BRITISH STANDARD

BS EN 62271-100:2001
IEC 62271-100:2001

High-voltage switchgear and controlgear —

Part 100: High-voltage alternating-current circuit-breakers

The European Standard EN 62271-100:2001 has the status of a British Standard

ICS 29.130.10

National foreword

This British Standard is the official English language version of EN 62271-100:2001. It is identical with IEC 62271-100:2001. It supersedes BS 5311:1996 which will be withdrawn on 2004-09-01.

The UK participation in its preparation was entrusted to Technical Committee PEL/17/1, High voltage switchgear and controlgear, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

From 1 January 1997, all IEC publications have the number 60000 added to the old number. For instance, IEC 27-1 has been renumbered as IEC 60027-1. For a period of time during the change over from one numbering system to the other, publications may contain identifiers from both systems.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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This British Standard, having been prepared under the direction of the Electrotechnical Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 22 March 2002

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EUROPEAN STANDARD **EN 62271-100**

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ICS 29.130.10 Supersedes HD 348 S7:1998

English version

High-voltage switchgear and controlgear
Part 100: High-voltage alternating-current circuit-breakers
(IEC 62271-100:2001)

Appareillage à haute tension
Partie 100: Disjoncteurs à courant alternatif à haute tension
(CEI 62271-100:2001)

Hochspannungs-Schaltgeräte
Teil 100: Hochspannungs-Wechselstrom-Leistungsschalter
(IEC 62271-100:2001)

This European Standard was approved by CENELEC on 2001-09-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. EN 62271-100:2001 E

Foreword

The text of document 17A/589/FDIS, future edition 1 of IEC 62271-100, prepared by SC 17A, High-voltage switchgear and controlgear, of IEC TC 17, Switchgear and controlgear, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62271-100 on 2001-09-01.

This European Standard supersedes HD 348 S7:1998.

NOTE This standard was voted as prEN 60056.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2002-06-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2004-09-01

This standard shall be read in conjunction with EN 60694:1996, to which it refers and which is applicable unless otherwise specified in this standard. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in EN 60694. Amendments to these clauses and subclauses are given under the same references whilst additional subclauses are numbered from 101.

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annexes A, B, C, D, E, F, G and ZA are normative and annexes H, I, J and K are informative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62271-100:2001 was approved by CENELEC as a European Standard without any modification.

CONTENTS

COMMON NUMBERING OF STANDARDS FALLING UNDER THE RESPONSIBILITY OF SC 17A AND SC 17C

In accordance with the decision taken at the joint SC 17A/SC 17C meeting in Frankfurt (item 20.7 of 17A/535/RM) a common numbering system will be established of the standards falling under the responsibility of SC 17A and SC 17C. IEC 62271 (with title High-voltage switchgear and controlgear) is the basis of the common standard.

Numbering of the standards will follow the following principle:

a) Common standards prepared by SC 17A and SC 17C will start with IEC 62271-001;

b) Standards of SC 17A will start with IEC 62271-100;

c) Standards of SC 17C will start with number IEC 62271-200;

d) Guides prepared by SC 17A and SC 17C will start with number IEC 62271-300.

The table below relates the new numbers to the old numbers:

Part	Title	Old number
1	Common specifications	IEC 60694 IEC 60516
100	High-voltage alternating current circuit-breakers	IEC 60056
101	Synthetic testing	IEC 60427
102	High-voltage alternating current disconnectors and earthing switches	IEC 60129
103	High-voltage switches for rated voltages above 1 kV and less than 52 kV	IEC 60265-1
104	High-voltage switches for rated voltages of 52 kV and above	IEC 60265-2
105	High voltage alternating current switch-fuse combinations	IEC 60420
106	High-voltage alternating current contactors and contactor based motor-starters	IEC 60470
200	Metal enclosed switchgear and controlgear for rated voltages up to and including 38 kV	IEC 60298
201	Insulation-enclosed switchgear and controlgear for rated voltages up to and including 52 kV	IEC 60466
202	High-voltage/low voltage prefabricated substations	IEC 61330
203	Gas-insulated metal enclosed switchgear for rated voltages above 52 kV	IEC 60517 IEC 61259
204	High-voltage gas-insulated transmission lines for rated voltages of 72,5 kV and above	IEC 61640
300	Guide for seismic qualification	IEC 61166
301	Guide for inductive load switching	IEC 61233
302	Guide for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers	IEC 61633
303	Use and handling of sulphur hexafluoride (SF_6)in high-voltage switchgear and controlgear	IEC 61634
304	Additional requirements for enclosed switchgear and controlgear from 1 kV to 72,5 kV to be used in severe climatic conditions	IEC 60932
305	Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	IEC 60859
306	Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	IEC 61639
307	The use of electronic and associated technologies in auxiliary equipment of switchgear and controlgear	IEC 62063
308	Guide for asymmetrical short-circuit breaking test duty T100a	-

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 100: High-voltage alternating-current circuit-breakers

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.

1.2 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

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1) Figures in square brackets refer to the bibliography.

references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

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

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

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

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

IEC 60059: 1999, IEC *standard current ratings*

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

IEC 60071-2:1996, *Insulation co-ordination – Part 2: Application guide*

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

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

IEC 60376:1971, *Specification and acceptance of new sulphur hexafluoride*

IEC 60427:1989, *Synthetic testing of high-voltage alternating current circuit-breakers*

IEC 60480:1974, *Guide to the checking of sulphur hexafluoride* (SF_6) *taken from electrical equipment*

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

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

IEC 61233:1994, *High-voltage alternating current circuit-breakers – 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* (SF_6) *in high-voltage switchgear and controlgear*

IEC 62215, *High-voltage alternating current circuit-breakers – Guide for asymmetrical short-circuit breaking test duty T100a* [2]

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[2] To be published

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.

3.2 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
SF_6 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

3.5 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]

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]

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.

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

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 transmission lines and rated at 52 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:

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

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:

$u_1 = k_{pp} \times \sqrt{2/3} \times U_r$;

t_1 is derived from u_1 and the specified value of the rate of rise u_1/t_1;

$u_c = k_{af} \times u_1$,where k_{af} is equal to

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

$t_2 = 3 \times t_1$.

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

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

t_3 = 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:

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

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

t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.

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 coordinate t').

For voltages lower than 52 kV:

$t_d = 0{,}15 \times t_3$, (this formula applies except for 48,3 kV, where $t_d = 0{,}05 \times t_3$);

$u' = u_c/3$ and

t' is derived from u', u_c/t_3 and t_d according to figure 11.

For rated voltages 52 kV and 72,5 kV:

$t_d = 0{,}05 \times t_3$ for terminal fault and short-line fault;

$u' = u_c/3$ and

t' is derived from u', u_c/t_3 and t_d according to figure 11.

For rated voltages higher than 72,5 kV:

$t_d = 0{,}21 \times t_1$ or 2 μs for terminal fault and short-line fault;

$u' = u_1/2$ and

t' is derived from u', u_1/t_1 and t_d according to figure 10.

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 below 100 kV, make use of two parameters. Values are given in table 1a.

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. Table 1c 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 short lengths of cable.

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;
c) circuit-breakers in substations with series reactors;
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 at 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 rated at 52 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 1a – Standard values of transient recovery voltage [a] – Rated voltages below 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[b] 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	77	12	3,1	38	0,12
4,76 [c]	Terminal fault	1,5	1,4	8,2	51	8	2,7	24	0,16
	Out-of-phase	2,5	1,25	12,1	101	15	4,0	48	0,12
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 [c]	Terminal fault	1,5	1,4	14,1	59	9	4,7	29	0,24
	Out-of-phase	2,5	1,25	21,0	117	18	7,0	57	0,18
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	118	18	10	56	0,26
15 [c]	Terminal fault	1,5	1,4	25,7	76	11	8,6	36	0,34
	Out-of-phase	2,5	1,25	38,3	147	22	13	72	0,26
17,5	Terminal fault	1,5	1,4	30	71	11	10	35	0,42
	Out-of-phase	2,5	1,25	45	145	22	15	70	0,31
24	Terminal fault	1,5	1,4	41	87	13	14	43	0,47
	Out-of-phase	2,5	1,25	61	174	26	20	83	0,35
25,8 [c]	Terminal fault	1,5	1,4	44	105	16	15	52	0,42
	Out-of-phase	2,5	1,25	66	213	32	22	103	0,31
36	Terminal fault	1,5	1,4	62	109	16	21	53	0,57
	Out-of-phase	2,5	1,25	92	214	32	31	104	0,43
38 [c]	Terminal fault	1,5	1,4	65	125	19	22	61	0,52
	Out-of-phase	2,5	1,25	97	249	37	32	119	0,39
48,3 [c]	Terminal fault	1,5	1,4	83	122	6	27	47	0,68
	Out-of-phase	2,5	1,25	123	262	39	41	126	0,47
52 [a]	Terminal fault	1,5	1,4	89	131	7	30	51	0,68
	Short-line fault	1	1,4	59	131	7	20	51	0,45
	Out-of-phase	2,5	1,25	133	266	40	44	128	0,50
72,5 *	Terminal fault	1,5	1,4	124	165	8	41	63	0,75
	Short-line fault	1	1,4	83	166	8	28	64	0,50
	Out-of-phase	2,5	1,25	185	336	50	62	163	0,55

[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.

