

Australian Standard[®]

High-voltage switchgear and controlgear

**Part 100: High-voltage alternating-
current circuit-breakers
(IEC 62271-100, Ed. 1.2 (2006) MOD)**



This Australian Standard® was prepared by Committee EL-007, Power Switchgear. It was approved on behalf of the Council of Standards Australia on 8 November 2007. This Standard was published on 12 March 2008.

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- Australian British Chamber of Commerce
 - Australian Electrical and Electronic Manufacturers Association
 - Australian Railway Association
 - Energy Networks Association
 - Engineers Australia
 - Testing interests
-

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Australian Standard[®]

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Part 100: High-voltage alternating- current circuit-breakers (IEC 62271-100, Ed. 1.2 (2006) MOD)

Originated as AS C89—1967.
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PREFACE

This Standard was prepared by the Standards Australia Committee EL-007, Power Switchgear to supersede AS 62271.100—2005.

The objective of this Standard is to provide requirements for a.c circuit breakers designed for indoor and outdoor service for operation on systems with frequencies up to 60 Hz and voltages higher than 1000 V.

This Standard is an adoption with national modifications and has been reproduced from IEC 62271-100, Ed. 1.2 (2006), *High-voltage switchgear and controlgear – Part 100: High-voltage alternating-current circuit-breakers*, and has been varied as indicated to take account of Australian conditions.

Variations to IEC 62271-100, Ed. 1.2 (2006) are indicated at the appropriate places throughout this standard. Strikethrough (~~example~~) identifies IEC text, tables and figures which, for the purposes of this Australian Standard, are deleted. Where text, tables or figures are added, each is set in its proper place and identified by shading (**example**). Added figures are not themselves shaded, but are identified by a shaded border.

Australian variations are summarized in Annex ZZ.

Common numbering of Standards falling under the responsibility of EL-007

In accordance with the decision taken by the committee EL-007, a common numbering system will be established in order to align the numbering of Australian Standards falling under the responsibility of EL-007 with IEC Standards. All high-voltage switchgear and controlgear Standards will, at their next revision (or as equivalent Standards become available in IEC), become parts of the AS 62271 (High-voltage switchgear and controlgear) series. The table below gives the relationship between future numbering and existing Standard numbers. Standards current at the time of publication of this Standard are marked with an asterisk (*).

AS 62271 Series	HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR	Old AS Number
1	Common specifications	*AS 2650
100*	High-voltage alternating-current circuit-breakers	AS 2006
102*	Alternating current disconnectors and earthing switches	AS 1306
103	Switches for rated voltages above 1 kV and less than 52 kV	*AS/NZS 60265.1
104	Switches for rated voltages of 52 kV and above	*AS 60265.2
105	Alternating current switch-fuse combinations	*AS 2024
106	Alternating current contactors and contactor-based motor-starters	*AS 60470
110*	Inductive load switching	AS 4372
200*	AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV	AS 2086
201*	AC insulation-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV	AS 2264
202*	High-voltage/low voltage prefabricated substation	AS 61330
203*	Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	AS 2263

AS 62271 Series	HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR	Old AS Number
301*	Dimensional standardization of terminals	AS 2395
303	Use and handling of sulphur hexafluoride (SF ₆) in high-voltage switchgear and controlgear	*AS 2791
304	Additional requirements for enclosed switchgear and controlgear from 1 kV to 72,5 kV to be used in severe climatic conditions	*AS 4243
308*	Guide for asymmetrical short-circuit breaking test duty T100a	-

As this Standard is reproduced from an International Standard, the following applies:

- (i) Its number does not appear on each page of text and its identity is shown only on the cover and title page.
- (ii) In the source text 'IEC 62271-100' should read 'AS 62271.100'.
- (iii) A full point should be substituted for a comma when referring to a decimal marker.

The terms 'normative' and 'informative' are used to define the application of the annex to which they apply. A normative annex is an integral part of a standard, whereas an informative annex is only for information and guidance.

CONTENTS

	<i>Page</i>
1 General.....	1
1.1 Scope	1
1.2 Normative references	2
2 Normal and special service conditions	4
3 Definitions.....	4
3.1 General terms	4
3.2 Assemblies	7
3.3 Parts of assemblies	7
3.4 Switching devices	7
3.5 Parts of circuit-breakers	9
3.6 Operation.....	11
3.7 Characteristic quantities	13
3.8 Index of definitions.....	19
4 Ratings	23
4.1 Rated voltage (U_r).....	24
4.2 Rated insulation level.....	24
4.3 Rated frequency (f_r)	25
4.4 Rated normal current (I_r) and temperature rise	25
4.5 Rated short-time withstand current (I_k)	25
4.6 Rated peak withstand current (I_p)	25
4.7 Rated duration of short circuit (t_k)	25
4.8 Rated supply voltage of closing and opening devices and of auxiliary and control circuits (U_a)	25
4.9 Rated supply frequency of closing and opening devices and auxiliary circuits	25
4.10 Rated pressures of compressed gas supply for insulation, operation and/or interruption	25
5 Design and construction.....	44
5.1 Requirements for liquids in circuit-breakers.....	44
5.2 Requirements for gases in circuit-breakers	44
5.3 Earthing of circuit-breakers	44
5.4 Auxiliary equipment	44
5.5 Dependent power closing.....	45
5.6 Stored energy closing	45
5.7 Independent manual operation	45
5.8 Operation of releases.....	45
5.9 Low- and high-pressure interlocking devices	47
5.10 Nameplates.....	47
5.11 Interlocking devices	49
5.12 Position indication.....	49
5.13 Degrees of protection by enclosures	49
5.14 Creepage distances	49
5.15 Gas and vacuum tightness	49
5.16 Liquid tightness.....	49
5.17 Flammability	49
5.18 Electromagnetic compatibility.....	49

	<i>Page</i>
6 Type tests	50
6.1 General	52
6.2 Dielectric tests	52
6.3 Radio interference voltage (r.i.v.) tests	55
6.4 Measurement of the resistance of the main circuit	55
6.5 Temperature-rise tests	55
6.6 Short-time withstand current and peak withstand current tests	56
6.7 Verification of the degree of protection	57
6.8 Tightness tests	57
6.9 Electromagnetic compatibility (EMC) tests	57
6.101 Mechanical and environmental tests	57
6.102 Miscellaneous provisions for making and breaking tests	68
6.103 Test circuits for short-circuit making and breaking tests	87
6.104 Short-circuit test quantities	89
6.105 Short-circuit test procedure	102
6.106 Basic short-circuit test-duties	104
6.107 Critical current tests	108
6.108 Single-phase and double earth-fault tests	109
6.109 Short-line fault tests	110
6.110 Out-of-phase making and breaking tests	114
6.111 Capacitive current switching tests	116
6.112 Special requirements for making and breaking tests on class E2 circuit-breakers	128
6.200 Dielectric dissipation factor	129
7 Routine tests	130
7.1 Dielectric test on the main circuit	130
7.2 Dielectric test on auxiliary and control circuits	130
7.3 Measurement of the resistance of the main circuit	130
7.4 Tightness test	130
7.5 Design and visual checks	130
7.200 Dielectric dissipation factor	132
7.201 Partial discharge test	132
8 Guide to the selection of circuit-breakers for service	133
9 Information to be given with enquiries, tenders and orders	141
10 Rules for transport, storage, installation, operation and maintenance	144
10.1 Conditions during transport, storage and installation	144
10.2 Installation	144
10.3 Operation	150
10.4 Maintenance	150
11 Safety	151
Annex A (normative) Calculation of transient recovery voltages for short-line faults from rated characteristics	200
Annex B (normative) Tolerances on test quantities during type tests	208
Annex C (normative) Records and reports of type tests	215
Annex D (normative) Determination of short-circuit power factor	218
Annex E (normative) Method of drawing the envelope of the prospective transient recovery voltage of a circuit and determining the representative parameters	220
Annex F (normative) Methods of determining prospective transient recovery voltage waves	224
Annex G (normative) Rationale behind introduction of circuit-breakers class E2	241
Annex H (informative) Inrush currents of single and back-to-back capacitor banks	242

	<i>Page</i>
Annex I (informative) Explanatory notes	247
Annex J (informative) Test current and line length tolerances for short-line fault testing	262
Annex K (informative) List of symbols and abbreviations used in IEC 62271-100.....	264
Annex L (informative) Explanatory notes on the revision of TRVs for circuit-breakers of rated voltages higher than 1 kV and less than 100 kV	270
Annex M (normative) Requirements for breaking of transformer-limited faults by circuit-breakers with rated voltage higher than 1 kV and less than 100 kV.....	274
Annex ZA (informative) Items subject to agreement between the manufacturer and user	277
Annex ZZ (normative) Variations to IEC 62271-100, Ed. 1.1 (2003) for application in Australia	279
Bibliography	280

STANDARDS AUSTRALIA

Australian Standard

High-voltage switchgear and controlgear
Part 100: High-voltage alternating-current circuit-breakers
(IEC 62271-100, Ed. 1.2 (2006) MOD)

Any table, figure or text of the international standard that is struck through is not part of this standard. Any Australian table, figure or text that is added is part of this standard and is identified by shading.

1 General**1.1 Scope**

This International Standard is applicable to a.c. circuit-breakers designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V.

It is only applicable to three-pole circuit-breakers for use in three-phase systems and single-pole circuit-breakers for use in single-phase systems. Two-pole circuit-breakers for use in single-phase systems and application at frequencies lower than 50 Hz are subject to agreement between manufacturer and user.

This standard is also applicable to the operating devices of circuit-breakers and to their auxiliary equipment. However, a circuit-breaker with a closing mechanism for dependent manual operation is not covered by this standard, as a rated short-circuit making-current cannot be specified, and such dependent manual operation may be objectionable because of safety considerations.

This standard does not cover circuit-breakers intended for use on motive power units of electrical traction equipment; these are covered by IEC 60077 [4]¹⁾.

Generator circuit-breakers installed between generator and step-up transformer are not within the scope of this standard.

Switching of inductive loads is covered by IEC 61233.

Circuit-breakers with an intentional non-simultaneity between the poles, with the exception of circuit-breakers providing single-pole auto-reclosing, are not within the scope of this standard.

This standard does not cover self-tripping circuit-breakers with mechanical tripping devices or devices which cannot be made inoperative.

By-pass circuit-breakers installed in parallel with line series capacitors and their protective equipment are not within the scope of this standard, these are covered by IEC 60143-2 [6].

NOTE Tests to prove the performance under abnormal conditions should be subject to agreement between manufacturer and user. Such abnormal conditions are, for instance, cases where the voltage is higher than the rated voltage of the circuit-breaker, conditions which may occur due to sudden loss of load on long lines or cables.

¹⁾ Figures in square brackets refer to the bibliography.

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

References to international standards that are struck through in this clause are replaced by references to Australian or Australian/New Zealand Standards that are listed immediately thereafter and identified by shading. Any Australian or Australian/New Zealand Standard that is identical to the International Standard it replaces is identified as such.

