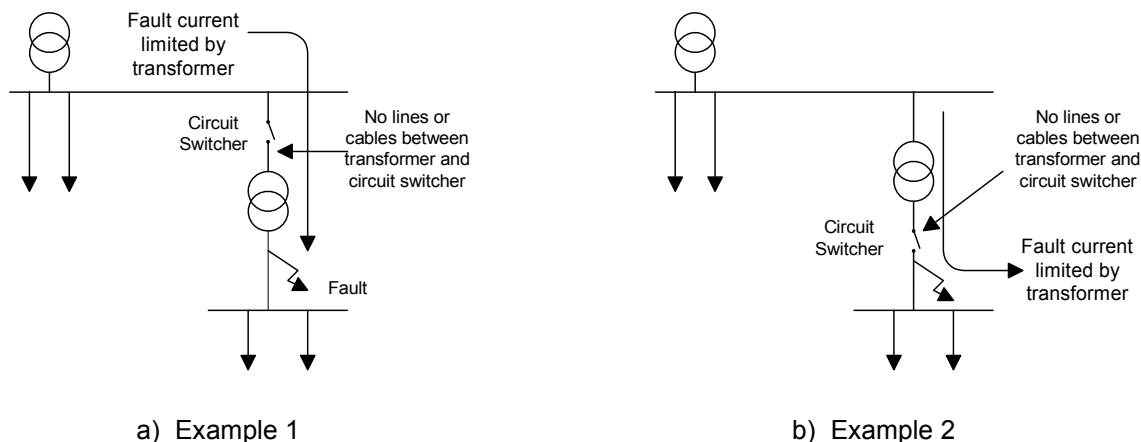


Figure 2—Diagrams of transformer limited faults

3.2 Definitions relating to gas and vacuum tightness

These definitions apply to all circuit switchers that use vacuum or gas, other than air at atmospheric pressure, as insulating or combined insulating and interrupting or operating medium.

3.2.1 absolute leakage rate (F): The amount of gas escaped by time unit, expressed in Pascal-meter cubed per second ($\text{Pa} \cdot \text{m}^3/\text{s}$).

3.2.2 closed pressure system for gas: A volume that is replenished only periodically by manual connection to an external gas source.

NOTE—Examples of closed pressure systems are sulfur hexafluoride (SF_6) single pressure circuit switchers.

3.2.3 controlled pressure system for gas: A volume that is automatically replenished from an external or internal gas source.

NOTE 1—Examples of controlled pressure systems are air-blast circuit switchers or pneumatic operating mechanisms.

NOTE 2—A volume may consist of several permanently connected gas-filled compartments.

3.2.4 cumulative leakage measurement: A measurement that takes into account all the leaks from a given assembly to determine the leakage rate.

3.2.5 gas-filled compartment: A compartment of a circuit switcher in which the gas pressure is maintained by one of the following systems: controlled pressure system, closed pressure system, or sealed system.

NOTE—Several gas-filled compartments may be permanently interconnected to form a common gas system (gas-tight assembly).

3.2.6 number of replenishments per day (N): The number of replenishments to compensate the leakage rate F . This value is applicable to controlled pressure systems.

3.2.7 permissible leakage rate (F_p): The maximum permissible absolute leakage rate of gas specified by the manufacturer for a part, a component, or a subassembly or by using the tightness coordination chart in Figure E.1 in Annex E of IEC 60694:2002 for an arrangement of parts, components, or subassemblies connected together in one pressure system.

3.2.8 pressure drop (Δp): The drop of pressure in a given time caused by the leakage rate F without replenishment.

3.2.9 relative leakage rate (F_{rel}): The absolute leakage rate related to the total amount of gas in the system at rated filling pressure (or density). It is expressed in percentage per year or per day.

3.2.10 sealed system: A volume for which no further gas or vacuum processing is required during its expected operating life.

NOTE 1—Examples of sealed systems are tubes of vacuum circuit switchers or some SF_6 circuit switchers.

NOTE 2—Sealed systems are completely assembled and tested in the factory.

3.2.11 sniffing: The action of slowly moving a leak meter sensing probe around an assembly to locate a gas leak.

3.2.12 tightness coordination chart: A survey document supplied by the manufacturer, used when testing parts, components, or subassemblies, to demonstrate the relationship between the tightness of a complete system and the tightness of the parts, components, and/or subassemblies.

3.2.13 time between replenishments (T): The time elapsed between two replenishments performed either manually or automatically when the pressure (density) reaches the alarm level to compensate the leakage rate F .