[c] Used in North America.

Table 1b – Standard values of transient recovery voltage [a] – Rated voltages 100 kV to 170 kV – Representation by four parameters

Rated voltage U_r kV	Type of test	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	First reference voltage u_1 kV	Time t_1 μs	TRV peak value u_c kV	Time t_2 μs	Time delay t_d μs	Voltage u' kV	Time t' μs	RRRV [b] u_1/t_1 kV/μs
100	Terminal fault	1,3	1,4	106	53	149	159	2	53	29	2,0
		1,5	1,4	122	61	171	183	2	61	33	2,0
	Short-line fault	1	1,4	82	41	114	123	2	41	22	2,0
	Out-of-phase	2	1,25	163	106	204	318	20	82	73	1,54
		2,5	1,25	204	122	255	366	23	102	84	1,67
123	Terminal fault	1,3	1,4	131	65	183	195	2	65	35	2,0
		1,5	1,4	151	75	211	225	2	75	40	2,0
	Short-line fault	1	1,4	100	50	141	150	2	50	27	2,0
	Out-of-phase	2	1,25	201	131	251	393	24	101	90	1,54
		2,5	1,25	251	150	314	450	28	126	103	1,67
145	Terminal fault	1,3	1,4	154	77	215	231	2	77	41	2,0
		1,5	1,4	178	89	249	267	2	89	47	2,0
	Short-line fault	1	1,4	118	59	166	177	2	59	32	2,0
	Out-of-phase	2	1,25	237	154	296	462	29	119	106	1,54
		2,5	1,25	296	177	370	531	33	148	122	1,67
170	Terminal fault	1,3	1,4	180	90	253	270	2	90	47	2,0
		1,5	1,4	208	104	291	312	2	104	54	2,0
	Short-line fault	1	1,4	139	69	194	207	2	69	37	2,0
	Out-of-phase	2	1,25	278	181	347	543	34	139	124	1,54
		2,5	1,25	347	208	434	624	39	174	143	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.

Table 1c – Standard values of transient recovery voltage [a] – Rated voltages 245 kV and above – Representation by four parameters

Rated voltage U_r kV	Type of test	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	First reference voltage u_1 kV	Time t_1 μs	TRV peak value u_c kV	Time t_2 μs	Time delay t_d μs	Voltage u' kV	Time t' μs	RRRV [b] u_1/t_1 kV/μs
245	Terminal fault	1,3	1,4	260	130	364	390	2	130	67	2,0
	Short-line fault	1	1,4	200	100	280	300	2	100	52	2,0
	Out-of-phase	2	1,25	400	260	500	780	49	200	179	1,54
300	Terminal fault	1,3	1,4	318	159	446	477	2	159	82	2,0
	Short-line fault	1	1,4	245	122	343	366	2	122	63	2,0
	Out-of-phase	2	1,25	490	318	612	954	60	245	219	1,54
362	Terminal fault	1,3	1,4	384	192	538	576	2	192	98	2,0
	Short-line fault	1	1,4	296	148	414	444	2	148	76	2,0
	Out-of-phase	2	1,25	591	384	739	1152	72	296	264	1,54
420	Terminal fault	1,3	1,4	446	223	624	669	2	223	114	2,0
	Short-line fault	1	1,4	343	171	480	513	2	171	88	2,0
	Out-of-phase	2	1,25	686	445	857	1335	83	343	306	1,54
550	Terminal fault	1,3	1,4	584	292	817	876	2	292	148	2,0
	Short-line fault	1	1,4	449	224	629	672	2	225	115	2,0
	Out-of-phase	2	1,25	898	583	1123	1749	109	449	401	1,54
800	Terminal fault	1,3	1,4	849	424	1189	1272	2	424	214	2,0
	Short-line fault	1	1,4	653	326	914	978	2	326	165	2,0
	Out-of-phase	2	1,25	1306	848	1633	2544	159	653	583	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.

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 2 – Standard multipliers for transient recovery voltage values for second and third clearing poles for rated voltages above 72,5 kV

First-pole-to-clear factor k_{pp}	Multipliers			
	Second clearing pole		Third clearing pole	
	RRRV	u_c	RRRV	u_c
1,5	0,70	0,58	0,70	0,58
1,3	0,95	0,98	0,70	0,77

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 For rated voltage of 72,5 kV and below, the values 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}* f_i kV/ kA		Time t_i μs
	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 three-pole circuit-breakers designed for direct connection to overhead transmission lines and having a rated voltage of 52 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.

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:

a) supply circuit characteristics:

- voltage equal to the phase-to-earth voltage $U_r/\sqrt{3}$;
- 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 tables 1a, 1b and 1c;
- 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** **50 Hz** s* (kV/μs)/ kA	**RRRV factor** **60 Hz**	**Time delay** t_{dL} μs
≤ 170	1 to 4	450	1,6	0,200	0,240	0,2
≥ 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 13-11).						
* 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/√3 times the rated voltage for solidly earthed neutral systems and 2,5/√3 times the rated voltage for other systems;

b) the transient recovery voltage shall be in accordance with:

– table 1a, for circuit-breakers with rated voltages below 100 kV;

– table 1b, for circuit-breakers with rated voltages from 100 kV up to and including 170 kV;

– table 1c, 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 U_r kV, r.m.s.	Rated line-charging breaking current I_l A, r.m.s.	Rated cable-charging breaking current I_c A, r.m.s.	Rated single capacitor bank breaking current I_{sb} A, r.m.s.	Rated back-to-back capacitor bank breaking current I_{bb} A, r.m.s.	Rated back-to-back capacitor bank inrush making current I_{bi} kA, peak	Frequency of the inrush current 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]:

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

with

$i_{\text{max peak}}$ 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]:

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

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 ($i_{\text{max peak}}$ x f_{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 ($i_{\text{max peak}} \times f_{\text{inrush}}$) 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.

4.109 Rated time quantities

Refer to figures 1, 2, 3, 4, 5, 6 and 7.

Rated values may be assigned to the following time quantities:

– opening time (no-load);
– break-time;
– closing time (no-load);
– open-close time (no-load);
– reclosing time (no-load);
– close-open time (no-load);
– pre-insertion time (no-load).

Rated time quantities are based on

– rated supply voltages of closing and opening devices and of auxiliary and control circuits (see 4.8);
– rated supply frequency of closing and opening devices and of auxiliary circuits (see 4.9);
– rated pressures of compressed gas supply for operation, for insulation and/or interruption, as applicable (see 4.10);
– rated pressure of hydraulic supply for operation;
– an ambient air temperature of 20 °C ± 5 °C.

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

4.109.1 Rated break-time

The maximum break time determined during terminal fault test-duties T30, T60 and T100s of 6.106.2, 6.106.3 and 6.106.4 with the circuit-breaker operated at auxiliary supply voltage and frequency and pressures of pneumatic or hydraulic supply at their rated values and at an ambient air temperature of 20 °C ± 5 °C shall not exceed the rated break time.

NOTE 1 According to 6.102.3.1 the basic short-circuit test-duties, with the exception of T100a, should be carried out at minimum voltage and/or pressures for operation and/or interruption. In order to verify the rated break time during these test-duties, the recorded maximum break time should be amended to take account of the lower auxiliary supply voltage and pressure as follows:

$$t_b \geq t_1 - (t_2 - t_3)$$

where

t_b is the rated break time;

t_1 is the maximum recorded break time during test-duties T30, T60 and T100s;

t_2 is the maximum recorded opening time on no-load, with auxiliary supply voltage and pressures for operation and/or interruption as used during test-duties T30, T60 and T100s;

t_3 is the rated opening time.

If the break time determined according to this procedure exceeds the rated break time, the test-duty that has given the longest break time may be repeated with auxiliary supply voltage and frequency and pressure for operation and/or interruption at their rated values.

NOTE 2 For single-phase tests simulating a three-phase operation, the recorded break time, amended according to note 1, may exceed the rated break time by one-tenth of a cycle because in these cases the current zeros occur less frequently than in the three-phase case.

NOTE 3 The break time during a make-break operating cycle of test-duty T100s should not exceed the rated break time by more than half-cycle of the power frequency.

4.110 Number of mechanical operations

A circuit-breaker shall be able to perform the following number of operations taking into account the programme of maintenance specified by the manufacturer:

Standard circuit-breaker (normal mechanical endurance) **class M1**	2 000 operating sequences
Circuit-breaker for special service requirements (extended mechanical endurance) **class M2**	10 000 operating sequences

4.111 Classification of circuit-breakers as a function of electrical endurance

Circuit-breakers required to have an electrical endurance capability, intended for auto-reclosing duty, as usual for overhead line networks, and of rated voltages up to and including 52 kV, are classified class E2 as defined in 3.4.113 and tested to 6.112.2 and table 21.