~~IEC 60050(151):1978, International Electrotechnical Vocabulary—Chapter 151: Electrical and magnetic devices~~

AS 1852.151, *International electrotechnical vocabulary—Electric and magnetic devices* (identical to IEC 60050(151):1978)

~~IEC 60050(441):1984, International Electrotechnical Vocabulary—Chapter 441: Switchgear, controlgear and fuses~~

AS 1852.441, *International electrotechnical vocabulary—Switchgear, controlgear and fuses* (identical to IEC 60050(441):1984)

~~IEC 60050(601):1985, International Electrotechnical Vocabulary—Chapter 601: Generation, transmission and distribution of electricity—General~~

AS 1852.601, *International electrotechnical vocabulary—Generation, transmission and distribution of electricity—General* (identical to IEC 60050(601):1985)

~~IEC 60050(604):1987, International Electrotechnical Vocabulary—Chapter 604: Generation, transmission and distribution of electricity—Operation~~

AS 1852.604, *International electrotechnical vocabulary—Generation, transmission and distribution of electricity—Operation* (identical to IEC 60050(604):1987)

IEC 60059: 1999, *IEC standard current ratings*

~~IEC 60060: all parts, High-voltage test techniques~~

AS 1931, *High-voltage test techniques*

~~IEC 60071-2:1996, Insulation co-ordination—Part 2: Application guide~~

AS 1824.2, *Insulation co-ordination (phase-to-earth and phase-to-phase, above 1 kV), Part 2: Application guide*

IEC 60129:1984, *Alternating current disconnectors and earthing switches*

~~IEC 60137:1995, Bushings for alternating voltages above 1 000 V~~

AS 1265, *Bushings for alternating voltages above 1000 V*

IEC 60255-3:1989, *Electrical relays – Part 3: Single output energizing quantity measuring relays with dependent or independent time*

~~IEC 60296:1982, Specification for unused mineral insulating oils for transformers and switchgear~~

AS 1767.1, *Insulating liquids Part 1: Specification for unused mineral insulating oils for transformers and switchgear*

~~IEC 60376:1971, Specification and acceptance of new sulphur hexafluoride~~ superseded by—

IEC 60376:2005, *Specification of technical grade sulfur hexafluoride (SF₆) for use in electrical equipment*

~~IEC 60427:1989, Synthetic testing of high-voltage alternating current circuit-breakers~~ superseded by—

IEC 62271-101, *High-voltage switchgear and controlgear - Part 101: Synthetic testing*

~~IEC 60480:1974, Guide to the checking of sulphur hexafluoride (SF₆) taken from electrical equipment~~ superseded by—

IEC 60480:2004, *Guidelines for the checking and treatment of sulfur hexafluoride (SF₆) taken from electrical equipment and specification for its re-use*

~~IEC 60529:1989, Degrees of protection provided by enclosures (IP code)~~

AS 60529, *Degrees of protection provided by enclosures (IP Code)*

~~IEC 60694:1996, Common specifications for high-voltage switchgear and controlgear standards~~

AS 2650, *Common specifications for high-voltage switchgear and controlgear standards*

~~IEC 61233:1994, High-voltage alternating current circuit-breakers – Inductive load switching~~

AS 62271.110, *High-voltage switchgear and controlgear, Part 110: Inductive load switching*

IEC 61633:1995, *High-voltage alternating current circuit-breakers – Guide for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers*

~~IEC 61634:1995, High-voltage switchgear and controlgear—Use and handling of sulphur hexafluoride (SF₆) in high-voltage switchgear and controlgear~~

AS 2791, *High-voltage switchgear and controlgear—Use and handling of sulphur hexafluoride (SF₆) in high-voltage switchgear and controlgear (identical to IEC 61634:1995)*

~~IEC 62271-308, High voltage alternating current circuit-breakers—Guide for asymmetrical short-circuit breaking test duty T100a~~

AS 62271.308, *High voltage switchgear and controlgear—Guide for asymmetrical short-circuit breaking test duty T100a (identical to IEC/TR 62271-308:2002)*

2 Normal and special service conditions

Clause 2 of IEC 60694 is applicable.

3 Definitions

For the purpose of this International Standard, the definitions of IEC 60050(441) and IEC 60694 apply. Some of them are recalled here for ease of reference.

Additional definitions are classified so as to be aligned with the classification used in IEC 60050(441).

3.1 General terms

3.1.101

switchgear and controlgear
[IEV 441-11-01]

3.1.102

indoor switchgear and controlgear
[IEV 441-11-04]

3.1.103

outdoor switchgear and controlgear
[IEV 441-11-05]

3.1.104

short-circuit current
[IEV 441-11-07]

3.1.105

isolated neutral system
[IEV 601-02-24]

3.1.106

solidly earthed (neutral) system
[IEV 601-02-25]

3.1.107

impedance earthed (neutral) system
[IEV 601-02-26]

3.1.108

**resonant earthed (neutral) system,
arc-suppression-coil-earth (neutral) system**
[IEV 601-02-27]

3.1.109

earth fault factor

ratio, at a selected location of a three-phase system (generally the point of installation of an equipment) and for a given system configuration, of the highest r.m.s. phase-to-earth power-frequency voltage on a sound phase during a fault to earth (affecting one or more phases at any point) to the r.m.s. phase-to-earth power-frequency voltage which would be obtained at the selected location without the fault

NOTE 1 This factor is a pure numerical ratio (generally higher than 1) and characterises in general terms the earthing conditions of a system as viewed from the stated location, independently of the actual operating values of the voltage at that location. The "earth fault factor" is the product of $\sqrt{3}$ and the "factor of earthing" which has been used in the past.

NOTE 2 The earth fault factors are calculated from the phase-sequence impedance components of the system, as viewed from the selected location, using for any rotating machines the subtransient reactance.

NOTE 3 If, for all credible system configurations, the zero-sequence reactance is less than three times the positive sequence reactance and if the zero-sequence resistance does not exceed the positive sequence reactance, the earth fault factor will not exceed 1,4.

3.1.110

ambient air temperature

[IEV 441-11-13]

3.1.111

temperature rise (of a part of a circuit-breaker)

difference between the temperature of the part and the ambient air temperature

3.1.112

single capacitor bank

bank of shunt capacitors in which the inrush current is limited by the inductance of the supply system and the capacitance of the bank of capacitors being energised, there being no other capacitors connected in parallel to the system sufficiently close to increase the inrush current appreciably

3.1.113

multiple (parallel) capacitor bank

back-to-back capacitor bank

bank of shunt capacitors or capacitor assemblies each of them switched independently to the supply system, the inrush current of one unit being appreciably increased by the capacitors already connected to the supply

3.1.114

overvoltage (in a system)

any voltage between one phase and earth or between phases having a peak value or values exceeding the corresponding peak of the highest voltage for equipment

[IEV 604-03-09, modified]

3.1.115

out-of-phase conditions

abnormal circuit conditions of loss or lack of synchronism between the parts of an electrical system on either side of a circuit-breaker in which, at the instant of operation of the circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value and may be as much as 180° (phase opposition)

3.1.116

out-of-phase (as prefix to a characteristic quantity)

qualifying term indicating that the characteristic quantity is applicable to operation of the circuit-breaker in out-of-phase conditions

3.1.117

unit test

test made on a making or breaking unit or group of units at the making current or the breaking current, specified for the test on the complete pole of a circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the circuit-breaker

3.1.118**loop**

part of the wave of the current embraced by two successive current zero crossings

NOTE A distinction is made between a major loop and a minor loop depending on the time interval between two successive current zero crossings being longer or shorter than the half-period of the alternating component of the current.

3.1.119**short-line fault (SLF)**

short-circuit on an overhead line at a short, but significant, distance from the terminals of the circuit-breaker

NOTE As a rule this distance is not more than a few kilometres.

3.1.120**power factor (of a circuit)**

ratio of the resistance to the impedance at power frequency of an equivalent circuit supposed to be formed by an inductance and a resistance in series

3.1.121**external insulation**

distances in air and the surfaces in contact with open air of solid insulation of the equipment, which are subject to dielectric stresses and to the effects of atmospheric and other external conditions such as pollution, humidity, vermin, etc.

[IEV 604-03-02, modified]

3.1.122**internal insulation**

internal solid, liquid or gaseous parts of the insulation of equipment, which are protected from the effects of atmospheric and other external conditions

[IEV 604-03-03]

3.1.123**self-restoring insulation**

insulation which completely recovers its insulating properties after a disruptive discharge

[IEV 604-03-04]

3.1.124**non-self restoring insulation**

insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge

[IEV 604-03-05]

3.1.125**disruptive discharge**

phenomenon associated with the failure of insulation under electric stress, in which the discharge completely bridges the insulation under test, reducing the voltage between the electrodes to zero or nearly to zero

NOTE 1 This term applies to discharges in solid, liquid and gaseous dielectrics and to combinations of these.

NOTE 2 A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength (non-self-restoring insulation); in a liquid or gaseous dielectric, the loss may be only temporary (self-restoring insulation).

NOTE 3 The term "sparkover" is used when a disruptive discharge occurs in a gaseous or liquid dielectric. The term "flashover" is used when a disruptive discharge occurs over the surface of a solid dielectric in a gaseous or liquid medium. The term "puncture" is used when a disruptive discharge occurs through a solid dielectric.

3.1.126**non-sustained disruptive discharge (NSDD)**

disruptive discharge between the contacts of a vacuum circuit-breaker during the power frequency recovery voltage period resulting in a high-frequency current flow which is related to stray capacitance near the interrupter

NOTE Non-sustained disruptive discharges are interrupted after one or a few loops of the high-frequency current.

3.1.127

restrike performance

expected probability of restrike during capacitive current interruption as demonstrated by specified type tests

NOTE Specific numeric probabilities cannot be applied throughout a circuit-breaker service life.

3.1.128

effectively earthed neutral system

system earthed through a sufficiently low impedance such that for all system conditions the ratio of the zero-sequence reactance to the positive-sequence reactance (X_0/X_1) is positive and less than 3, and the ratio of the zero-sequence resistance to the positive-sequence reactance (R_0/X_1) is positive and less than 1. Normally such systems are solidly earthed (neutral) systems or low impedance earthed (neutral) systems

NOTE For the correct assessment of the earthing conditions not only the physical earthing conditions around the relevant location but the total system is to be considered.

3.1.129

non-effectively earthed neutral system

system other than effectively earthed neutral system, not meeting the conditions given in 3.1.128. Normally such systems are isolated neutral systems, high impedance earthed (neutral) systems or resonant earthed (neutral) systems

NOTE For the correct assessment of the earthing conditions not only the physical earthing conditions around the relevant location but the total system is to be considered.

3.2 Assemblies

No particular definitions.

3.3 Parts of assemblies

No particular definitions.

3.4 Switching devices

3.4.101

switching device

[IEV 441-14-01]

3.4.102

mechanical switching device

[IEV 441-14-02]

3.4.103

circuit-breaker

[IEV 441-14-20]

3.4.104

dead tank circuit-breaker

[IEV 441-14-25]

3.4.105

live tank circuit-breaker

[IEV 441-14-26]

3.4.106
air circuit-breaker
 [IEV 441-14-27]

3.4.107
oil circuit-breaker
 [IEV 441-14-28]

3.4.108
vacuum circuit-breaker
 [IEV 441-14-29]

3.4.109
gas-blast circuit-breaker
 [IEV 441-14-30]

3.4.110
sulphur hexafluoride circuit-breaker
SF₆ circuit-breaker
 [IEV 441-14-31]

3.4.111
air-blast circuit-breaker
 [IEV 441-14-32]

3.4.112
circuit-breaker class E1
 circuit-breaker with basic electrical endurance not falling into the category of class E2 as defined in 3.4.113

3.4.113
circuit-breaker class E2
 circuit-breaker designed so as not to require maintenance of the interrupting parts of the main circuit during its expected operating life, and only minimal maintenance of its other parts (circuit-breaker with extended electrical endurance)

NOTE 1 Minimal maintenance may include lubrication, replenishment of gas and cleaning of external surfaces, where applicable.