4. Rating

The characteristics of a circuit switcher, including its operating devices and auxiliary equipment, that shall be used to determine the rating are referred to as the *rated operating sequence* and are the following:

- a) Rated characteristics to be given for all circuit switchers
 - 1) Rated maximum voltage
 - 2) Rated insulation level
 - i) Rated power-frequency withstand voltage
 - ii) Rated lightning impulse withstand voltage
 - 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 primary-bus fault breaking current
 - 9) Rated transient recovery voltage (TRV) for the rated primary-bus fault breaking current
 - 10) Rated transformer-limited fault breaking current
 - 11) Rated TRV for the rated transformer-limited fault breaking current
 - 12) Rated short-circuit making current
 - 13) Rated operating sequence
 - 14) Rated time quantities
 - 15) Rated active load switching current
 - 16) Rated static terminal load
 - 17) Rated pressures of compressed gas supply for insulation, operation, and/or interruption
 - 18) Rated control voltage of closing and opening devices and of auxiliary circuits
 - 19) Rated control frequency of closing and opening devices and of auxiliary circuits
- b) Rated characteristics to be given on request
 - 1) Rated line-charging switching current
 - 2) Rated cable-charging switching current
 - 3) Rated shunt capacitor bank switching current
 - 4) Rated peak capacitive inrush current

4.1 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.

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

^aThese values are to be used for both the wet and dry test.

^bTest voltages for isolating distances are applicable to the disconnect blade only, not the interrupter.

^cMinimum time to sparkover for the chopped wave is 2 μ sec.

4.2 Rated insulation level

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

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.

4.3 Rated power frequency (f_r)

The preferred values of the rated power frequency are 50 Hz and 60 Hz.

4.4 Rated continuous current (I_r)

The preferred values of rated continuous current are selected from the R10 series (see 3.1.8). The rated continuous current is determined by test in the standard with the temperature specified in Section 4.4.2 of IEC 60694:2002 or 5.3.2 of IEEE Std C37.04-1999.

NOTE—Some manufacturers may produce circuit switchers that have values of rated continuous current that do not follow the R10 series. For example, the R10 series gives a 1250 A rating, but many circuit switchers are rated at 1200 A.

4.5 Rated short-time withstand current (I_k)

The rated short-time withstand current is the root-mean-square (rms) value of the current that the circuit switcher can carry in the closed position for the rated short-time withstand duration.

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.

The preferred values of rated short-time withstand current are selected from the R10 series (see 3.1.8)

4.6 Rated peak withstand current (I_p)

The rated peak withstand current is the peak current associated with the first major loop of the rated short-time withstand current that a circuit switcher can carry in the closed position under prescribed conditions of use and behavior.

The rated peak withstand current shall correspond to the rated power frequency. For a rated power frequency of 50 Hz and below, it is equal to 2.5 times the rated short-time withstand current; and for a rated power frequency of 60 Hz, it is equal to 2.6 times the rated short-time withstand current.

4.7 Rated short-time withstand current duration (t_k)

The rated duration of short circuit is the interval of time for which a circuit switcher can carry, in the closed position, a current equal to its rated short-time withstand current.

The preferred value of rated duration of short circuit is 1 s for rated voltages greater than 72.5 kV and 2 s for rated voltages of 72.5 kV and below.

If it is necessary, a value lower or higher than 1 s may be chosen. The recommended values are 0.5 s, 2 s and 3 s.

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

Refer to ANSI C37.06 or to Section 4.8, Table 4, and Table 5 of IEC 60694:2002 for applicable control voltages.

4.9 Rated control frequency of operating devices and auxiliary circuits

The preferred values of rated control frequency are dc voltage and 50 Hz and 60 Hz ac voltage.

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

The value of rated pressure shall be specified by the manufacturer.

4.11 Rated primary-bus fault breaking current (I_{SF})

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 4.12.

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

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

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.

4.11.1 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 (see 3.1.8).