Circuit-breakers required to have an electrical endurance ability, but intended for use without auto-reclosing duty capability, for example in cable-connected networks, and of rated voltages up to and including 52 kV, are classified class E2 as defined in 3.4.113 and tested to 6.112.1.

Class E2 is termed extended electrical endurance.

Circuit-breakers not requiring this electrical endurance capability are classified class E1 as defined in 3.4.112, termed basic electrical endurance.

5 Design and construction

5.1 Requirements for liquids in circuit-breakers

Subclause 5.1 of IEC 60694 is applicable.

5.2 Requirements for gases in circuit-breakers

Subclause 5.2 of IEC 60694 is applicable.

5.3 Earthing of circuit-breakers

Subclause 5.3 of IEC 60694 is applicable.

5.4 Auxiliary equipment

Subclause 5.4 of IEC 60694 is applicable with the following additions:

– where shunt opening and closing releases are used, appropriate measures shall be taken in order to avoid damage on the releases when permanent orders for closing or opening are applied. For example, those measures may be the use of series control contacts arranged so that when the circuit-breaker is closed, the close release control contact ("b" contact or break contact) is open and the open release control contact ("a" contact or make contact) is closed, and when the circuit-breaker is open, the open release control contact is open and the close release control contact is closed;

NOTE 1 Systems other than contacts are possible and may be used.

– for shunt closing releases the protective measures for the shunt closing releases as mentioned in the first indent above shall operate no sooner than the minimum close duration (3.7.147) provided by the circuit-breaker and no later than the rated closing time;

NOTE 2 If the current of the shunt closing release is interrupted by the control contact, the closing command shall be positively longer than the rated closing time.

– for shunt opening releases the protecting measures for the shunt opening releases as mentioned in the first indent above shall operate no sooner than the minimum trip duration (3.7.146) required by the circuit-breaker and no later than 20 ms after separation of the main contacts;
– for short close-open time requirements the protective measures for the shunt releases as mentioned in the first indent above shall operate no sooner than when main contacts close and no later than one half-cycle after main contacts close;
– where auxiliary switches are used as position indicators, they shall indicate the end position of the circuit-breaker at rest, open or closed. The signalling shall be sustained;
– connections shall withstand the stresses imposed by the circuit-breaker, especially those due to mechanical forces during operations;
– in the case of outdoor circuit-breakers, all auxiliary equipment including the wiring shall be adequately protected against rain and humidity;
– where special items of control equipment are used, they shall operate within the limits specified for supply voltages of auxiliary and control circuits, interrupting and/or insulating and operating media, and be able to switch the loads which are stated by the circuit-breaker manufacturer;
– special items of auxiliary equipment such as liquid indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts shall operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of interrupting and/or insulating and operating media;
– the power consumption of heaters at rated voltage shall be within the tolerance of ± 10 % of the value stated by the manufacturer;
– where anti-pumping devices are part of the circuit-breaker control scheme, they shall act on each control circuit, if more than one is installed;
– where a control scheme of pole discrepancy is part of the circuit-breaker, the position of the poles shall be supervised, open or closed. Depending on the application, the delay time shall be adjustable between 0,1 s and 3 s.

5.5 Dependent power closing

Subclause 5.5 of IEC 60694 is applicable with the following addition:

– a circuit-breaker arranged for dependent power closing with external energy supply shall also be capable of opening immediately following the closing operation with the rated short-circuit making current.

5.6 Stored energy closing

Subclause 5.6 of IEC 60694 is applicable with the following addition to the first paragraph.

A circuit-breaker arranged for stored energy closing shall also be capable of opening immediately following the closing operation with the rated short-circuit making current.

5.7 Independent manual operation

Subclause 5.7 of IEC 60694 is not applicable for circuit-breakers.

5.8 Operation of releases

Subclause 5.8 of IEC 60694 is applicable with the following additions:

5.8.101 Over-current release

5.8.101.1 Operating current

An over-current release shall be marked with its rated normal current and its current setting range.

Within the current setting range, the over-current release shall always operate at currents of 110 % and above of the current setting, and shall never operate at currents of 90 % and below of this current setting.

5.8.101.2 Operating time

For an inverse time delay over-current release, the operating time shall be measured from the instant at which the over-current is established until the instant at which the release actuates the tripping mechanism of the circuit-breaker.

The manufacturer shall provide tables or curves, each with the applicable tolerances, showing the operating time as a function of current, between twice and six times the operating current. These tables or curves shall be provided for extreme current settings together with extreme settings of time delay.

5.8.101.3 Resetting current

If the current in the main circuit falls below a certain value, before the time delay of the over-current release has expired, the release shall not complete its operation and shall reset to its initial position.

The relevant information shall be given by the manufacturer.

5.8.102 Multiple releases

If a circuit-breaker is fitted with more than one release for the same function, a defect in one release shall not disturb the function in the others. Releases used for the same function shall be physically separated, i.e. magnetically decoupled.

For circuit-breakers rated at 72,5 kV and above accommodation should be made for one additional closing and one additional shunt opening release.

5.8.103 Operation limits of releases

For shunt opening releases the minimum trip duration and for shunt closing releases the minimum command duration at rated supply voltage shall not be less than 2 ms.

The minimum supply voltage for operation of shunt releases shall not be less than 20 % of the rated supply voltage.

5.8.104 Power consumption of releases

The power consumption of shunt closing or opening releases of a three-pole circuit-breaker should not exceed 1 200 VA. For certain circuit-breaker designs higher values may be required.

5.8.105 Integrated relays for self-tripping circuit-breakers

When an integrated relay is used for self-tripping circuit-breakers, it shall comply with IEC 60255-3. The input energising quantity is the current through the main contacts.

5.9 Low- and high-pressure interlocking devices

Subclause 5.9 of IEC 60694 is replaced by the following:

All circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see 5.6.1 of IEC 60694) and all circuit-breakers except sealed pressure devices, using compressed gas for interruption (see 5.103) shall be fitted with a low-pressure interlocking device, and can also be fitted with a high-pressure interlocking device, set to operate at, or within, the appropriate limits of pressure stated by the manufacturer.

5.10 Nameplates

Subclause 5.10 of IEC 60694 is applicable with the following additions: the nameplates of a circuit-breaker and its operating devices shall be marked in accordance with table 6.

Coils of operating devices shall have a reference mark permitting the complete data to be obtained from the manufacturer.

Releases shall bear the appropriate data.

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

Table 6 – Nameplate information

	Abbreviation	Unit	Circuit-breaker	Operating device	Condition: Marking only required if
1	2	3	4	5	6
Manufacturer			X	X	
Type designation and serial number			X	X	
Rated voltage	U_r	kV	X		
Rated lightning impulse withstand voltage	U_p	kV	X		
Rated switching impulse withstand voltage	U_s	kV	y		Rated voltage 300 kV and above
Rated frequency	f_r	Hz	y		Rating is not applicable at both 50 Hz and 60 Hz
Rated normal current	I_r	A	X		
Rated duration of short circuit	t_k	s	y		Different from 1 s
Rated short-circuit breaking current	I_{sc}	kA	X		
DC component of the rated short-circuit breaking current		%	y		More than 20 %
First pole-to-clear factor	k_{pp}		y		Different from 1,3 for rated voltages 100 kV to 170 kV
Rated out-of-phase breaking current	I_d	kA	(X)		
Rated line-charging breaking current	I_l	A	y		Rated voltage equal to or greater than 72,5 kV
Rated cable-charging breaking current	I_c	A	y		Rated voltage equal to or less than 52 kV
Rated single capacitor bank-breaking current	I_{sb}	A	(X)		
Rated back-to-back capacitor bank-breaking current	I_{bb}	A	(X)		
Rated capacitor bank inrush making current	I_{si}	kA	y		Rated capacitor bank inrush making current is assigned
Rated back-to-back capacitor bank inrush making current	I_{bi}	kA	(X)		
Rated filling pressure for operation	p_{rm}	MPa		(X)	
Rated filling pressure for interruption	p_{re}	MPa	(X)		
Rated supply voltage of closing and opening devices	U_{op}	V		(X)	
Rated supply frequency of closing and opening devices		Hz		(X)	
Rated supply voltage of auxiliary circuits	U_a	V		(X)	
Rated supply frequency of auxiliary circuits		Hz		(X)	
Mass (including oil for oil circuit-breakers)	M	kg	y	y	More than 300 kg
Mass of fluid for interruption	m	kg	y		If gas or oil circuit-breakers

Table 6 *(continued)*

	Abbreviation	Unit	Circuit-breaker	Operating device	Condition: Marking only required if
1	2	3	4	5	6
Rated operating sequence			X		
Year of manufacture			X		
Temperature class			y	y	Different from – 5 °C indoor –25 °C outdoor
Classification			y		If different from E1, C1 and M1
Relevant standard with date of issue			X	X	
X = the marking of these values is mandatory; blanks indicate the value zero. (X) = the marking of these values is optional. y = the marking of these values to the conditions in column (6).					
NOTE The abbreviations in column 2 may be used instead of the terms in column 1. When terms in column 1 are used, the word “rated“ need not appear.					