NOTE 2 This definition is restricted to distribution circuit-breakers having a rated voltage above 1 kV, and up to and including 52 kV. See annex G for rationale behind introduction of class E2.

3.4.114
circuit-breaker class C1
 circuit-breaker with low probability of restrike during capacitive current breaking as demonstrated by specific type tests

3.4.115
circuit-breaker class C2
 circuit-breaker with very low probability of restrike during capacitive current breaking as demonstrated by specific type tests

3.4.116
circuit-breaker class M1
 circuit-breaker with normal mechanical endurance (mechanically type tested for 2 000 operations) not falling into the category of class M2 as defined in 3.4.117

3.4.117**circuit-breaker class M2**

frequently operated circuit-breaker for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests (circuit-breaker with extended mechanical endurance, mechanically type tested for 10 000 operations)

NOTE A combination of the different classes of circuit-breakers with regard to electrical endurance, mechanical endurance and the restrike probability during capacitive current breaking is possible. For the designation of these circuit-breakers the notation of the different classes are combined following an alphabetical order, for example C1-M2.

3.4.118**self-tripping circuit-breaker**

circuit-breaker which is tripped by a current in the main circuit without the aid of any form of auxiliary power

3.4.119**cable system**

system in which the TRV during breaking of terminal fault at 100 % of short-circuit breaking current does not exceed the two-parameter envelope derived from Table 24 of this standard

NOTE 1 This definition is restricted to systems of rated voltages higher than 1 kV and less than 100 kV.

NOTE 2 Circuit-breakers of indoor substations with cable connection are generally in cable-systems.

NOTE 3 A circuit-breaker in an outdoor substation is considered to be in a cable-system if the total length of cable (or equivalent length when capacitors are also present) connected on the supply side of the circuit-breaker is at least 100 m. However if in an actual case with an equivalent length of cable shorter than 100 m a calculation can show that the actual TRV is covered by the envelope defined from Table 24, then this system is considered as a cable system.

NOTE 4 The capacitance of cable-systems on the supply side of circuit-breakers is provided by cables and/or capacitors and/or insulated bus.

3.4.120**line system**

system in which the TRV during breaking of terminal fault at 100 % of short-circuit breaking current is covered by the two-parameter envelope derived from Table 25 of this standard and exceeds the two-parameter envelope derived from Table 24 of this standard

NOTE 1 This definition is restricted to systems of rated voltages equal to or higher than 15 kV and less than 100 kV.

NOTE 2 In line-systems, no cable is connected on the supply side of the circuit-breaker, with the possible exception of a total length of cable less than 100 m between the circuit-breaker and the supply transformer(s).

NOTE 3 Systems with overhead lines directly connected to a busbar (without intervening cable connections) are typical examples of line-systems.

3.4.121**circuit-breaker class S1**

circuit-breaker intended to be used in a cable system

3.4.122**circuit-breaker class S2**

circuit-breaker intended to be used in a line-system, or in a cable-system with direct connection (without cable) to overhead lines

3.5 Parts of circuit-breakers**3.5.101****pole**

[IEV 441-15-01]

3.5.102**main circuit**

[IEV 441-15-02]

3.5.103
control circuit
[IEV 441-15-03]

3.5.104
auxiliary circuit
[IEV 441-15-04]

3.5.105
contact
[IEV 441-15-05]

3.5.106
contact piece
[IEV 441-15-06]

3.5.107
main contact
[IEV 441-15-07]

3.5.108
arcing contact
[IEV 441-15-08]

3.5.109
control contact
[IEV 441-15-09]

3.5.110
auxiliary contact
[IEV 441-15-10]

3.5.111
auxiliary switch
[IEV 441-15-11]

3.5.112
“a” contact;
make contact
[IEV 441-15-12]

3.5.113
“b” contact;
break contact
[IEV 441-15-13]

3.5.114
sliding contact
[IEV 441-15-15]

3.5.115
rolling contact
[IEV 441-15-16]

3.5.116
release
[IEV 441-15-17]

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3.5.117
arc control device
 [IEV 441-15-18]

3.5.118
position indicating device
 [IEV 441-15-25]

3.5.119
connection (bolted or equivalent)
 two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

3.5.120
terminal
 component provided for the connection of a device to external conductors
 [IEV 151-01-03]

3.5.121
making (or breaking) unit
 part of a circuit-breaker which in itself acts as a circuit-breaker and which, in series with one or more identical and simultaneously operated making or breaking units, forms the complete circuit-breaker

NOTE 1 Making units and breaking units may be separate or combined. Each unit may have several contacts.

NOTE 2 The means controlling the voltage distribution between units may differ from unit to unit.

3.5.122
module
 assembly which generally comprises making or breaking units, post-insulators and mechanical parts and which is mechanically and electrically connected to other identical assemblies to form a pole of a circuit-breaker

3.5.123
enclosure
 part of switchgear and controlgear providing a specified degree of protection (see IEC 60529) of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts
 [IEV 441-13-01, modified]

3.6 Operation

3.6.101
operation
 [IEV 441-16-01]

3.6.102
operating cycle
 [IEV 441-16-02]

3.6.103
operating sequence
 [IEV 441-16-03]

3.6.104
closing operation
 [IEV 441-16-08]

3.6.105
opening operation
 [IEV 441-16-09]

3.6.106
auto-reclosing
 [IEV 441-16-10]

3.6.107
positive opening operation
 [IEV 441-16-11]

3.6.108
positively driven operation
 [IEV 441-16-12]

3.6.109
dependent manual operation
 [IEV 441-16-13]

3.6.110
dependent power operation
 [IEV 441-16-14]

3.6.111
stored energy operation
 operation by means of energy stored in the mechanism itself prior to the switching operation and sufficient to complete the specified operating sequence under predetermined conditions

3.6.112
independent manual operation
 [IEV 441-16-16]

3.6.113
closed position
 [IEV 441-16-22]

3.6.114
open position
 [IEV 441-16-23]

3.6.115
instantaneous release
 [IEV 441-16-32]

3.6.116
making-current release
 release which permits a circuit-breaker to open, without any intentional time delay, during a closing operation, if the making current exceeds a predetermined value, and which is rendered inoperative when the circuit-breaker is in the closed position

3.6.117
over-current release
 [IEV 441-16-33]

3.6.118
definite time-delay over-current release
 [IEV 441-16-34]

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3.6.119
inverse time-delay over-current release
 [IEV 441-16-35]

3.6.120
direct over-current release
 [IEV 441-16-36]

3.6.121
indirect over-current release
 [IEV 441-16-37]

3.6.122
shunt release
 [IEV 441-16-41]

3.6.123
under-voltage release
 [IEV 441-16-42]

3.6.124
reverse current release (d.c. only)
 [IEV 441-16-43]

3.6.125
operating current (of an over-current release)
 [IEV 441-16-45]

3.6.126
current setting (of an over-current release)
 [IEV 441-16-46]

3.6.127
current setting range (of an over-current release)
 [IEV 441-16-47]

3.6.128
anti-pumping device
 [IEV 441-16-48]

3.6.129
interlocking device
 [IEV 441-16-49]

3.6.130
circuit-breaker with lock-out preventing closing
 [IEV 441-14-23]

3.7 Characteristic quantities

Figures 1 to 7 illustrate some definitions of this subclause.

Time quantities, see definitions 3.7.133 to 3.7.147, are expressed in milliseconds or in cycles. When expressed in cycles, the power frequency should be stated in brackets. In the case of circuit-breakers incorporating switching resistors, a distinction is made, where applicable, between time quantities associated with the contacts switching the full current and the contacts switching the current limited by switching resistors.

Unless otherwise stated, the time quantities referred to are associated with the contacts switching the full current.

3.7.101

rated value

quantity value assigned, generally by a manufacturer, for a specified operating condition of component, device or equipment

[IEV 151-04-03]

3.7.102

prospective current (of a circuit and with respect to a switching device or a fuse)

[IEV 441-17-01]

3.7.103

prospective peak current

peak value of the first major loop of the prospective current during the transient period following initiation

NOTE The definition assumes that the current is made by an ideal circuit-breaker, i.e. with instantaneous and simultaneous transition of its impedance across the terminals of each pole from infinity to zero. The peak value may differ from one pole to another; it depends on the instant of current initiation relative to the voltage wave across the terminals of each pole.

3.7.104

peak current

peak value of the first major loop of current during the transient period following initiation

3.7.105

prospective symmetrical current (of an a.c. circuit)

[IEV 441-17-03]

3.7.106

maximum prospective peak current (of an a.c. circuit)

[IEV 441-17-04]

3.7.107

prospective making current (for a pole of a switching device)

[IEV 441-17-05]

3.7.108

(peak) making current

peak value of the first major loop of the current in a pole of a circuit-breaker during the transient period following the initiation of current during a making operation

NOTE 1 The peak value may differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage.

NOTE 2 Where, for a polyphase circuit, a single value of (peak) making current is referred to, this is, unless otherwise stated, the highest value in any phase.

3.7.109

prospective breaking current (for a pole of a switching device)

prospective current evaluated at the instant corresponding to the initiation of the arc during breaking process

3.7.110

breaking current

[IEV 441-17-07]

3.7.111**critical (breaking) current**

value of breaking current, less than rated short-circuit breaking current, at which the arcing time is a maximum and is significantly longer than at the rated short-circuit breaking current. It will be assumed that this is the case if the minimum arcing times in any of the test-duties T10, T30 or T60 is one half-cycle or more longer than the minimum arcing times in the adjacent test-duties

3.7.112**breaking capacity**

[IEV 441-17-08]

3.7.113**line-charging (line off-load) breaking capacity**

breaking capacity for which the specified conditions of use and behaviour include the opening of an overhead line operating at no-load

3.7.114**cable-charging (cable off-load) breaking capacity**

breaking capacity for which the specified conditions of use and behaviour include the opening of an insulated cable operating at no-load

3.7.115**capacitor bank breaking capacity**

breaking capacity for which the specified conditions of use and behaviour include the opening of a capacitor bank

3.7.116**making capacity**

[IEV 441-17-09]

3.7.117**capacitor bank inrush making capacity**

making capacity for which the specified conditions of use and behaviour include the closing onto a capacitor bank

3.7.118**out-of-phase (making or breaking) capacity**

making or breaking capacity for which the specified conditions of use and behaviour include the loss or the lack of synchronism between the parts of an electrical system on either side of the circuit-breaker

3.7.119**short-circuit making capacity**

[IEV 441-17-10]

3.7.120**short-circuit breaking capacity**

[IEV 441-17-11]

3.7.121**short-time withstand current**

[IEV 441-17-17]

3.7.122**peak withstand current**

[IEV 441-17-18]

3.7.123
applied voltage
 [IEV 441-17-24]

3.7.124
recovery voltage
 [IEV 441-17-25]

3.7.125
transient recovery voltage (TRV)
 [IEV 441-17-26]

3.7.126
prospective transient recovery voltage (of a circuit)
 [IEV 441-17-29]

3.7.127
power frequency recovery voltage
 [IEV 441-17-27]

3.7.128
peak arc voltage
 [IEV 441-17-30]

3.7.129
clearance
 [IEV 441-17-31]

3.7.130
clearance between poles
 [IEV 441-17-32]

3.7.131
clearance to earth
 [IEV 441-17-33]

3.7.132
clearance between open contacts
 [IEV 441-17-34]

3.7.133
opening time

opening time of a circuit-breaker defined according to the tripping method as stated below and with any time delay device forming an integral part of the circuit-breaker adjusted to its minimum setting:

- a) for a circuit-breaker tripped by any form of auxiliary power, the opening time is the interval of time between the instant of energising the opening release, the circuit-breaker being in the closed position, and the instant when the arcing contacts have separated in all poles;
- b) for a self-tripping circuit-breaker, the opening time is the interval of time between the instant at which, the circuit-breaker being in the closed position, the current in the main circuit reaches the operating value of the overcurrent release and the instant when the arcing contacts have separated in all poles.