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

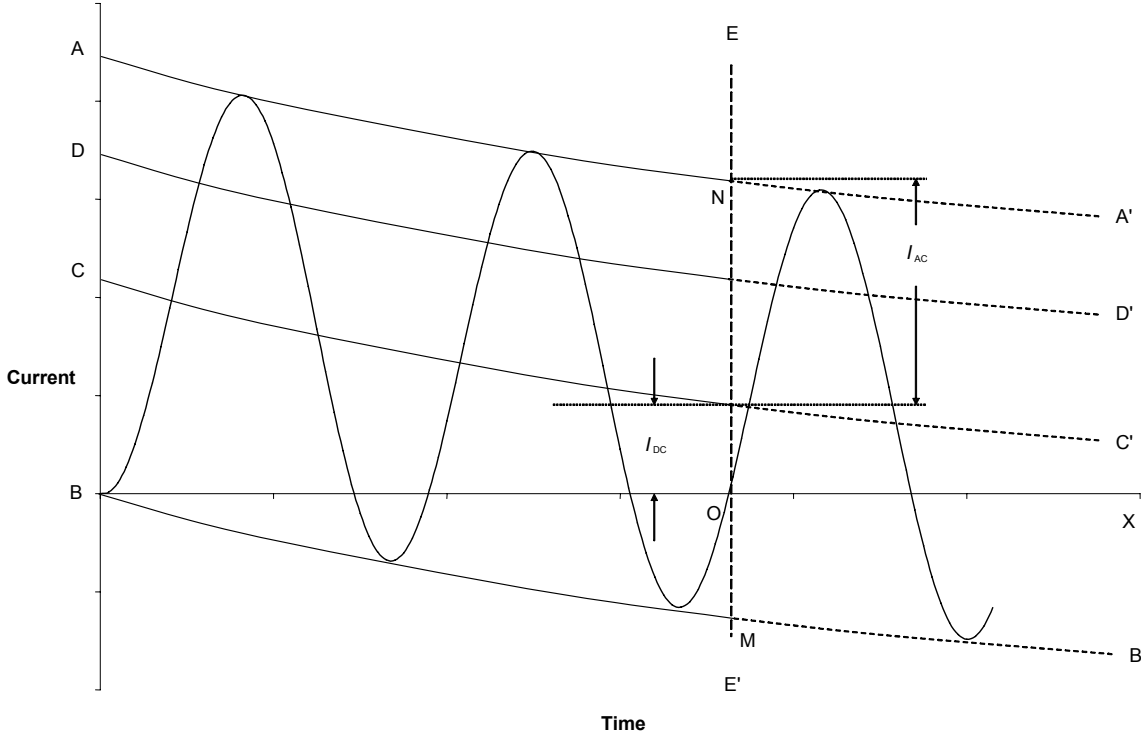
The percentage dc component shall correspond to a time interval equal to the minimum opening time of the first opening pole T_{op} of the circuit switcher plus an assumed relay time of one half-cycle of rated power frequency (T_r). (The opening time plus the assumed relay time is also known as the *contact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

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:

$$\% dc = 100 \cdot e^{\frac{-(T_{op} + T_r)}{\tau}}$$

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

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

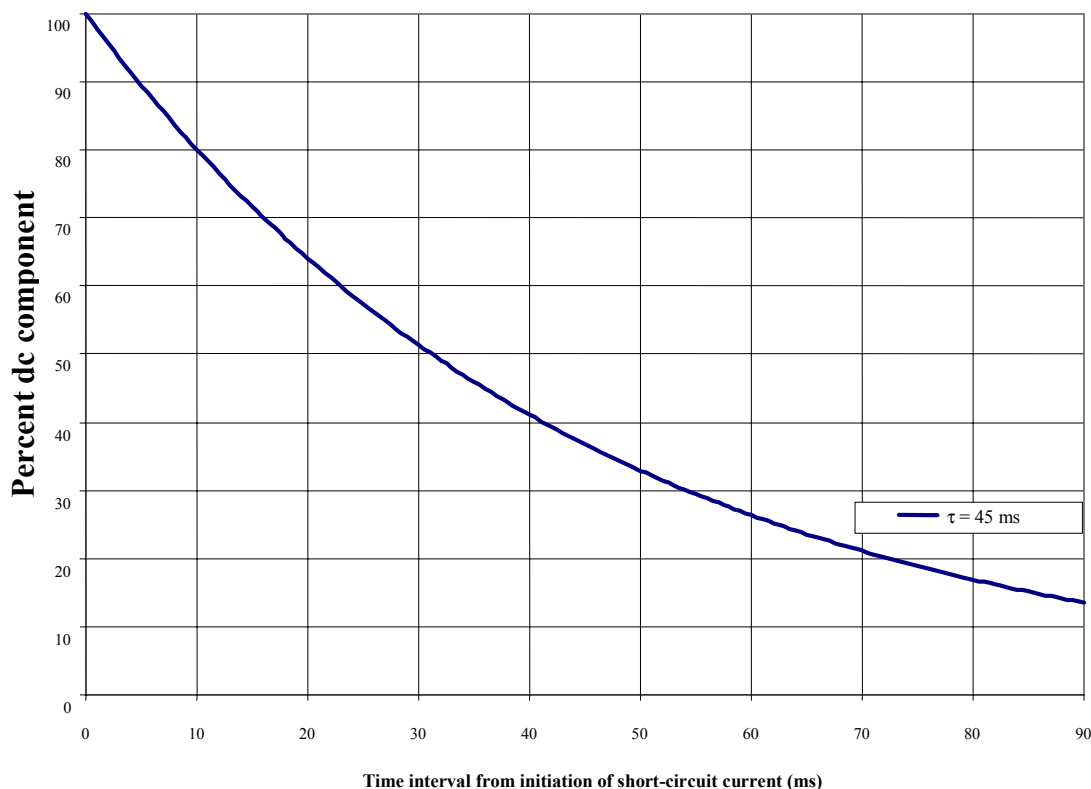


Figure 4—Percentage dc component in relation to time interval ($T_{op} + T_r$) for standard time constant $\tau = 45$ ms

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

The TRV related to the rated primary-bus fault breaking current in accordance with 4.11 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.

4.12.1 Representation of TRV waves

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.¹¹

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.¹¹

¹¹ Methods of drawing TRV envelopes are given in Annex E of IEC 62271-100.

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.

4.12.2 Representation of TRV

The following parameters are used for the representation of TRV:

- a) Four-parameter reference line (see Figure 6)

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

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}):

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

t_1 is derived from u_1 and the specified value of the rate of rise $u_1/t_1 = \text{RRRV}$.

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

$$t_2 = 4 t_1$$

- 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 (μ s)

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}):

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

t_3 is derived from u_c and the specified value of the rate of rise $u_c/t_3 = \text{RRRV}$.

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

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

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:

$$t_d = 0.05 t_3$$

$$u' = u_c/3 \text{ and}$$

t' is derived from u' , u_c/t_3 , and t_d according to Figure 5.

For rated maximum voltages 100 kV and above:

$$t_d = 2 \mu\text{s}$$

$$u' = u_1/2 \text{ and}$$

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

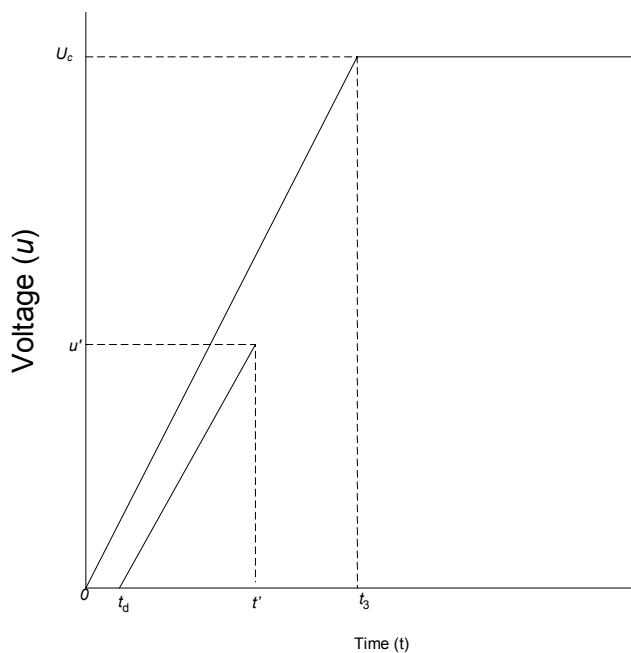


Figure 5—Representation of specified TRV by two-parameter reference and delay line

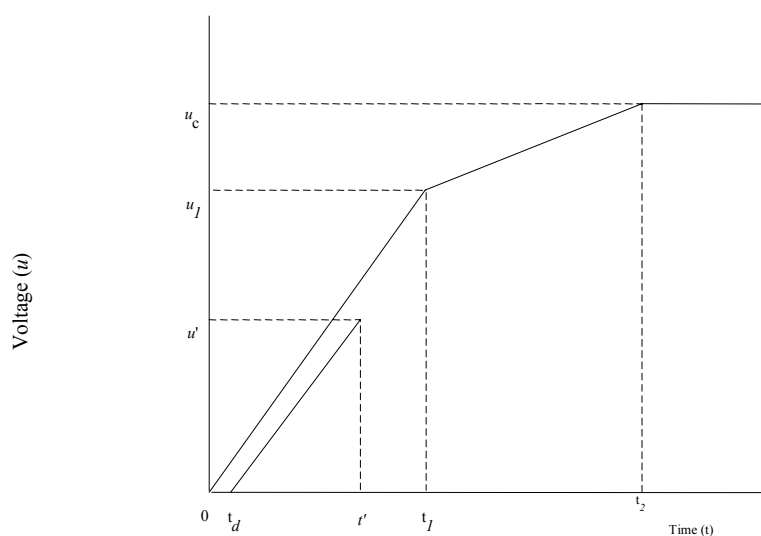


Figure 6—Representation of specified TRV by four-parameter reference and delay line

4.12.3 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 4.12.4).