5.11 Interlocking devices

Subclause 5.11 of IEC 60694 is applicable.

5.12 Position indication

Subclause 5.12 of IEC 60694 is applicable.

5.13 Degrees of protection by enclosures

Subclause 5.13 of IEC 60694 is applicable.

5.14 Creepage distances

Subclause 5.14 of IEC 60694 is applicable.

5.15 Gas and vacuum tightness

Subclause 5.15 of IEC 60694 is applicable.

5.16 Liquid tightness

Subclause 5.16 of IEC 60694 is applicable.

5.17 Flammability

Subclause 5.17 of IEC 60694 is applicable.

5.18 Electromagnetic compatibility

Subclause 5.18 of IEC 60694 is applicable.

5.101 Requirements for simultaneity of poles during single closing and single opening operations

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts touching during closing shall not exceed a quarter of a cycle of rated frequency.

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts separating during opening shall not exceed a sixth of a cycle of rated frequency. If one pole consists of more than one interrupter unit connected in series, the maximum difference between the instants of contact separation within these series connected interrupter units shall not exceed an eighth of a cycle of rated frequency.

NOTE For a circuit-breaker having separate poles, the requirement is applicable when these operate in the same conditions; after a single-pole reclosing operation, the conditions of operation for the three mechanisms may not be the same.

5.102 General requirement for operation

A circuit-breaker, including its operating devices, shall be capable of completing its rated operating sequence (4.104) in accordance with the relevant provisions of 5.5 to 5.9 and 5.103 for the whole range of ambient temperatures within its temperature class as defined in clause 2 of IEC 60694.

This requirement is not applicable to auxiliary manual operating devices; where provided, these shall be used only for maintenance and for emergency operation on a dead circuit.

Circuit-breakers provided with heaters shall be designed to permit an opening operation at the minimum ambient temperature defined by the temperature class when the heaters are not operational for a minimum time of 2 h.

5.103 Pressure limits of fluids for operation

The manufacturer shall state the maximum and minimum pressures of the fluid for operation at which the circuit-breaker is capable of performing according to its ratings and at which the appropriate low- and high-pressure interlocking devices shall be set (see 5.9). The manufacturer shall state the minimum functional pressure for operation and interruption (see 3.7.157 and 3.7.158).

The manufacturer may specify pressure limits at which the circuit-breaker is capable of each of the following performances:

a) breaking its rated short-circuit breaking current, i.e. an "O" operation;
b) making its rated short-circuit making current immediately followed by breaking its rated short-circuit breaking current, i.e. a "CO" operating cycle;
c) for circuit-breakers intended for rapid auto-reclosing; breaking its rated short-circuit breaking current followed after a time interval t of the rated operating sequence (4.104) by making its rated short-circuit making current, immediately followed again by breaking its rated short-circuit breaking current, i.e. an "O - t - CO" operating sequence.

The circuit-breakers shall be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

5.104 Vent outlets

Vent outlets are devices which allow a deliberate release of pressure in a circuit-breaker during operation.

NOTE This is applicable to air, air-blast and oil circuit-breakers.

Vent outlets of circuit-breakers shall be so situated that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons may be present. The necessary safety distance shall be stated by the manufacturer.

The construction shall be such that gas cannot collect at any point where ignition can be caused, during or after operation, by sparks arising from normal operation of the circuit-breaker or its auxiliary equipment.

6 Type tests

Clause 6 of IEC 60694 is applicable with the following additions:

The type tests for circuit-breakers are listed in table 7.

For the type tests, the tolerances on test quantities are given in annex B.

The individual type tests shall, in principle, be performed on a circuit-breaker in a new and clean condition. In case of circuit-breakers using SF_6 for insulation, interruption and/or operation, the quality of the gas shall at least comply with the acceptance levels of IEC 60480.

The responsibility of the manufacturer is limited to the declared rated values and not to those values achieved during the type tests.

The uncertainty of each measurement by oscillograph or equivalent equipment (for example transient recorder), including associated equipment, of the quantities which determine the ratings (for example short-circuit current, applied voltage and recovery voltage) shall be within ±5 % (equal to a coverage factor of 2,0).

NOTE For the meaning of coverage factor, see ISO Guide to the expression of uncertainty in measurement (1995) [12].

Table 7 – Type tests

Mandatory type tests	Subclauses
Dielectric tests	6.2
Radio interference voltage tests	6.3
Measurement of the resistance of the main circuit	6.4
Temperature-rise tests	6.5
Short-time withstand current and peak withstand current tests	6.6
Tightness tests	6.8
EMC tests	6.9
Mechanical operation test at ambient temperature	6.101.2.1 to 6.101.2.3
Short-circuit current making and breaking tests	6.102 to 6.106
Capacitive current switching tests: line-charging current breaking tests ($U_r \geq$ 72,5 kV)	6.111.5.1
Capacitive current switching tests: cable-charging current breaking tests ($U_r \leq$ 52 kV)	6.111.5.2
Mandatory type tests, where applicable	**Subclauses**
Verification of the degree of protection	6.7
Extended mechanical endurance tests on circuit-breakers for special service conditions *#	6.101.2.4
Low and high temperature tests	6.101.3
Humidity test	6.101.4
Static terminal load tests	6.101.6
Critical current tests	6.107
Short-line fault tests *	6.109
Out-of-phase making and breaking tests *#	6.110
Electrical endurance tests (only for rated voltages of 52 kV and below) *#	6.112
Test to prove operation under severe ice conditions *#	6.101.5
Single-phase and double earth fault tests *#	6.108
Capacitive current switching tests: – line-charging current breaking tests* ($U_r \leq$ 52 kV) – cable-charging current breaking tests # ($U_r \geq$ 72,5 kV) – single capacitor bank switching tests *# – back-to-back capacitor bank switching tests *#	 6.111.5.1 6.111.5.2 6.111.5.3 6.111.5.3
Switching of shunt reactors and motors *#	IEC 61233 *

NOTE All type tests shall be carried out using the number of test samples specified in 6.1.1 of IEC 60694 and in 6.102.2. Where, in the case of circuit-breakers with a rated voltage of up to and including 52 kV, the test is marked by*, an additional test sample is allowed for the marked test.

Where, in the case of circuit-breakers with a rated voltage of 72,5 kV and above, the test is marked by #, an additional test sample is allowed for the marked test.

6.1 General

6.1.1 Grouping of tests

Subclause 6.1.1 of IEC 60694 is applicable.

6.1.2 Information for identification of specimens

Subclause 6.1.2 of IEC 60694 is applicable.

6.1.3 Information to be included in type test reports

Subclause 6.1.3 of IEC 60694 is applicable with the following addition:

Further details relating to records and reports of type tests for making, breaking and short-time current performance are given in annex C.

6.2 Dielectric tests

6.2.1 Ambient air conditions during tests

Subclause 6.2.1 of IEC 60694 is applicable.

6.2.2 Wet test procedure

Subclause 6.2.2 of IEC 60694 is applicable with the following note:

NOTE In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

6.2.3 Condition of circuit-breaker during dielectric tests

Subclause 6.2.3 of IEC 60694 is applicable.

6.2.4 Criteria to pass the test

Subclause 6.2.4 of IEC 60694 is applicable with the following addition:

The circuit-breaker has passed the impulse tests if the following conditions are fulfilled:

a) the number of disruptive discharges shall not exceed two for each series of 15 impulses;

b) no disruptive discharges on non-self-restoring insulation shall occur.

This is verified by at least five impulses without disruptive discharge following that impulse out of the series of 15 impulses, which caused the last disruptive discharge. If this impulse is one of the last five out of the series of 15 impulses, additional impulses shall be applied.

If disruptive discharges occur and, for any reason, evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, after the completion of the dielectric tests the circuit-breaker shall be dismantled and inspected. If punctures of non-self-restoring insulation are observed, the circuit-breaker has failed the test.

NOTE 1 For GIS circuit-breakers tested with test bushings which are not part of the circuit-breaker, flashover across the test bushings should be disregarded.

NOTE 2 The determination of the location of the observed disruptive discharges should be carried out by the laboratory using sufficient detection means, for example, photographs, video recordings, internal inspection, etc.

6.2.5 Application of test voltage and test conditions

Subclause 6.2.5 of IEC 60694 is applicable.

6.2.6 Tests of circuit-breakers of $U_r \leq 245$ kV

Subclause 6.2.6 of IEC 60694 is applicable.

6.2.6.1 Power-frequency voltage tests

Subclause 6.2.6.1 of IEC 60694 is applicable with the following note:

NOTE In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

6.2.6.2 Lightning impulse voltage test

Subclause 6.2.6.2 of IEC 60694 is applicable.

6.2.7 Tests of circuit-breakers of $U_r > 245$ kV

Subclause 6.2.7 of IEC 60694 is applicable.