NOTE 1 The opening time may vary with the breaking current.

NOTE 2 For circuit-breakers with more than one interrupting unit per pole, the instant when the arcing contacts have separated in all poles is determined as the instant of contact separation in the first unit of the last pole.

NOTE 3 The opening time includes the operating time of any auxiliary equipment necessary to open the circuit-breaker and forming an integral part of the circuit-breaker.

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3.7.134**arcing time (of a multipole switching device)**

interval of time between the instant of the first initiation of an arc and the instant of final arc extinction in all poles
[IEV 441-17-38]

3.7.135**break time**

interval of time between the beginning of the opening time of a mechanical switching device and the end of the arcing time
[IEV 441-17-39, modified]

3.7.136**closing time**

interval of time between energising the closing circuit, the circuit-breaker being in the open position, and the instant when the contacts touch in all poles

NOTE The closing time includes the operating time of any auxiliary equipment necessary to close the circuit-breaker and forming an integral part of the circuit-breaker.

3.7.137**make time**

interval of time between energising the closing circuit, the circuit-breaker being in the open position, and the instant when the current begins to flow in the first pole
[IEV 441-17-40, modified]

NOTE 1 The make time includes the operating time of any auxiliary equipment necessary to close the circuit-breaker and forming an integral part of the circuit-breaker.

NOTE 2 The make time may vary, e.g. due to the variation of the pre-arcing time.

3.7.138**pre-arcing time**

interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions

NOTE 1 The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore may vary considerably.

NOTE 2 This definition for pre-arcing time for a circuit-breaker should not be confused with the definition for pre-arcing time for a fuse.

3.7.139**open-close time (during auto-reclosing)**

interval of time between the instant when the arcing contacts have separated in all poles and the instant when the contacts touch in the first pole during a reclosing cycle

3.7.140**dead time (during auto-reclosing)**

interval of time between final arc extinction in all poles in the opening operation and the first re-establishment of current in any pole in the subsequent closing operation

NOTE The dead time may vary, e.g. due to the variation of the pre-arcing time.

3.7.141**reclosing time**

interval of time between the beginning of the opening time and the instant when the contacts touch in all poles during a reclosing cycle

3.7.142**re-make time (during reclosing)**

interval of time between the beginning of the opening time and the first re-establishment of current in any pole in the subsequent closing operation

NOTE The re-make time may vary, e.g. due to the variation of the pre-arcing time.

3.7.143

close-open time

interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation

[IEV 441-17-42, modified]

NOTE Unless otherwise stated, it is assumed that the opening release incorporated in the circuit-breaker is energised at the instant when the contacts touch in the first pole during closing. This represents the minimum close-open time.

3.7.144

make-break time

interval of time between the initiation of current flow in the first pole during a closing operation and the end of the arcing time during the subsequent opening operation

NOTE 1 Unless otherwise stated, it is assumed that the opening release of the circuit-breaker is energised one half-cycle after current begins to flow in the main circuit during making. It should be noted that the use of relays with shorter operating time may subject the circuit-breaker to asymmetrical currents that are in excess of those provided for in 6.106.5.

NOTE 2 The make-break time may vary due to the variation of the pre-arcing time.

3.7.145

pre-insertion time

interval of time during a closing operation in any one pole between the instant of contact touch in the closing resistor element and the instant of contact touch in the main breaking unit of that pole

NOTE For circuit-breakers having series connected breaking units, the pre-insertion time is defined as the interval of time between the instant of the last contact touch in any closing resistor element and the instant of the last contact touch in any main breaking unit.

3.7.146

minimum trip duration

minimum time the auxiliary power is applied to the opening release to ensure complete opening of the circuit-breaker

3.7.147

minimum close duration

minimum time the auxiliary power is applied to the closing device to ensure complete closing of the circuit-breaker

3.7.148

re-ignition (of an a.c. mechanical switching device)

[IEV 441-17-45]

3.7.149

restrike (of an a.c. mechanical switching device)

[IEV 441-17-46]

3.7.150

normal current

current which the main circuit of a circuit-breaker is capable of carrying continuously under specified conditions of use and behaviour

3.7.151

peak factor (of the line transient voltage)

ratio between the maximum excursion and the initial value of the line transient voltage to earth of a phase of an overhead line after the breaking of a short-line fault current

NOTE The initial value of the transient voltage corresponds to the instant of arc extinction in the pole considered.

3.7.152**first-pole-to-clear factor (in a three-phase system)**

when interrupting any symmetrical three-phase current the first-pole-to-clear factor is the ratio of the power frequency voltage across the interrupting pole before current interruption in the other poles, to the power frequency voltage occurring across the pole or the poles after interruption in all three poles

3.7.153**amplitude factor**

ratio between the maximum excursion of the transient recovery voltage to the crest value of the power frequency recovery voltage

3.7.154**insulation level**

for a circuit-breaker, a characteristic defined by one or two values indicating the insulation withstand voltages

[IEV 604-03-47, modified]

3.7.155**power frequency withstand voltage**

r.m.s. value of sinusoidal power frequency voltage that the circuit-breaker can withstand during tests made under specified conditions and for a specified time

[IEV 604-03-40, modified]

3.7.156**impulse withstand voltage**

peak value of the standard impulse voltage wave which the insulation of the circuit-breaker withstands under specified test conditions

NOTE Depending on the shape of wave, the term may be qualified as "switching impulse withstand voltage" or "lightning impulse withstand voltage".

3.7.157**minimum functional pressure for operation**

pressure, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a circuit-breaker are maintained and at which a replenishment of the operating device becomes necessary

NOTE This pressure is often designated as interlocking pressure (refer to 3.6.4.6 of IEC 60694).

3.7.158**minimum functional pressure for interruption and insulation**

pressure for interruption and for insulation, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a circuit-breaker are maintained and at which a replenishment of the interrupting and/or insulating fluid becomes necessary

NOTE 1 See also 3.6.4.5 of IEC 60694.

NOTE 2 For circuit-breakers with a sealed pressure system (also termed sealed-for-life), the minimum functional pressure for interruption is the one at which the rated characteristics of the circuit-breaker are maintained taking into account the pressure drop at the end of the expected operating life.

3.8 Index of definitions**A**

"a" contact, make contact	3.5.112
Air-blast circuit-breaker	3.4.111
Air circuit-breaker	3.4.106
Ambient air temperature	3.1.110
Amplitude factor	3.7.153
Anti-pumping device	3.6.128
www.standards.org.au	

Applied voltage	3.7.123
Arcing contact	3.5.108
Arcing time	3.7.134
Arc control device	3.5.117
Arc-suppression-coil-earth (neutral) system	3.1.108
Auto-reclosing	3.6.106
Auxiliary circuit	3.5.104
Auxiliary contact	3.5.110
Auxiliary switch	3.5.111

B

Back-to-back capacitor bank	3.1.113
"b" contact, break contact	3.5.113
Break contact	3.5.113
Breaking capacity	3.7.112
Breaking current	3.7.110
Breaking unit	3.5.121
Break-time	3.7.135

C

Cable-charging (cable off-load) breaking capacity	3.7.114
Cable off-load breaking capacity	3.7.114
Cable system	3.4.119
Capacitor bank breaking capacity	3.7.115
Capacitor bank inrush making capacity	3.7.117
Circuit-breaker	3.4.103
Circuit-breaker class C1	3.4.114
Circuit-breaker class C2	3.4.115
Circuit-breaker class E1	3.4.112
Circuit-breaker class E2	3.4.113
Circuit-breaker class M1	3.4.116
Circuit-breaker class M2	3.4.117
Circuit-breaker class S1	3.4.121
Circuit-breaker class S2	3.4.122
Circuit-breaker with lock-out preventing closing	3.6.130
Clearance	3.7.129
Clearance between open contacts	3.7.132
Clearance between poles	3.7.130
Clearance to earth	3.7.131
Closed position	3.6.113
Close-open time	3.7.143
Closing operation	3.6.104
Closing time	3.7.136
Connection (bolted or the equivalent)	3.5.119
Contact	3.5.105
Contact piece	3.5.106
Control circuit	3.5.103
Control contact	3.5.109
Critical (breaking) current	3.7.111
Current setting (of an over-current release)	3.6.126
Current setting range (of an over-current release)	3.6.127

D

Dead tank circuit-breaker	3.4.104
Dead time (during auto-reclosing)	3.7.140

Definite time-delay over-current release	3.6.118
Dependent manual operation	3.6.109
Dependent power operation	3.6.110
Direct over-current release	3.6.120
Disruptive discharge	3.1.125
E	
Earth fault factor	3.1.109
Effectively earthed neutral system	3.1.128
Enclosure	3.5.123
External insulation	3.1.121
F	
First-pole-to-clear factor (in a three-phase system)	3.7.152
G	
Gas-blast circuit-breaker	3.4.109
I	
Impedance earthed (neutral) system	3.1.107
Impulse withstand voltage	3.7.156
Independent manual operation	3.6.112
Indirect over-current release	3.6.121
Indoor switchgear and controlgear	3.1.102
Instantaneous release	3.6.115
Insulation level	3.7.154
Interlocking device	3.6.129
Internal insulation	3.1.122
Inverse time-delay over-current release	3.6.119
Isolated neutral system	3.1.105
L	
Line-charging (line off-load) breaking capacity	3.7.113
Line off-load breaking capacity	3.7.113
Line system	3.4.120
Live tank circuit-breaker	3.4.105
Loop	3.1.118
M	
Main circuit	3.5.102
Main contact	3.5.107
Make-break time	3.7.144
Make contact	3.5.112
Make-time	3.7.137
Making capacity	3.7.116
(Peak) Making current	3.7.108
Making-current release	3.6.116
Making unit	3.5.121
Maximum prospective peak current (of an a.c. circuit)	3.7.106
Mechanical switching device	3.4.102
Minimum close duration	3.7.147
Minimum functional pressure for interruption and insulation	3.7.158
Minimum functional pressure for operation	3.7.157
Minimum trip duration	3.7.146
Module	3.5.122
Multiple (parallel) capacitor bank	3.1.113
www.standards.org.au	

N

Non-effectively earthed neutral system	3.1.129
Non-self-restoring insulation	3.1.124
Non-sustained disruptive discharge (NSDD)	3.1.126
Normal current	3.7.150
NSDD	3.1.126