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

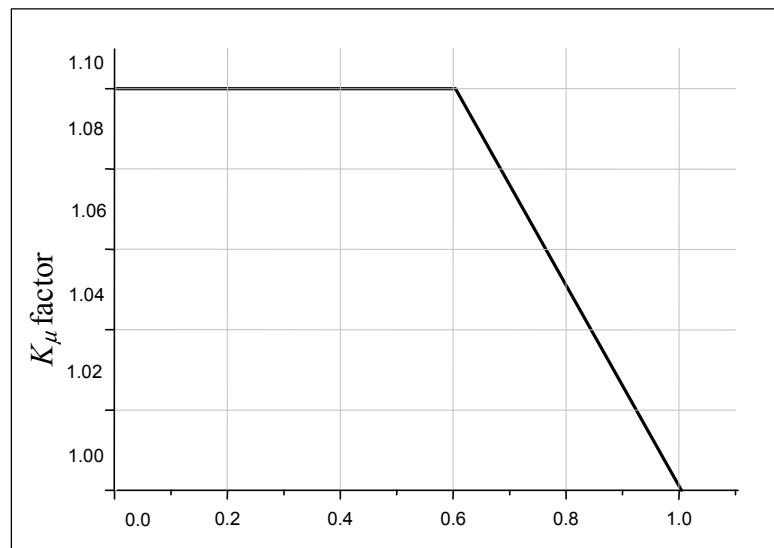
The circuit switcher shall be capable of withstanding a TRV envelope greater than the rated TRV when interrupting primary-bus fault currents are less than the rated primary-bus fault breaking current. The TRV parameters for currents below the rated primary-bus fault breaking current are defined as a 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 $t_d = 0.05$.
- Time t' is derived from u' , u_c/t_3 , and t_d according to Figure 5.

For rated maximum voltages 100 kV and above, 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 $t_d = 2 \mu\text{s}$.
- Time t' is derived from u' , u_1/t_1 , and t_d according to Figure 6.



Per unit rated primary-bus fault breaking current

Figure 7— K_u Factor

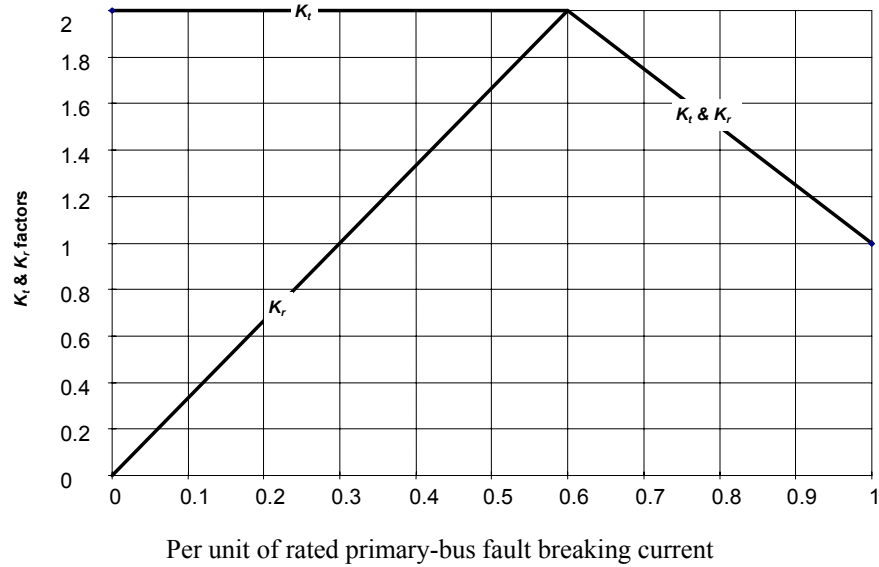


Figure 8— K_t & K_r factors

4.13 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 4.14. The preferred rated transformer-limited fault breaking currents are selected from the R 10 series (see 3.1.8).

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

The TRV related to the rated transformer-limited fault breaking current in accordance with 4.13 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.

4.14.1 Representation of TRV waves

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.¹²

¹² Methods of drawing TRV envelopes are given in Annex E of IEC 62271-100.