6.2.7.1 Power-frequency voltage tests

Subclause 6.2.7.1 of IEC 60694 is applicable with the following addition:

The test procedure following the alternative method is more severe than the test procedure following the preferred method.

6.2.7.2 Switching impulse voltage tests

Subclause 6.2.7.2 of IEC 60694 is applicable with the following addition:

For outdoor circuit-breakers dry tests shall be performed using voltage of positive polarity only. With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of table 9 of IEC 60694.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of table 9 of IEC 60694.

A second test series, with the test voltages according to column 6 of tables 2a and 2b of IEC 60694, shall be performed for circuit-breakers intended for special applications as stated in 4.2. For each test condition of table 11 of IEC 60694, one terminal shall be energised with switching impulse voltage and the opposite terminal with power-frequency voltage.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series consists of the application, to each terminal in turn, of impulses at a voltage equal to the sum of the switching impulse voltage and the peak value stated in column (6) of tables 2a and 2b in IEC 60694, the opposite terminal being earthed.

Item b) of 6.2.5.2 of IEC 60694 shall be taken into account. In general, this test is more severe than that following the specified test procedure.

6.2.7.3 Lightning impulse voltage tests

Subclause 6.2.7.3 of IEC 60694 is applicable with the following addition:

With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of table 9 of IEC 60694.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage across the open switching device shall be applied for each test condition of table 11 of IEC 60694.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series applies to each terminal in turn (or on one terminal if the arrangement of the terminals is symmetrical with respect to the base), 15 consecutive impulses at a voltage equal to the sum of the rated lightning impulse withstand voltage and the peak value stated in column (8) of tables 2a and 2b of IEC 60694, the opposite terminal being earthed. Item a) and item b) of 6.2.5.2 of IEC 60694 shall be taken into account. In general, this test is more severe than that following the specified test procedure.

6.2.8 Artificial pollution tests

Subclause 6.2.8 of IEC 60694 is applicable.

6.2.9 Partial discharge tests

Subclause 6.2.9 of IEC 60694 is applicable with the following addition:

Partial discharge tests are not normally required to be performed on the complete circuit-breaker. However, in the case of circuit-breakers using components for which a relevant IEC standard exists, including partial discharge measurements (for example, bushings, see IEC 60137), evidence shall be produced by the manufacturer showing that those components have passed the partial discharge tests as laid down in the relevant IEC standard.

6.2.10 Tests on auxiliary and control circuits

Subclause 6.2.10 of IEC 60694 is applicable.

6.2.11 Voltage test as a condition check

Subclause 6.2.11 of IEC 60694 is applicable with the following addition:

Where after making, breaking or switching tests (see 6.102.9) or where after mechanical or environmental tests (see 6.101.1.4) a voltage test is performed as a condition check, the following conditions shall apply:

For circuit-breakers with an asymmetrical current path, the connections shall be reversed. The complete tests shall be carried out once for each arrangement of the connections.

– Circuit-breakers with $U_r \leq 72,5$ kV

  A 1 min power-frequency voltage test shall be performed. The test voltage shall be 80 % of the value in table 1a, column (2) of IEC 60694.

– Circuit-breakers with 72,5 kV < U_r ≤ 245 kV

  An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 60 % of the highest relevant value in table 1a, column (4) of IEC 60694.

– Circuit-breakers with 300 kV ≤ U_r ≤ 420 kV

  An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in table 2a of IEC 60694. The rated switching impulse withstand voltage may be taken either from column (4) or from column (6) of this table. The reference value for the condition check shall be taken from the same column.

– Circuit-breakers with 550 kV ≤ U_r ≤ 800 kV

  An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in table 2a of IEC 60694. The rated switching impulse withstand voltage may be taken either from column (4) or from column (6) of this table. The reference value for the condition check shall be taken from the same column.

Where an impulse voltage test shall be carried out, five impulses of each polarity shall be applied. The circuit-breaker shall be considered to have passed the test if no disruptive discharge occurs.

For the impulse voltage test, the synthetic testing equipment of the power laboratory may be applied. The waveshape of the impulse voltage shall be either a standard switching impulse or a waveshape according to the TRV specified for terminal fault T10. For the test with the waveshape according to T10, timing tolerances of –10 % and +200 % on time t_3 are permitted.

NOTE 1 Comparative tests have shown that there are almost no differences in the behaviour of the circuit-breakers, both in new and in worn conditions, when testing is performed with standard switching impulses or with TRV impulses with a waveshape in accordance with terminal fault T10, respectively.

NOTE 2 If the tests are performed using the TRV impulse with a T10 waveshape, equivalence is maintained to the standard switching impulse if the following rules are applied:

– the damping of the TRV should be such that the second peak of the TRV oscillation is not higher than 80 % of the first one;

– about 2,5 ms after the peak the actual value of the recovery voltage should be in the range of 50 % of the peak value.

6.3 Radio interference voltage (r.i.v.) tests

Subclause 6.3 of IEC 60694 is applicable with the following addition:

Tests may be performed on one pole of the circuit-breaker in both closed and open position. During the tests the circuit-breaker shall be equipped with all accessories such as grading capacitors, corona rings, HV connectors, etc., which may influence the radio interference voltage performance.

6.4 Measurement of the resistance of the main circuit

Subclause 6.4 of IEC 60694 is applicable.

6.5 Temperature-rise tests

6.5.1 Conditions of the circuit-breaker to be tested

Subclause 6.5.1 of IEC 60694 is applicable.

6.5.2 Arrangement of the equipment

Subclause 6.5.2 of IEC 60694 is applicable with the following additions:

For a circuit-breaker not fitted with series connected accessories, the test shall be made with the rated normal current of the circuit-breaker.

For a circuit-breaker fitted with series connected accessories having a range of rated normal currents, the following tests shall be made:

a) a test of the circuit-breaker fitted with the series connected accessories having a rated normal current equal to that of the circuit-breaker, and made at the rated normal current of the circuit-breaker;
b) a series of tests of the circuit-breaker fitted with the intended accessories, and made with currents equal to the rated normal current of each accessory.

NOTE If the accessories can be removed from the circuit-breaker, and if it is evident that the temperature rise of the circuit-breaker and of the accessories do not appreciably influence each other, test b) above may be replaced by a series of tests on the accessories alone.

6.5.3 Measurement of the temperature and the temperature rise

Subclause 6.5.3 of IEC 60694 is applicable.

6.5.4 Ambient air temperature

Subclause 6.5.4 of IEC 60694 is applicable.

6.5.5 Temperature-rise tests of the auxiliary and control equipment

Subclause 6.5.5 of IEC 60694 is applicable.

6.5.6 Interpretation of the temperature-rise tests

Subclause 6.5.6 of IEC 60694 is applicable.

6.6 Short-time withstand current and peak withstand current tests

Subclause 6.6 of IEC 60694 is applicable.

6.6.1 Arrangement of the circuit-breaker and of the test circuit

Subclause 6.6.1 of IEC 60694 is applicable with the following addition:

If the circuit-breaker is fitted with direct over-current releases, these shall be arranged for test with the coil of the minimum operating current set to operate at the maximum current and maximum time delay; the coil shall be connected to the source side of the test circuit. If the circuit-breaker can be used without direct over-current releases, it shall also be tested without it.

For other self-tripping circuit-breakers, the over-current release shall be arranged for test with the settings to operate at the maximum current and maximum delay time. If the circuit-breaker can be used without the release, it shall also be tested without it.

6.6.2 Test current and duration

Subclause 6.6.2 of IEC 60694 is applicable with the following addition:

For self-tripping circuit-breakers, the rated operating sequence confined to opening operations only shall be performed. The average of the r.m.s. values of the a.c. components of the breaking current in all phases and operations shall be considered as the r.m.s. value of the short-time current except that where the test is made at rated voltage, prospective current values may be used.

6.6.3 Behaviour of the circuit-breaker during test

Subclause 6.6.3 of IEC 60694 is applicable.

6.6.4 Conditions of the circuit-breaker after test

Subclause 6.6.4 of IEC 60694 is applicable with the following addition:

After the tests of self-tripping circuit-breakers, the conditions of the circuit-breaker shall comply with 6.102.9, and it shall be demonstrated that the over-current release is still in order to operate correctly. A primary injection test at 110 % of the minimum tripping current, as declared by the manufacturer, is a satisfactory demonstration.

6.7 Verification of the degree of protection

6.7.1 Verification of the IP coding

Subclause 6.7.1 of IEC 60694 is applicable to all parts of circuit-breakers which are accessible in normal service.

6.7.2 Mechanical impact test

Subclause 6.7.2 of IEC 60694 is applicable.

6.8 Tightness tests

Subclause 6.8 of IEC 60694 is applicable.

6.9 Electromagnetic compatibility (EMC) tests

Subclause 6.9 of IEC 60694 is applicable.