O

Oil circuit-breaker	3.4.107
Open-close time (during auto-reclosing)	3.7.139
Opening operation	3.6.105
Opening time	3.7.133
Open position	3.6.114
Operating current (of an over-current release)	3.6.125
Operating cycle	3.6.102
Operating sequence	3.6.103
Operation	3.6.101
Outdoor switchgear and controlgear	3.1.103
Out-of-phase (as prefix to a characteristic quantity)	3.1.116
Out-of-phase (making or breaking) capacity	3.7.118
Out-of-phase conditions	3.1.115
Over-current release	3.6.117
Overvoltage (in a system)	3.1.114

P

Parallel capacitor bank	3.1.113
Peak arc voltage	3.7.128
Peak current	3.7.104
Peak factor (of the line transient voltage)	3.7.151
(Peak) making current	3.7.108
Peak withstand current	3.7.122
Pole	3.5.101
Position indicating device	3.5.118
Positively driven operation	3.6.108
Positive opening operation	3.6.107
Power factor (of a circuit)	3.1.120
Power frequency recovery voltage	3.7.127
Power frequency withstand voltage	3.7.155
Pre-arcing time	3.7.138
Pre-insertion time	3.7.145
Prospective breaking current (for a pole of a circuit-breaker)	3.7.109
Prospective current (of a circuit and with respect to a switching device or a fuse)	3.7.102
Prospective making current (of an a.c. circuit)	3.7.107
Prospective peak current	3.7.103
Prospective symmetrical current (of an a.c. circuit)	3.7.105
Prospective transient recovery voltage (of a circuit)	3.7.126

R

Rated value	3.7.101
Reclosing time	3.7.141
Recovery voltage	3.7.124
Re-ignition (of an a.c. mechanical switching device)	3.7.148
Re-make time (during reclosing)	3.7.142
Release	3.5.116

Resonant earthed (neutral) system	3.1.108
Restrike (of an a.c. mechanical switching device)	3.7.149
Restrike performance	3.1.127
Reverse current release (d.c. only)	3.6.124
Rolling contact	3.5.115
S	
Self-restoring insulation	3.1.123
Self-tripping circuit-breaker	3.4.118
SF ₆ circuit-breaker	3.4.110
Short-circuit current	3.1.104
Short-circuit breaking capacity	3.7.120
Short-circuit making capacity	3.7.119
Short-line fault	3.1.119
Short-time withstand current	3.7.121
Shunt release	3.6.122
Single capacitor bank	3.1.112
Sliding contact	3.5.114
Solidly earthed (neutral) system	3.1.106
Stored energy operation	3.6.111
Sulphur hexafluoride circuit-breaker	3.4.110
Switchgear and controlgear	3.1.101
Switching device	3.4.101
T	
Temperature rise (of a part of a circuit-breaker)	3.1.111
Terminal	3.5.120
Transient recovery voltage (TRV)	3.7.125
TRV	3.7.125
U	
Under-voltage release	3.6.123
(Making or breaking) Unit	3.5.121
Unit test	3.1.117
V	
Vacuum circuit-breaker	3.4.108

4 Ratings

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

Rated characteristics to be given for all circuit-breakers

- a) rated voltage;
- b) rated insulation level;
- c) rated frequency;
- d) rated normal current;
- e) rated short-time withstand current;
- f) rated peak withstand current;
- g) rated duration of short-circuit;
- h) rated supply voltage of closing and opening devices and of auxiliary circuits;
- i) rated supply frequency of closing and opening devices and of auxiliary circuits;
- j) rated pressures of compressed gas supply and/or of hydraulic supply for operation, interruption and insulation, as applicable;

- k) rated short-circuit breaking current;
- l) transient recovery voltage related to the rated short-circuit breaking current;
- m) rated short-circuit making current;
- n) rated operating sequence;
- o) rated time quantities.

Rated characteristics to be given in the specific cases indicated below

- p) characteristics for short-line faults related to the rated short-circuit breaking current, for circuit-breakers designed for direct connection to overhead lines, irrespective of the type of network on the source side, and rated at 15 kV and above and at more than 12,5 kA rated short-circuit breaking current;
- q) rated line-charging breaking current, for three-pole circuit-breakers intended for switching over-head transmission lines (mandatory for circuit-breakers of rated voltages equal to or greater than 72,5 kV).
- r) rated cable-charging breaking current, for three-pole circuit-breakers intended for switching cables (mandatory for circuit-breakers of rated voltages equal to or less than 52 kV).

Rated characteristics to be given on request

- s) rated out-of-phase making and breaking current;
- t) rated single capacitor bank breaking current;
- u) rated back-to-back capacitor bank breaking current;
- v) rated capacitor bank inrush making current;
- w) rated back-to-back capacitor bank inrush making current.

The rated characteristics of the circuit-breaker are referred to the rated operating sequence.

4.1 Rated voltage (U_r)

Subclause 4.1 of IEC 60694 is applicable.

4.2 Rated insulation level

Subclause 4.2 of IEC 60694 is applicable with the following addition:

The standard values of rated withstand voltages across the open circuit-breaker are given in tables 1a, 1b, 2a and 2b of IEC 60694.

However, for circuit-breakers intended for use in synchronising operations simultaneously with a substantial transient or temporary overvoltage, the insulation of a standard circuit-breaker may be insufficient. In such cases it is suggested either to use a standard circuit-breaker having a higher rated voltage or to use a special circuit-breaker, increasing the severity of the test with the circuit-breaker open. In this last case the rated power frequency withstand voltage across the isolating distance according to columns (3) of the tables mentioned above shall be applied across the open circuit-breaker. The transient overvoltage stress is taken into account by the testing method given in 6.2.7.2. For circuit-breakers having a rated voltage equal to or higher than 300 kV, the standard value of rated power frequency withstand voltage and the rated switching impulse withstand voltage across the open switching device are respectively given in columns (3) and (6) of tables 2a and 2b of IEC 60694.

When, for single-phase capacitive current switching tests a test voltage factor of 1,4 is specified, the insulation across the open terminals of the circuit-breaker may be insufficient. In such cases, the value of rated short-duration power-frequency withstand voltage across the open switching device may be increased to $2,8 U_r/\sqrt{3}$.

4.3 Rated frequency (f_r)

Subclause 4.3 of IEC 60694 is applicable with the following addition:

The standard values for the rated frequency of high voltage circuit-breakers are 50 Hz and 60 Hz.

4.4 Rated normal current (I_r) and temperature rise

Subclause 4.4 of IEC 60694 is applicable.

If the circuit-breaker is fitted with a series connected accessory, such as a direct over-current release, the rated normal current of the accessory is the r.m.s. value of the current which the accessory shall be able to carry continuously without deterioration at its rated frequency, with a temperature rise not exceeding the values specified in Table 3 of IEC 60694.

4.5 Rated short-time withstand current (I_k)

Subclause 4.5 of IEC 60694 is applicable with the following addition:

The rated short-time withstand current is equal to the rated short-circuit breaking current (see 4.101).

4.6 Rated peak withstand current (I_p)

Subclause 4.6 of IEC 60694 is applicable with the following addition:

The rated peak withstand current is equal to the rated short-circuit making current (see 4.103).

4.7 Rated duration of short circuit (t_k)

Subclause 4.7 of IEC 60694 is applicable with the following addition:

A rated duration of a short-circuit need not be assigned to a self-tripping circuit-breaker provided that the following applies. When connected in a circuit the prospective breaking current of which is equal to its rated short-circuit breaking current, the circuit-breaker shall be capable of carrying the resulting current for the break-time required. This break time is that required by the circuit-breaker with the overcurrent release set for the maximum time lag when operating in accordance with its rated operating sequence.

NOTE Direct overcurrent releases include integrated tripping systems.

4.8 Rated supply voltage of closing and opening devices and of auxiliary and control circuits (U_a)

Subclause 4.8 of IEC 60694 is applicable.

4.9 Rated supply frequency of closing and opening devices and auxiliary circuits

Subclause 4.9 of IEC 60694 is applicable.

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

Subclause 4.10 of IEC 60694 is applicable.

4.101 Rated short-circuit breaking current (I_{sc})

The rated short-circuit breaking current is the highest short-circuit current which the circuit-breaker shall be capable of breaking under the conditions of use and behaviour prescribed in this standard. Such a current is found in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the circuit-breaker and having a transient recovery voltage equal to the value specified in 4.102. For three-pole circuit-breakers, the a.c. component relates to a three-phase short-circuit. Where applicable, the provisions of 4.105 concerning short-line faults shall be taken into account.

The rated short-circuit breaking current is characterised by two values:

- the r.m.s. value of its a.c. component;
- the percentage d.c. component.

NOTE If the d.c. component does not exceed 20 %, the rated short-circuit breaking current is characterised only by the r.m.s. value of its a.c. component.

For determination of the a.c. and d.c. components, see figure 8.

The circuit-breaker shall be capable of breaking any short-circuit current up to its rated short-circuit breaking current containing any a.c. component up to the rated value and, associated with it, any percentage d.c. component up to that specified, under the conditions mentioned above.

The following applies to a standard circuit-breaker:

- a) at voltages below and equal to the rated voltage, it shall be capable of breaking its rated short-circuit breaking current;
- b) at voltages above the rated voltage, no short-circuit breaking current is guaranteed except to the extent provided for in 4.106.

4.101.1 AC component of the rated short-circuit breaking current

The standard value of the a.c. component of the rated short-circuit breaking current shall be selected from the R10 series specified in IEC 60059.

NOTE The R10 series comprises the numbers 1 – 1,25 – 1,6 – 2 – 2,5 – 3,15 – 4 – 5 – 6,3 – 8 and their products by 10^n .

4.101.2 DC component of the rated short-circuit breaking current

The value of the percentage d.c. component shall be determined as follows:

- for a self-tripping circuit-breaker, the percentage d.c. component shall correspond to a time interval equal to the minimum opening time of the first opening pole T_{op} of the circuit-breaker. Time T_r in the formula below is to be set to 0 ms;
- for a circuit-breaker which is tripped solely by any form of auxiliary power, the percentage d.c. component shall correspond to a time interval equal to the minimum opening time of the first opening pole T_{op} of the circuit-breaker plus one half-cycle of rated frequency (T_r).

The minimum opening time mentioned above is that specified by the manufacturer.

NOTE 1 The minimum opening time is the shortest opening time, which is expected by the manufacturer to cover the entire population of the circuit-breaker concerned under any operational conditions when breaking asymmetrical currents in accordance with this standard (terminal fault test-duty T100a). It should be chosen in such a manner that the d.c. component applied in test-duty T100a, which is based on this minimum opening time among others, is so large, that each circuit-breaker manufactured in the product life time will be covered by this test.

The percentage value of the dc component (% dc) can be derived from figure 9 and is based on the time interval ($T_{op} + T_r$) and the time constant τ using the formula:

$$\% \text{ dc} = 100 \times e^{-\frac{T_{op} + T_r}{\tau}}$$

The graphs of the d.c. component against time given in figure 9 are based on:

- a) standard time constant of 45 ms;
- b) special case time constants, related to the rated voltage of the circuit-breaker:
 - 120 ms for rated voltages up to and including 52 kV;
 - 60 ms for rated voltages from 72,5 kV up to and including 420 kV;
 - 75 ms for rated voltages 550 kV and above.

These special case time constant values recognise that the standard value may be inadequate in some systems. They are provided as unified values for such special system needs, taking into account the characteristics of the different ranges of rated voltage, for example their particular system structures, design of lines, etc.

NOTE 2 In addition, some applications may require even higher values, for example if a circuit-breaker is close to a generator. In these circumstances, the required d.c. component and any additional test requirements should be specified in the enquiry.

NOTE 3 More detailed information on the use of the standard time constant and the special case time constants is given in the explanatory note in I.2.1.

4.102 Transient recovery voltage related to the rated short-circuit breaking current

The transient recovery voltage (TRV) related to the rated short-circuit breaking current in accordance with 4.101, is the reference voltage which constitutes the limit of the prospective transient recovery voltage of circuits which the circuit-breaker shall be capable of withstanding under fault conditions.

4.102.1 Representation of TRV waves

The waveform of transient recovery voltages varies according to the arrangement of actual circuits.

In some cases, particularly in systems with a voltage 100 kV and above, and where the short-circuit currents are relatively large in relation to the maximum short-circuit current at the point under consideration, the transient recovery voltage contains first a period of high rate of rise, followed by a later period of lower rate of rise. This waveform is generally adequately represented by an envelope consisting of three line segments defined by means of four parameters. Methods of drawing TRV envelopes are given in annex E.

In other cases, particularly in systems with a voltage less than 100 kV, or in systems with a voltage greater than 100 kV in conditions where the short-circuit currents are relatively small in relation to the maximum short-circuit currents and fed through transformers, the transient recovery voltage 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. Methods of drawing TRV envelopes are given in annex E.

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-breaker 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.

It appears that every part of the TRV wave may influence the interrupting capability of a circuit-breaker. The very beginning of the TRV may be of importance for some types of circuit-breakers. This part of the TRV, called initial TRV (ITRV), is caused by the initial oscillation of small amplitude due to reflections from the first major discontinuity along the busbar. The ITRV is mainly determined by the busbar and line bay configuration of the substation. The ITRV is a physical phenomenon which is very similar to the short-line fault. Compared with the short-line fault, the first voltage peak is rather low, but the time to the first peak is extremely short, that is, within the first microseconds after current zero. Therefore the thermal mode of interruption may be influenced.

If the circuit-breaker has a short-line fault rating, the ITRV requirements are considered to be covered if the short-line fault tests are carried out using a line with insignificant time delay (see 6.104.5.2 and 6.109.3) unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in note 4 of 6.109.3). In this case test circuits, which produce an equivalent TRV stress across the circuit-breaker may be used as an alternative.

Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA and for circuit-breakers with a rated voltage below 100 kV. In addition the ITRV requirements can be neglected for circuit-breakers installed in metal enclosed gas insulated switchgear (GIS) because of the low surge impedance.

4.102.2 Representation of TRV

The following parameters are used for the representation of TRV:

- a) Four-parameter reference line (see figure 10):
- u_1 = first reference voltage, in kilovolts;
 - t_1 = time to reach u_1 , in microseconds;
 - u_c = second reference voltage (TRV peak value), in kilovolts;
 - t_2 = time to reach u_c , in microseconds.

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

$$u_1 = 0,75 \times k_{pp} U_r \sqrt{\frac{2}{3}}$$

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

t_1 for out-of-phase = $2 \times t_1$ (for terminal fault)

$$u_c = k_{af} \times k_{pp} U_r \sqrt{\frac{2}{3}}, \text{ where } k_{af} \text{ is equal to:}$$

- 1,4 for terminal fault and short-line fault,
- 1,25 for out-of-phase.

$t_2 = 4t_1$ for terminal fault and short-line fault;

t_2 for out-of-phase = between t_2 (for terminal fault) and $2 \times t_2$ (for terminal fault).

- b) Two-parameter reference line (see Figure 11):

u_c = reference voltage (TRV peak value), in kV;

t_3 = time in μs .

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

$$u_c = k_{pp} \times k_{af} \sqrt{(2/3)} \times U_r$$

where k_{af} is equal to

1,4 for terminal fault in the case of cable systems;

1,54 for terminal fault and short-line fault, in the case of line systems;

1,25 for out-of-phase;

t_3 for the supply side circuit for short-line fault = t_3 (terminal fault).

t_3 for out-of-phase = $2 \times t_3$ (terminal fault).

- c) Delay line of TRV (see Figures 10 and 11):

t_d = time delay, in microseconds;

u' = reference voltage, in kilovolts;

t' = time to reach u' , in microseconds

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

For rated voltages lower than 100 kV:

$t_d = 0,15 \times t_3$, for terminal fault and out-of-phase in the case of cable systems;

$t_d = 0,05 \times t_3$, for terminal fault and short-line-fault in the case of line systems;

$t_d = 0,15 \times t_3$, for out-of-phase in the case of line systems;

$u' = u_c/3$;

t' is derived from t_d and t_3 according to Figure 11, $t' = t_d + t_3/3$.

For rated voltages equal or higher than 100 kV:

$t_d = 2 \mu\text{s}$ for terminal fault and for the supply side circuit for short-line fault;

$t_d = 2 \mu\text{s}$ to $0,1 \times t_1$ for out-of-phase;

$u' = u_1/2$;

t' is derived from u' , u_1/t_1 (RRRV) and t_d according to Figure 10, $t' = t_d + u'/\text{RRRV}$.

- d) ITRV (see figure 12b):

u_i = reference voltage (ITRV peak), in kilovolts;

t_i = time to reach u_i , in microseconds.

The rate of rise of the ITRV is dependent on the interrupted short-circuit current and its amplitude depends upon the distance to the first discontinuity along the busbar. The ITRV is defined by the voltage u_i and the time t_i . The inherent waveshape shall follow a straight line drawn using the 20 % and the 80 % point of the ITRV peak voltage u_i and the required rate of rise of the ITRV.

4.102.3 Standard values of TRV related to the rated short-circuit breaking current

Standard values of TRV for three-pole circuit-breakers of rated voltages less than 100 kV make use of two parameters. Values are given in:

- Table 24, for cable systems;
- Table 25, for line systems.

For rated voltages of 100 kV and above, four parameters are used. Table 1b gives values for rated voltages of 100 kV up to 170 kV for solidly earthed systems. Table 1c gives values for rated voltages of 100 kV up to 170 kV for non-solidly earthed systems. Table 1d gives values for rated voltages of 245 kV and above.

The tables also indicate values of rate of rise, taken as u_c/t_3 and u_1/t_1 , in the two-parameter and four-parameter cases, respectively, which together with TRV peak values u_c may be used for purposes of specification of TRV.

The values given in the tables are prospective values. They apply to circuit-breakers for general transmission and distribution in three-phase systems having service frequencies of 50 Hz or 60 Hz and consisting of transformers, overhead lines and cables.

In the case of single-phase systems or where circuit-breakers are for use in an installation having more severe conditions, the values may be different, particularly for the following cases:

- a) circuit-breakers adjacent to generator circuits;
- b) circuit-breakers directly connected to transformers without appreciable additional capacitance between the circuit-breaker and the transformer which provides approximately 50 % or more of the rated short-circuit breaking-current of the circuit-breaker. However the special case of circuit-breakers of rated voltage less than 100 kV with a connection of low capacitance to a transformer is covered in Annex M;
- c) circuit-breakers in substations with series reactors (information is given in 8.103.7 and in Clause L.5 for circuit-breakers rated less than 100 kV);
- d) circuit-breakers used for series compensated lines;
- e) circuit-breakers in substations with capacitor banks.

The transient recovery voltage corresponding to the rated short-circuit breaking current when a terminal fault occurs, is used for testing at short-circuit breaking currents equal to the rated value. However, for testing with short-circuit breaking currents less than 100 % of the rated value, other values of transient recovery voltage are specified (see 6.104.5). Further additional requirements apply to circuit-breakers designed for direct connection to overhead lines, rated at 15 kV and above and having rated short-circuit breaking currents exceeding 12,5 kA, which may be operated in short-line fault conditions (see 4.105).

**Table 24 – Standard values of transient recovery voltage for class S1 circuit-breakers –
Rated voltage higher than 1 kV and less than 100 kV –
Representation by two parameters**

Rated voltage U_r kV	Type of test	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 μs	Time delay t_d μs	Voltage u' kV	Time t' μs	RRRV ^a u_c/t_3 kV/ μs
3,6	Terminal fault	1,5	1,4	6,2	41	6	2,1	20	0,15
	Out-of-phase	2,5	1,25	9,2	82	12	3,1	40	0,11
4,76 ^b	Terminal fault	1,5	1,4	8,2	44	7	2,7	21	0,19
	Out-of-phase	2,5	1,25	12,1	88	13	4,0	43	0,14
7,2	Terminal fault	1,5	1,4	12,3	51	8	4,1	25	0,24
	Out-of-phase	2,5	1,25	18,4	102	15	6,1	49	0,18
8,25 ^b	Terminal fault	1,5	1,4	14,1	52	8	4,7	25	0,27
	Out-of-phase	2,5	1,25	21,1	104	16	7,0	50	0,20
12	Terminal fault	1,5	1,4	20,6	61	9	6,9	29	0,34
	Out-of-phase	2,5	1,25	30,6	122	18	10,2	59	0,25
15 ^b	Terminal fault	1,5	1,4	25,7	66	10	8,6	32	0,39
	Out-of-phase	2,5	1,25	38,3	132	20	12,8	64	0,29
17,5	Terminal fault	1,5	1,4	30	71	11	10,0	34	0,42
	Out-of-phase	2,5	1,25	44,7	142	21	14,9	69	0,31
24	Terminal fault	1,5	1,4	41,2	87	13	13,7	42	0,47
	Out-of-phase	2,5	1,25	61,2	174	26	20,4	84	0,35
25,8 ^b	Terminal fault	1,5	1,4	44,2	91	14	14,7	44	0,49
	Out-of-phase	2,5	1,25	65,8	182	27	21,9	88	0,36
36	Terminal fault	1,5	1,4	61,7	109	16	20,6	53	0,57
	Out-of-phase	2,5	1,25	91,9	218	33	30,6	105	0,42
38 ^b	Terminal fault	1,5	1,4	65,2	109	16	21,7	53	0,60
	Out-of-phase	2,5	1,25	97,0	218	33	32,3	105	0,45
48,3 ^b	Terminal fault	1,5	1,4	82,8	125	19	27,6	60	0,66
	Out-of-phase	2,5	1,25	123	250	38	41,1	121	0,49
52	Terminal fault	1,5	1,4	89,2	131	20	29,7	63	0,68
	Out-of-phase	2,5	1,25	133	262	39	44,2	127	0,51
72,5	Terminal fault	1,5	1,4	124	165	25	41,4	80	0,75
	Out-of-phase	2,5	1,25	185	330	50	61,7	160	0,56

^a RRRV = rate of rise of recovery voltage.
^b Used in North America.