6.101 Mechanical and environmental tests

6.101.1 Miscellaneous provisions for mechanical and environmental tests

6.101.1.1 Reference mechanical travel characteristics

At the beginning of the type tests, the mechanical travel characteristics of the circuit-breaker shall be established, for example, by recording no-load travel curves. These curves will serve as the reference mechanical travel characteristics. The purpose of these reference mechanical travel characteristics is to characterise the mechanical behaviour of the circuit-breaker. Similar tests are required before and/or after other tests including environmental, making, breaking and switching tests and at the time of routine testing and commissioning tests, if applicable.

The following operating characteristics shall be recorded:

- mechanical travel characteristics for opening and closing operation;
- the sensor used for the record of the mechanical travel characteristics shall be mounted at a suitable location making it possible to provide the mechanical travel characteristics at best, either directly or indirectly. The location shall be stated in the test report. The mechanical travel characteristics curve may be recorded continuously or discretely. In the latter case, at least 20 discrete values shall be given for the complete stroke;
- closing time;
- opening time.

The reference mechanical travel characteristics shall be produced during a no-load test made with the operating sequence O - t - CO or CO for the rated operating sequence O - t - CO – t' - CO or CO – t'' - CO respectively at rated supply voltage of operating devices and of auxiliary and control circuits, rated functional pressure for operation and, for convenience of testing, at the minimum functional pressure for interruption. The reference no-load test may be taken from any appropriate no-load test being part of an individual type test.

The reference mechanical travel characteristics shall be used to confirm that the different test samples used during the mechanical, making, breaking and switching type tests behave mechanically in a similar way. All test samples used for mechanical, making, breaking and switching type tests shall have a mechanical travel characteristic within the following described envelopes. When, due to variable measuring methods at different laboratories, a direct comparison between the envelopes cannot be made, the manufacturer shall be able to show evidence that the envelopes correspond.

The reference mechanical travel characteristics shall be used for determining the limits of the allowable deviations over or under this reference curve. From this reference curve, two envelope curves shall be drawn from the instant of contact separation for opening and contact touch for closing to the end of the contact travel. The distance of the two envelopes from the original course shall be ±5 % of the total stroke as shown in figure 23b. In case of circuit-breakers with a total stroke of 20 mm or less the distance of the two envelopes from the original course shall be ±2 mm. It is recognised that for some designs of circuit-breakers these methods are inappropriate. In such cases, the manufacturer shall justify the method and limits used.

The series of figures 23a to 23d are for illustrative purposes and only illustrate the opening operation. They are idealised, and do not show the variation in profile caused by the friction effect of the contacts or the end of travel damping. In particular, it is important to note that the effects of damping are not shown in these diagrams. The oscillations produced at the end of travel are dependent upon the efficiency of the damping of the drive system. The shape of these oscillations may be a deliberate function of the design or be caused by poor design, manufacture, assembly or adjustment. Therefore, it is important that any variations in the curve at the end of the stroke, which are outside the tolerance margin given by the envelope, are fully explained and understood before they are rejected or accepted as showing equivalence with the reference curves. In general, all curves should fall within the envelopes for acceptance.

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the reference mechanical travel characteristics of –0 %, +10 % and –10 %, +0 %, respectively as shown in figures 23c and 23d. The displacement of the envelope can be used only once for the complete procedure in order to get a maximum total deviation from the reference characteristic of 10 %.

The opening time and the closing time recorded in the reference no-load test shall be used as reference closing and reference opening time. The allowable deviations from these reference times correspond to the tolerances given by the manufacturer, but shall not exceed ±10 %, when performed at rated control voltage.

6.101.1.2 Component tests

When testing of a complete circuit-breaker is not practicable, component tests may be accepted as type tests. The manufacturer should determine the components which are suitable for testing.

Components are separate functional sub-assemblies which can be operated independently of the complete circuit-breaker (for example, pole, breaking unit, operating mechanism).

When component tests are made, the manufacturer shall prove that the mechanical and environmental stresses on the component during the tests are not less than those applied to the same component when the complete circuit-breaker is tested. Component tests shall cover all different types of components of the complete circuit-breaker, provided that the particular test is applicable to the component. The conditions for the component type tests shall be the same as those which could be employed for the complete circuit-breaker.

Parts of auxiliary and control equipment which have been manufactured in accordance with relevant standards shall comply with these standards. The proper function of such parts in connection with the function of the other parts of the circuit-breaker shall be verified.

6.101.1.3 Characteristics and settings of the circuit-breaker to be recorded before and after the tests

Before and after the tests, the following operating characteristics or settings shall be recorded and evaluated:

a) closing time;

b) opening time;

c) time spread between units of one pole;

d) time spread between poles (if multi-pole tested);

e) recharging time of the operating device;

f) consumption of the control circuit;

g) consumption of the tripping devices, possible recording of the current of the releases;

h) duration of opening and closing command impulse;

i) tightness, if applicable;

j) gas densities or pressures, if applicable;

k) resistance of the main circuit;

l) time-travel chart;

m) other important characteristics or settings as specified by the manufacturer.

The above operating characteristics shall be recorded at

– rated supply voltage and rated filling pressure for operation;
– maximum supply voltage and maximum filling pressure for operation;
– maximum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and maximum filling pressure for operation.

6.101.1.4 Condition of the circuit-breaker during and after the tests

During and after the tests, the circuit-breaker shall be in such a condition that it is capable of operating normally, carrying its rated normal current, making and breaking its rated short-circuit current and withstanding the voltage values according to its rated insulation level.

In general, these requirements are fulfilled if

– during the tests, the circuit-breaker operates on command and does not operate without command;
– after the tests, the characteristics measured according to 6.101.1.3 are within the tolerances given by the manufacturer;
– after the tests, all parts, including contacts, do not show undue wear;
– after the tests, coated contacts are such that a layer of coating material remains at the contact area. If this is not the case, the contacts shall be regarded as bare and the test requirements are fulfilled only if the temperature rise of the contacts during the temperature-rise test (according to 6.5) does not exceed the value permitted for bare contacts;
– during and after the tests, any distortion of mechanical parts is not such that it adversely affects the operation of the circuit-breaker or prevents the proper fitting of any replacement part;
– after the tests the insulating properties of the circuit-breaker in the open position shall be in essentially the same condition as before the tests. Visual inspection of the circuit-breaker after the tests is usually sufficient for verification of the insulating properties. In the case of circuit-breakers with sealed-for-life interrupter units, a voltage test as a condition check in accordance with 6.2.11 may be necessary.

6.101.1.5 Condition of the auxiliary and control equipment during and after the tests

During and after the tests, the following conditions for the auxiliary and control equipment shall be fulfilled:

– during the tests, care should be taken to prevent undue heating;
– during the tests, a set of contacts (both make and break auxiliary contacts) shall be arranged to switch the current of the circuits to be controlled (see 5.4);
– during and after the tests, the auxiliary and control equipment shall fulfil its functions;

– during and after the tests, capability of the auxiliary circuits of the auxiliary switches and of the control equipment shall not be impaired. In case of doubt, the tests according to 6.2.10 of IEC 60694 shall be performed;
– during and after the tests, the contact resistance of the auxiliary switches shall not be affected adversely. The temperature rise when carrying the rated current shall not exceed the specified values (see table 3 of IEC 60694).

6.101.2 Mechanical operation test at ambient air temperature

6.101.2.1 General

The mechanical operation test shall be made at the ambient air temperature of the test location. The ambient air temperature should be recorded in the test report. Auxiliary equipment forming part of the operating devices shall be included.

The mechanical operation test shall consist of 2 000 operating sequences.

Except for circuit-breakers fitted with over-current releases the test shall be made without voltage on or current in the main circuit.

For circuit-breakers fitted with over-current releases, approximately 10 % of the operating sequences shall be performed with the opening device energised by the current in the main circuit. The current shall be the minimum current necessary to operate the over-current release. For these tests, the current through over-current releases may be supplied from a suitable low-voltage source.

During the test, lubrication is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

6.101.2.2 Condition of the circuit-breaker before the test

The circuit-breaker for test shall be mounted on its own support and its operating mechanism shall be operated in the specified manner. It shall be tested according to its type as follows:

A multipole circuit-breaker actuated by a single operating device and/or with all poles mounted on a common frame shall be tested as a complete unit.

Tests shall be conducted at the rated filling pressure for interruption according to 6.101.1.3, item j).

A multipole circuit-breaker in which each pole or even each column is actuated by a separate operating device should be tested preferably as a complete multipole circuit-breaker. However, for convenience, or owing to limitations of the dimensions of the test bay, one single-pole unit of the circuit-breaker may be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete multipole circuit-breaker over the range of tests, for example in respect of

– reference mechanical travel characteristics;
– power and strength of closing and opening mechanism;
– rigidity of structure.

6.101.2.3 Description of the test on class M1 circuit-breakers

The circuit-breaker shall be tested in accordance with table 8.