**Table 25 – Standard values of transient recovery voltage ^c for class S2 circuit-breakers
– Rated voltage equal to or higher than 15 kV and less than 100 kV –
Representation by two parameters**

Rated voltage U_r kV	Type of test	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	TRV peak value u_c kV	Time t_3 μ s	Time delay t_d μ s	Voltage u' kV	Time t' μ s	RRRV ^a u_c/t_3 kV/ μ s
15 ^b	Terminal fault	1,5	1,54	28,3	31	2	9,4	12	0,91
	Short-line fault	1	1,54	18,9	31	2	6,3	12	0,61
	Out-of-phase	2,5	1,25	38,3	62	9	12,8	30	0,62
17,5	Terminal fault	1,5	1,54	33,0	34	2	11,0	13	0,97
	Short-line fault	1	1,54	22,0	34	2	7,3	13	0,65
	Out-of-phase	2,5	1,25	45	68	10	14,9	33	0,65
24	Terminal fault	1,5	1,54	45,3	43	2	15,1	16	1,05
	Short-line fault	1	1,54	30,2	43	2	10,1	16	0,70
	Out-of-phase	2,5	1,25	61	86	13	20,4	42	0,71
25,8 ^b	Terminal fault	1,5	1,54	48,7	45	2	16,2	17	1,08
	Short-line fault	1	1,54	32,4	45	2	10,8	17	0,72
	Out-of-phase	2,5	1,25	66	90	14	21,9	44	0,73
36	Terminal fault	1,5	1,54	67,9	57	3	22,6	22	1,19
	Short-line fault	1	1,54	45,3	57	3	15,1	22	0,79
	Out-of-phase	2,5	1,25	92	114	17	30,6	55	0,81
38 ^b	Terminal fault	1,5	1,54	71,7	59	3	23,9	23	1,21
	Short-line fault	1	1,54	47,8	59	3	15,9	23	0,81
	Out-of-phase	2,5	1,25	97	118	18	32,3	57	0,82
48,3 ^b	Terminal fault	1,5	1,54	91,1	70	4	30,4	27	1,30
	Short-line fault	1	1,54	60,7	70	4	20,2	27	0,87
	Out-of-phase	2,5	1,25	123	140	21	41,1	68	0,88
52	Terminal fault	1,5	1,54	98,1	74	4	32,7	28	1,33
	Short-line fault	1	1,54	65,4	74	4	21,8	28	0,88
	Out-of-phase	2,5	1,25	133	148	22	44,2	72	0,90
72,5	Terminal fault	1,5	1,54	137	93	5	45,6	36	1,47
	Short-line fault	1	1,54	91,2	93	5	30,4	36	0,98
	Out-of-phase	2,5	1,25	185	186	28	61,7	90	0,99
^a RRRV = rate of rise of recovery voltage. ^b Used in North America. ^c For short-line faults: transient recovery voltage and time quantities are those of the supply circuit. Short-line fault is only applicable for circuit-breakers designed for direct connection to overhead lines.									

**Table 1b – Standard values of transient recovery voltage ^a –
Rated voltages of 100 kV to 170 kV for solidly earthed systems –
Representation by four parameters**

Rated voltage	Test-duty	First-pole-to-clear factor	Amplitude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	RRRV ^b
U_r kV		k_{pp} p.u.	k_{af} p.u.	u_1 kV	t_1 μs	u_c kV	t_2 μs	t_d μs	u' kV	t' μs	u_1/t_1 kV/ μs
100	Terminal fault	1,3	1,40	80	40	149	160	2	40	22	2
	Short-line fault	1	1,40	61	31	114	124	2	31	17	2
	Out-of-phase	2	1,25	122	80	204	160-320	2-8	61	48	1,54
123	Terminal fault	1,3	1,40	98	49	183	196	2	49	26	2
	Short-line fault	1	1,40	75	38	141	152	2	38	21	2
	Out-of-phase	2	1,25	151	98	251	196-392	2-10	75	59	1,54
145	Terminal fault	1,3	1,40	115	58	215	232	2	58	31	2
	Short-line fault	1	1,40	89	44	166	176	2	44	24	2
	Out-of-phase	2	1,25	178	116	296	232-464	2-12	89	70	1,54
170	Terminal fault	1,3	1,40	135	68	253	272	2	68	36	2
	Short-line fault	1	1,40	104	52	194	208	2	52	28	2
	Out-of-phase	2	1,25	208	136	347	272-544	2-14	104	81	1,54
^a In case of short-line faults, transient recovery voltage and time quantities are those of the supply circuit.											
^b RRRV = rate of rise of recovery voltage.											

**Table 1c – Standard values of transient recovery voltage ^a –
Rated voltages of 100 kV to 170 kV for non-solidly earthed systems –
Representation by four parameters**

Rated voltage	Test-duty	First-pole-to-clear factor	Amplitude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	RRRV ^b
U_r kV		k_{pp} p.u.	k_{af} p.u.	u_1 kV	t_1 μ s	u_c kV	t_2 μ s	t_d μ s	u' kV	t' μ s	u_1/t_1 kV/ μ s)
100	Terminal fault	1,5	1,40	92	46	171	184	2	46	25	2
	Short-line fault	1	1,40	61	31	114	124	2	31	17	2
	Out-of-phase	2,5	1,25	153	92	255	184-368	2-9	77	55	1,67
123	Terminal fault	1,5	1,40	113	56	211	224	2	56	30	2
	Short-line fault	1	1,40	75	38	141	152	2	38	21	2
	Out-of-phase	2,5	1,25	188	112	314	224-448	2-11	94	67	1,67
145	Terminal fault	1,5	1,40	133	67	249	268	2	67	35	2
	Short-line fault	1	1,40	89	44	166	176	2	44	24	2
	Out-of-phase	2,5	1,25	222	134	370	268-536	2-13	111	79	1,67
170	Terminal fault	1,5	1,40	156	78	291	312	2	78	41	2
	Short-line fault	1	1,40	104	52	194	208	2	52	28	2
	Out-of-phase	2,5	1,25	260	156	434	312-624	2-16	130	94	1,67
^a In case of short-line faults, transient recovery voltage and time quantities are those of the supply circuit. ^b RRRV = rate of rise of recovery voltage.											

In order to obtain the values of rate of rise of recovery voltage (RRRV) and u_c for the second and third clearing poles, a multiplier shall be applied to the values of RRRV and u_c of the first clearing pole at the relevant first-pole-to-clear factor. The values of these multipliers are given in Table 2.

RRRV multipliers are related to u_1/t_1 ; the times t_1 and t_2 are the same for the first, second and last clearing poles.

**Table 1d – Standard values of transient recovery voltage ^a –
Rated voltages 245 kV and above for solidly earthed systems –
Representation by four parameters**

Rated voltage	Test-duty	First-pole-to-clear factor	Amplitude factor	First reference voltage	Time	TRV peak value	Time	Time delay	Voltage	Time	RRRV ^b
U_r kV		k_{pp} p.u.	k_{af} p.u.	u_1 kV	t_1 μs	u_c KV	t_2 μs	t_d μs	u' kV	t' μs	u_1/t_1 kV/ μs
245	Terminal fault	1,3	1,40	195	98	364	392	2	98	51	2
	Short-line fault	1	1,40	150	75	280	300	2	75	40	2
	Out-of-phase	2	1,25	300	196	500	392-784	2-20	150	117	1,54
300	Terminal fault	1,3	1,40	239	119	446	476	2	119	62	2
	Short-line fault	1	1,40	184	92	343	368	2	92	48	2
	Out-of-phase	2	1,25	367	238	612	476-952	2-24	184	143	1,54
362	Terminal fault	1,3	1,40	288	144	538	576	2	144	74	2
	Short-line fault	1	1,40	222	111	414	444	2	111	57	2
	Out-of-phase	2	1,25	443	288	739	576-1152	2-29	222	173	1,54
420	Terminal fault	1,3	1,40	334	167	624	668	2	167	86	2
	Short-line fault	1	1,40	257	129	480	516	2	129	66	2
	Out-of-phase	2	1,25	514	334	857	668-1336	2-33	257	202	1,54
550	Terminal fault	1,3	1,40	438	219	817	876	2	219	111	2
	Short-line fault	1	1,40	337	168	629	672	2	168	86	2
	Out-of-phase	2	1,25	674	438	1 123	876-1752	2-44	337	263	1,54
800	Terminal fault	1,3	1,40	637	318	1 189	1 272	2	318	161	2
	Short-line fault	1	1,40	490	245	914	980	2	245	124	2
	Out-of-phase	2	1,25	980	636	1 633	1272-2544	2-64	490	382	1,54

^a In case of short-line faults, transient recovery voltage and time quantities are those of the supply circuit.
^b RRRV = rate of rise of recovery voltage.

Table 2 – Standard multipliers for transient recovery voltage values for second and third clearing poles for rated voltages above 1 kV

First-pole-to-clear factor k_{pp}	Multipliers			
	2nd clearing pole		3rd clearing pole	
	RRRV	u_c	RRRV	u_c
For solidly earthed systems				
1,3	0,95	0,98	0,70	0,77
For non-solidly earthed systems				
1,5	0,70	0,58	0,70	0,58

The multipliers of Table 2 have been calculated under the following assumptions:

- only three-phase earthed faults are considered;
- the rate of rise of recovery voltage (RRRV) at 100 % short-circuit currents is mainly determined by overhead lines and is calculated as the product of di/dt at current zero and the equivalent surge impedance;
- the equivalent surge impedance is calculated from the zero sequence (Z_0) and positive sequence (Z_1) surge impedances seen from the terminals of the circuit-breaker. For the relation of Z_0/Z_1 a value of approximately 2 has been chosen;
- the peak value of TRV (u_c) is proportional to the instantaneous value of power frequency recovery voltage at interruption.

See also figures 13 and 14.

NOTE 1 Values for rated voltages higher than 1 kV and less than 100 kV are under consideration.

NOTE 2 This Table is valid for test-duty T10, T30, T60, T100s and T100a. For test-duty T100a, the same reduction method must be applied as indicated in IEC 60427 for the first clearing pole. The values are an approximation for test-duty T10, T30 and T60 and are subject to further consideration.

NOTE 3 The values are rounded values, depending on Z_0/Z_1 of the TRV circuits, the time constant of the system and the rated voltages.

4.102.4 Standard values of ITRV

**Table 3 – Standard values of initial transient recovery voltage –
Rated voltages 100 kV and above**

Rated voltage U_r kV	Multiplying factor to determine u_i as function of the r.m.s. value of the short-circuit breaking current I_{sc}^*		Time t_i μs
	f_i kV/ kA		
	50 Hz	60 Hz	
100	0,046	0,056	0,4
123	0,046	0,056	0,4
145	0,046	0,056	0,4
170	0,058	0,070	0,5
245	0,069	0,084	0,6
300	0,081	0,098	0,7
362	0,092	0,112	0,8
420	0,092	0,112	0,8
550	0,116	0,139	1,0
800	0,159	0,191	1,1

NOTE These values cover both three-phase and single-phase faults and are based on the assumption that the busbar, including the elements connected to it (supports, current and voltage transformers, disconnectors, etc.), can be roughly represented by a resulting surge impedance Z_i of about 260 Ω in the case of a rated voltage lower than 800 kV and by a resulting surge impedance Z_i of about 325 Ω in the case of a rated voltage of 800 kV. The relation between f_i and t_i is then:

$$f_i = t_i \times Z_i \times \omega \times \sqrt{2}$$

where

$\omega = 2 \pi \times f_r$ is the angular frequency corresponding to the rated frequency of the circuit-breaker.

* The actual initial peak voltages are obtained by multiplying the values in these columns by the r.m.s. value of the short-circuit breaking current.