Table 8 – Number of operating sequences

Operating sequence	Supply voltage and operating pressure	Number of operating sequences	
		Circuit-breakers for auto-reclosing	Circuit-breakers not for auto-reclosing
C - t_a - O - t_a	Minimum	500	500
	Rated	500	500
	Maximum	500	500
O - t - CO - t_a - C - t_a	Rated	250	-
CO - t_a	Rated	-	500

O = opening;

C = closing;

CO = a closing operation followed immediately (i.e., without any intentional time-delay) by an opening operation;

t_a = time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the circuit-breaker (this time can be different according to the type of operation);

t = 0,3 s for circuit-breakers intended for rapid auto-reclosing, if not otherwise specified.

6.101.2.4 Extended mechanical endurance tests on class M2 circuit-breakers for special service requirements

For special service requirements in the case of frequently operated circuit-breakers, extended mechanical endurance tests may be carried out, as follows.

The tests shall be made according to 6.101.1, 6.101.2.1, 6.101.2.2 and 6.101.2.3 with the following addition:

– the tests shall consist of 10 000 operating sequences comprising five times the relevant test series specified in table 8;
– between the test series specified, some maintenance, such as lubrication and mechanical adjustment, is allowed, and shall be performed in accordance with the manufacturer's instructions. Change of contacts is not permitted;
– the programme of maintenance during the tests shall be defined by the manufacturer before the tests and recorded in the test report.

6.101.2.5 Acceptance criteria for the mechanical operation tests

The criteria given below apply for mechanical operation tests on class M1 and class M2 circuit-breakers.

a) Before and after the total test programme, the following operations shall be performed:
   – five close-open operating cycles at the rated supply voltage of closing and opening devices and of auxiliary and control circuits and/or the rated pressure for operation;
   – five close-open operating cycles at the minimum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the minimum pressure for operation;

– five close-open operating cycles at the maximum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the maximum pressure for operation.

During these operating cycles, the operating characteristics (see 6.101.1.3) shall be recorded and evaluated. It is not necessary to publish all the oscillograms recorded. However, at least one oscillogram for each set of conditions given above shall be included in the test report.

In addition, the following checks and measurements shall be performed (see 10.2.102):

– measurements of characteristic operating fluid pressures and consumption during operations, if applicable;
– verification of the rated operating sequence;
– checks of certain specific operations, if applicable.

The variation between the mean values of each parameter measured before and after the extended mechanical endurance tests shall be within the tolerances given by the manufacturer.

b) After each series of 2 000 operating sequences the operating characteristics a), b), c), d), e) and l) in 6.101.1.3 shall be recorded.

c) After the total test programme the condition of the circuit-breaker shall be in accordance with 6.101.1.4.

6.101.3 Low and high temperature tests

6.101.3.1 General

The two tests need not be performed in succession, and the order in which they are made is arbitrary. For class –5 °C indoor circuit-breakers and for class –10 °C outdoor circuit-breakers, no low temperature test is required.

For single enclosure circuit-breakers or multi-enclosure circuit-breakers with a common operating device, three-pole tests shall be made. For multi-enclosure circuit-breakers with independent poles, testing of one complete pole is permitted.

Owing to limitations of the test facilities, multi-enclosure type circuit-breakers may be tested using one or more of the following alternatives provided that the circuit-breaker in its testing arrangement is not in a more favourable condition than normal condition for mechanical operation (see 6.101.2.2):

a) reduced length of phase-to-earth insulation;
b) reduced pole spacing;
c) reduced number of modules.

If heat sources are required, they shall be in operation.

Liquid or gas supplies for circuit-breaker operation are to be at the test air temperature unless the circuit-breaker design requires a heat source for these supplies.

No maintenance, replacement of parts, lubrication or readjustment of the circuit-breaker is permissible during the tests.

NOTE In order to determine the material temperature characteristics, ageing, etc., tests of longer duration than those specified in the following subclauses may be necessary.

As an alternative approach to the methods in this standard, a manufacturer may establish compliance with performance requirements for an established circuit-breaker family by documenting satisfactory circuit-breaker field experience in at least one location with ambient air temperatures frequently at or above the specified maximum ambient air temperature of 40 °C, and at least one location with satisfactory field experience in specified minimum ambient air temperature depending on the class of the circuit-breaker (see clause 2 of IEC 60694).

6.101.3.2 Measurement of ambient air temperature

The ambient air temperature of the immediate test environment shall be measured at half the height of the circuit-breaker and at a distance of 1 m from the circuit-breaker.

The maximum temperature deviation over the height of the circuit-breaker shall not exceed 5 K.

6.101.3.3 Low temperature test

The diagram of the test sequences and identification of the application points for the tests specified are given in figure 17a.

If the low temperature test is performed immediately after the high temperature test, the low temperature test can proceed after completion of item u) of the high temperature test. In this case items a) and b) are omitted.

a) The test circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

b) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 6.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C (T_A). The tightness test (if applicable) shall be performed according to 6.8.

c) With the circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate, minimum ambient air temperature (T_L), according to the class of the circuit-breaker as given in 2.1.1, 2.1.2 and 2.2.3 of IEC 60694. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_L.

d) During the 24 h period with the circuit-breaker in the closed position at temperature T_L, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of table 12 of IEC 60694.

e) After 24 h at temperature T_L, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The opening time and the closing time shall be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible.

f) The low temperature behaviour of the circuit-breaker and its alarms and lock-out systems shall be verified by disconnecting the supply of all heating devices, including also the anti-condensation heating elements, for a duration t_x. During this interval, occurrence of the alarm is acceptable but lock-out is not. At the end of the interval t_x, an opening order, at rated values of supply voltage and operating pressure, shall be given. The circuit-breaker shall then open. The opening time shall be recorded (and the mechanical travel characteristics measured, if feasible) to allow assessment of the interrupting capability.

   The manufacturer shall state the value of t_x (not less than 2 h) up to which the circuit-breaker is still operable without auxiliary power to the heaters. In the absence of such a statement, the preferred value shall be equal to 2 h.

g) The circuit-breaker shall be left in the open position for 24 h.

h) During the 24 h period with the circuit-breaker in the open position at temperature T_L, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of table 12 of IEC 60694.

i) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at temperature T_L. At least a 3 min interval shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible. Following the first closing operation (C) and the first opening operation (O) three CO operating cycles (no intentional time delay) shall be performed. The additional operations shall be made by performing C - t_a - O - t_a operating sequences (t_a is defined in table 8).

j) After completing the 50 opening and 50 closing operations, the air temperature shall be increased to ambient air temperature T_A at a rate of change of approximately 10 K per hour.

   During the temperature transition period the circuit-breaker shall be subjected to alternate C - t_a - O - t_a - C and O - t_a - C - t_a - O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in open and closed positions for 30 min periods between the operating sequences.

k) After the circuit-breaker has stabilised thermally at ambient air temperature T_A, a recheck shall be made of the circuit-breaker settings, operating characteristics and tightness as in Items a) and b) for comparison with the initial characteristics.

The accumulated leakage during the complete low temperature test sequence from item b) to item j) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

6.101.3.4 High-temperature test

The diagram of the test sequence and identification of the application points for the tests specified are given in figure 17b.

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of item j) of the low temperature test. In this case, items k) and l) below are omitted.

l) The test circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

m) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 6.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C (T_A). The tightness test (if applicable) shall be performed according to 6.8.

n) With the circuit-breaker in the closed position, the air temperature shall be increased to the appropriate, maximum ambient air temperature (T_H), according to the upper limit of ambient air temperature as given in 2.1.1, 2.1.2 and 2.2.3 of IEC 60694. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_H.

NOTE The influence of solar radiation is not considered.

o) During the 24 h period with the circuit-breaker in the closed position at the temperature T_H, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of table 12 of IEC 60694.

p) After 24 h at the temperature T_H, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The opening time and the closing time shall be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

q) The circuit-breaker shall be opened and left open for 24 h at the temperature T_H.

r) During the 24 h period with the circuit-breaker in the open position at the temperature T_H, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of table 12 of IEC 60694.

s) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at the temperature T_H. An interval of at least 3 min shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

   Following the first closing operation (C) and the first opening operation (O) three CO operation cycles (no intentional time delay) shall be performed. The additional operations shall be made by performing C - t_a - O - t_a operating sequences (t_a is defined in table 8).

t) After completing the 50 opening and 50 closing operations, the air temperature shall be decreased to ambient air temperature T_A, at a rate of change of approximately 10 K/h.

   During the temperature transition period, the circuit-breaker shall be subjected to alternate C - t_a - O - t_a - C and O - t_a - C - t_a - O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in the open and closed positions for 30 min periods between the operating sequences.

u) After the circuit-breaker has stabilised thermally at ambient air temperature T_A, a recheck shall be made of the circuit-breaker settings, operating characteristics and tightness as in items k) and l) for comparison with the initial characteristics.

   The accumulated leakage during the complete high temperature test sequence from item l) to item t) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

6.101.4 Humidity test

6.101.4.1 General

The humidity test shall not be applied on equipment which is designed to be directly exposed to precipitation, for example primary parts of outdoor circuit-breakers. The test shall be performed on circuit-breakers or circuit-breaker components, where due to sudden changes of the temperature condensation may occur on insulating surfaces which are continuously stressed by voltage. This is mainly the insulation of the secondary wiring of indoor installed circuit-breakers. It is also not necessary where effective means against condensation are provided, for example control cubicles with anti-condensation heaters.