4.103 Rated short-circuit making current

The rated short-circuit making current (see figure 8) of a circuit-breaker having simultaneity of poles is that which corresponds to the rated voltage and the rated frequency. The following values apply:

- for a rated frequency of 50 Hz and the standard value of the time constant of 45 ms (see 4.101.2) it is equal to 2,5 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current (see 4.101);
- for a rated frequency of 60 Hz and the standard value of the time constant of 45 ms (see 4.101.2) it is equal to 2,6 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current (see 4.101);
- for all special case time constants (see 4.101.2) it is equal to 2,7 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current, independent of the rated frequency of the circuit-breaker (see 4.101).

4.104 Rated operating sequence

The rated characteristics of the circuit-breaker are referred to the rated operating sequence. There are two alternative rated operating sequences as follows:

a) O - t - CO - t' - CO

Unless otherwise specified:

t = 3 min for circuit-breakers not intended for rapid auto-reclosing;

t = 0,3 s for circuit-breakers intended for rapid auto-reclosing (dead time)

t' = 3 min.

NOTE Instead of $t' = 3$ min, other values: $t' = 15$ s and $t' = 1$ min are also used for circuit-breakers intended for rapid auto-reclosing.

b) CO - t'' - CO

with:

$t'' = 15$ s for circuit-breakers not intended for rapid auto-reclosing

where

O represents an opening operation;

CO represents a closing operation followed immediately (that is, without any intentional delay) by an opening operation;

t , t' and t'' are time intervals between successive operations;

t and t' should always be expressed in minutes or in seconds and

t'' should always be expressed in seconds.

If the dead time is adjustable, the limits of adjustment shall be specified.

4.105 Characteristics for short-line faults

Characteristics for short-line faults are required for class S2 circuit-breakers designed for direct connection to overhead lines (without intervening cable connections) and having a rated voltage of 15 kV and above and a rated short-circuit breaking current exceeding 12,5 kA. These characteristics relate to the breaking of a single-phase earth fault in a system with earthed neutral, where the first-pole-to-clear factor is equal to 1,0.

NOTE In this standard, a single-phase test at phase-to-earth voltage covers all types of short-line fault (see Annex L, Clause L.3).

The short-line fault circuit is composed of a supply circuit on the source side of the circuit-breaker and a short-line on its load side (see Figure 15), with the following characteristics:

supply circuit characteristics:

- voltage equal to the phase-to-earth voltage $U_r/\sqrt{3}$ corresponding to the rated voltage U_r of the circuit-breaker;
- short-circuit current, in case of terminal fault, equal to the rated short-circuit breaking current of the circuit-breaker;
- prospective transient recovery voltage, in case of short-line fault, given by the standard values in
 - Table 25, for circuit-breakers in line systems with rated voltages less than 100 kV ;
 - Tables 1b and 1c, for circuit-breakers with rated voltages from 100 kV up to and including 170 kV;
 - Table 1d, for circuit-breakers with rated voltages 245 kV and above.

- ITRV characteristics for circuit-breakers of 100 kV and above derived from Table 3.
- b) line characteristics:
- standard values of the RRRV factor, based on a surge impedance Z of 450 Ω , the peak factor k and the line side time delay t_{dL} are given in Table 4. For determination of the line side time delay and the rate-of-rise of the line side voltage, see Figure 16;
 - the method for calculation of transient recovery voltages from the characteristics is given in Annex A.

Table 4 – Standard values of line characteristics for short-line faults

Rated voltage U_r kV	Number of conductors per phase	Surge impedance Z Ω	Peak factor k	RRRV factor		Time delay t_{dL} μs
				50 Hz	60 Hz	
$15 \leq U_r \leq 38$	1	450	1,6	0,200	0,240	0,1
$48,3 \leq U_r \leq 170$	1 to 4	450	1,6	0,200	0,240	0,2
$U_r \geq 245$	1 to 4	450	1,6	0,200	0,240	0,5
NOTE These values cover the short-line faults dealt with in this standard. For very short lines ($t_L < 5t_{dL}$) not all requirements as given in the Table can be met. The procedures for approaching very short lines will be given in the application guide to this standard (currently prepared by CIGRE WG A3-11).						
* For the RRRV factor s , see Annex A.						

4.106 Rated out-of-phase making and breaking current

The rated out-of-phase breaking current is the maximum out-of-phase current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour prescribed in this standard in a circuit having a recovery voltage as specified below.

The specification of a rated out-of-phase making and breaking current is not mandatory. If a rated out-of-phase breaking current is assigned, the following applies:

- a) the power frequency recovery voltage shall be $2,0/\sqrt{3}$ times the rated voltage for solidly earthed neutral systems and $2,5/\sqrt{3}$ times the rated voltage for other systems;
- b) the transient recovery voltage shall be in accordance with:
 - Table 24, for circuit-breakers in cable systems with rated voltages less than 100 kV;
 - Table 25, for circuit-breakers in line systems with rated voltages less than 100 kV;
 - Tables 1b and 1c, for circuit-breakers with rated voltages from 100 kV up to and including 170 kV;
 - Table 1d, for circuit-breakers with rated voltages 245 kV and above.
- c) the rated out-of-phase breaking current shall be 25 % of the rated short-circuit breaking current and the rated out-of-phase making current shall be the crest value of the rated out-of-phase breaking current, unless otherwise specified.

The standard conditions of use with respect to the rated out-of-phase making and breaking current are as follows:

- opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the circuit-breaker and its auxiliary equipment;

- earthing condition of the neutral for the power system corresponding to that for which the circuit-breaker has been tested;
- absence of a fault on either side of the circuit-breaker.

4.107 Rated capacitive switching currents

Capacitive switching currents may comprise part or all of the operating duty of a circuit-breaker 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-breaker for capacitive current switching shall include, where applicable:

- rated line-charging breaking current;
- rated cable-charging breaking current;
- rated single capacitor bank breaking current ;
- rated back-to-back capacitor bank breaking current;
- rated single capacitor bank inrush making current;
- rated back-to-back capacitor bank inrush making current.

Preferred values of rated capacitive switching currents are given in Table 5.

The recovery voltage related to capacitive current switching depends on:

- the earthing of the system;
- the earthing 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 earth faults.

Two classes of circuit-breakers are defined according to their restrike performances:

- class C1: low probability of restrike during capacitive current breaking;
- class C2: very low probability of restrike during capacitive current breaking.

NOTE 1 The probability is related to the performance during the series of type tests stated in 6.111.

NOTE 2 A circuit-breaker can be of class C2 for one kind of application (for example in earthed 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 earthed neutral systems).

NOTE 3 Circuit-breakers with a restrike probability other than that of class C1 or class C2 are not covered by this standard.

4.107.1 Rated line-charging breaking current

The rated line-charging breaking current is the maximum line-charging current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard. The specification of a rated line-charging breaking current is mandatory for circuit-breakers of rated voltages equal to or greater than 72,5 kV.

4.107.2 Rated cable-charging breaking current

The rated cable-charging breaking current is the maximum cable-charging current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard. The specification of a rated cable-charging breaking current is mandatory for circuit-breakers of rated voltages equal to or less than 52 kV.

4.107.3 Rated single capacitor bank breaking current

The rated single capacitor bank breaking current is the maximum capacitor current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard. This breaking current refers to the switching of a shunt capacitor bank where no shunt capacitors are connected to the source side of the circuit-breaker.

Table 5 – Preferred values of rated capacitive switching currents

	Line	Cable	Single capacitor bank	Back-to-back capacitor bank		
Rated voltage	Rated line-charging breaking current	Rated cable-charging breaking current	Rated single capacitor bank breaking current	Rated back-to-back capacitor bank breaking current	Rated back-to-back capacitor bank inrush making current	Frequency of the inrush current
U_r kV, r.m.s.	I_l A, r.m.s.	I_c A, r.m.s.	I_{sb} A, r.m.s.	I_{bb} A, r.m.s.	I_{bi} kA, peak	f_{bi} Hz
3,6	10	10	400	400	20	4 250
4,76	10	10	400	400	20	4 250
7,2	10	10	400	400	20	4 250
8,25	10	10	400	400	20	4 250
12	10	25	400	400	20	4 250
15	10	25	400	400	20	4 250
17,5	10	31,5	400	400	20	4 250
24	10	31,5	400	400	20	4 250
25,8	10	31,5	400	400	20	4 250
36	10	50	400	400	20	4 250
38	10	50	400	400	20	4 250
48,3	10	80	400	400	20	4 250
52	10	80	400	400	20	4 250
72,5	10	125	400	400	20	4 250
100	20	125	400	400	20	4 250
123	31,5	140	400	400	20	4 250
145	50	160	400	400	20	4 250
170	63	160	400	400	20	4 250
245	125	250	400	400	20	4 250
300	200	315	400	400	20	4 250
362	315	355	400	400	20	4 250
420	400	400	400	400	20	4250
550	500	500	400	400	20	4 250
800	900					

NOTE 1 The values given in this Table are chosen for standardization purposes.

NOTE 2 For actual cases, the inrush currents can be calculated based on annex H.

NOTE 3 If back-to-back capacitor switching tests are performed, single capacitor bank switching tests are not required.

NOTE 4 The peak of the inrush current and the inrush current frequency may be higher or lower than the preferred values stated in Table 5 depending on system conditions, for example whether or not current limiting reactors are used.

4.107.4 Rated back-to-back capacitor bank breaking current

The rated back-to-back capacitor bank breaking current is the maximum capacitor current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard.

This breaking current refers to the switching of a shunt capacitor bank where one or several shunt capacitor banks are connected to the source side of the circuit-breaker giving an inrush making current equal to the rated back-to-back capacitor bank inrush making current.

NOTE Similar conditions could apply for switching at substations with cables.

4.107.5 Rated single capacitor bank inrush making current

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

NOTE For single capacitor banks, no preferred values for the rated inrush making current and for the frequency of the inrush current are specified. For usual applications, the rated single capacitor bank inrush making current is in the range of 5 kA to 10 kA. It may be roughly estimated using the following formula taken from Table 1 of ANSI/IEEE, C37.012 [11]:

$$i_{\max \text{ peak}} \approx \sqrt{2kI_{\text{sh}}I_{\text{sb}}}$$

with

$i_{\max \text{ peak}}$ peak inrush making current;

I_{sh} short-circuit current at the location of the capacitor bank, r.m.s. value;

I_{sb} single capacitor bank current, r.m.s. value;

k = 1,15, multiplier to cover tolerances and possible overvoltage.

The frequency of the inrush current is in the range of 200 Hz to 1 000 Hz. It may be roughly estimated using the following formula [11]:

$$f_{\text{inrush}} \approx f_r \sqrt{I_{\text{sh}} / I_{\text{sb}}}$$

with

f_r rated frequency;

f_{inrush} frequency of inrush current.

The single capacitor bank making performance is covered when the product of the required peak inrush making current times the required frequency of the inrush current ($i_{\max \text{ peak}} \times f_{\text{inrush}}$) is equal to or lower than the product of those values used in the relevant test.

4.107.6 Rated back-to-back capacitor bank inrush making current

The rated back-to-back capacitor bank inrush making current is the peak value of the current that the circuit-breaker shall be capable of making at its rated voltage and with a frequency of the inrush current appropriate to the service conditions (see Table 5).

NOTE The back-to-back capacitor bank making performance is covered when the product of the required peak inrush making current times the required frequency of the inrush current ($i_{\max \text{ peak}} \times f_{\text{inrush}}$) is equal to or lower than the product of those values used in the relevant test.

4.108 Small inductive breaking current

No rating is assigned. See IEC 61233.