Applying the test procedure described in 6.101.4.2, the withstand of the test object, primarily circuit-breaker components, to humidity effects, which may produce condensation on the surface of the test specimen, is determined in an accelerated manner.

6.101.4.2 Test procedure

The test object shall be arranged in a test chamber containing circulating air and in which the temperature and humidity shall follow the cycle given below:

During about half of the cycle the surfaces of the test object shall be wet, and dry during the other half. To obtain this result the test cycle consists of a period t_4 with low air temperature (T_{min} = 25 °C ± 3 °C) and a period t_2 with high air temperature (T_{max} = 40 °C ± 2 °C) inside the test chamber. Both periods shall be equal in time. The generation of fog shall be maintained for that half of the cycle (see figure 18) in which the low air temperature is applied.

The beginning of fog generation coincides in principle with the beginning of the low air temperature period. However, to wet the vertical surfaces of materials with a high thermal time constant, it may be necessary to start the fog generation later within the low air temperature period.

The duration of the test cycle depends on the thermal characteristics of the test objects, and shall be sufficiently long, both at high and low temperature, to cause wetting and drying of all insulation surfaces. In order to obtain these conditions, steam should be injected directly into the test chamber or heated water should be atomised; the rise from 25 °C to 40 °C may be obtained with the provision of heat coming from the steam or atomised water or, if necessary, by additional heaters. Preliminary cycles shall be carried out with the test object placed in the test chamber in order to observe and to check these conditions.

NOTE For low-voltage components of high-voltage circuit-breakers, usually having time constants smaller than 10 min, the duration of the time intervals given in figure 18 are: t_1 = 10 min, t_2 = 20 min, t_3 = 10 min and t_4 = 20 min.

The fog is obtained by the continuous or periodical atomisation of 0,2 l to 0,4 l of water (with the resistivity characteristics given below) per hour and per cubic metre of test chamber volume. The diameter of the droplets shall be less than 10 μm; such a fog may be obtained by mechanical atomisers. The direction of the spraying shall be such that the surfaces of the test object are not directly sprayed. No water shall drop from the ceiling upon the test object. During the fog generation the test chamber shall be closed and no additional forced air-circulation is permitted.

The water used to create the humidity shall be such that the water collected in the test chamber has a resistivity equal to or greater than 100 Ωm and contains neither salt (NaCl) nor any corrosive element.

The temperature and the relative humidity of the air in the test chamber shall be measured in the immediate vicinity of the test object and shall be recorded for the whole duration of the test. No value of relative humidity is specified during the drop in temperature; however, the humidity shall be above 80 % during the period when the temperature is maintained at 25 °C. The air shall be circulated in order to obtain uniform distribution of the humidity in the test chamber.

The number of cycles shall be 350.

During and after the test, the operating characteristics of the test objects shall not be affected. The auxiliary and control circuits shall withstand a power frequency voltage of 1 500 V for 1 min. The degree of corrosion, if any, should be indicated in the test report.

6.101.5 Test to prove the operation under severe ice conditions

The test under severe ice conditions is applicable only to outdoor circuit-breakers having moving external parts and for which a class of 10 mm or 20 mm of ice thickness is specified. The test shall be performed under the conditions described in IEC 60129.

6.101.6 Static terminal load test

6.101.6.1 General

The static terminal load test is performed to demonstrate that the circuit-breaker operates correctly when loaded by stresses resulting from ice, wind and connected conductors.

The static terminal load test is applicable only to outdoor circuit-breakers having rated voltages of 52 kV and above.

If the manufacturer, using calculations, can prove that the circuit-breaker can withstand the stresses, tests need not be performed.

Ice coating and wind pressure on the circuit-breaker shall be in accordance with 2.1.2 of IEC 60694.

Some examples of forces due to flexible and tubular connected conductors (not including wind or ice load or the dynamic loads on the circuit-breaker itself) are given as a guide in table 9.

The tensile force due to the connected conductors is assumed to act at the outermost end of the circuit-breaker terminal.

For simultaneous action of ice, wind and connected conductors, the resultant terminal forces, F_{shA}, F_{shB} and F_{sv} respectively (see figure 19) are defined as rated static terminal loads.

6.101.6.2 Tests

The tests shall be made at the ambient air temperature of the test room.

The tests should be made on at least one complete pole of the circuit-breaker. If the manufacturer can prove that there is no interaction between different columns in the pole, it is sufficient to test only one column. For circuit-breakers which are symmetrical about the pole unit vertical centreline, only one terminal need be tested with the rated static terminal load. For circuit-breakers which are not symmetrical, each terminal shall be tested.

Tests shall be made separately, firstly with a horizontal force, F_{shA}, applied in longitudinal axis of the terminal (direction A in figure 20), secondly with a horizontal force, F_{shB}, applied in two directions successively at 90° from the longitudinal axis of the terminals (directions B_1 and B_2 in figure 20) and thirdly, with a vertical force, F_{sv} applied in two directions successively (directions C_1 and C_2 in figure 20). To avoid the need to apply a special force representing the force of wind acting at the circuit-breaker's centre of application of pressure, this wind load may be applied at the terminal (see figure 19) and reduced in magnitude in proportion to the longer lever arm (the bending moment at the lowest part of the circuit-breaker should be the same).

Two operating cycles shall be performed for each of the five terminal load tests.

Table 9 – Examples of static horizontal and vertical forces for static terminal load test

Rated voltage range U_r kV	Rated current range I_r A	Static horizontal force F_{th} Longitudinal F_{thA} N	 Transversal F_{thB} N	Static vertical force (vertical axis-upward and downward) F_{tv} N
52 – 72,5	800 – 1 250	500	400	500
52 – 72,5	1 600 – 2 500	750	500	750
100 – 170	1 250 – 2 000	1 000	750	750
100 – 170	2 500 – 4 000	1 250	750	1 000
245 – 362	1 600 – 4 000	1 250	1 000	1 250
420 – 800	2000 – 4 000	1 750	1 250	1 500

6.102 Miscellaneous provisions for making and breaking tests

The following subclauses are applicable to all making and breaking tests unless otherwise specified in the relevant clauses.

Where applicable, prior to the commencement of the tests, the manufacturer shall declare the values of

– minimum conditions of the operating mechanism guaranteeing the rated operating sequence (for example the minimum functional pressure for operation in case of a hydraulic operating mechanism);

– minimum conditions of the interrupting device guaranteeing the rated operating sequence (for example the minimum functional pressure for interruption in case of a SF_6 circuit-breaker).

6.102.1 General

Circuit-breakers shall be capable of making and breaking all short-circuit currents, symmetrical and asymmetrical, up to and including the rated short-circuit breaking currents: this is demonstrated, when the circuit-breakers make and break the specified three-phase symmetrical and asymmetrical currents between 10 % (or such lower currents as specified in 6.107.2 if 6.107.1 is applicable) and 100 % of the rated short-circuit breaking current at rated voltage.

In addition, circuit-breakers intended to be used in an earthed neutral system or for single-pole operation shall make and break single-phase short-circuit currents between 10 % (or such lower currents as specified in 6.107.2 if 6.107.1 is applicable) and 100 % of the rated short-circuit breaking current at phase-to-earth voltage ($U_r/\sqrt{3}$).

Circuit-breakers to which any capacitive current switching rating has been assigned shall be capable of switching capacitive currents up to and including the rated capacitive switching current at a voltage level up to and including the specified one (see 6.111.7). This is demonstrated when the circuit-breakers switch the rated capacitive switching current at the specified test voltage.

Three-phase making and breaking requirements should preferably be proved in three-phase circuits.

If the tests are carried out in a laboratory, the applied voltage, current, transient and power-frequency recovery voltages may all be obtained from a single power source (direct tests) or from several sources where all of the current, or a major portion of it, is obtained from one source, and the transient recovery voltage is obtained wholly or in part from one or more separate sources (synthetic tests).

If, due to limitations of the testing facilities, the short-circuit performance of the circuit-breaker cannot be proved in the above way, several methods employing either direct or synthetic test methods may be used either singly or in combination, depending on the circuit-breaker type:

a) single-pole testing (see 6.102.4.1);

b) unit testing (see 6.102.4.2);

c) multi-part testing (see 6.102.4.3).

6.102.2 Number of test specimens

Subclause 6.1.1 of IEC 60694 is applicable with the following addition:

As a recommended practice for the performance of short-circuit making and breaking tests and of switching tests (including terminal fault, short-line fault, out-of-phase and capacitive current switching tests where applicable), a unique test specimen should be used. Where required, maintenance is allowed and should be performed as permitted, between each individual test-duty in the case of short-circuit tests and between each test series in the case of other than short-circuit tests. The manufacturer shall provide a statement to the testing laboratory of those parts that may be renewed during the tests.

It is, however, recognised that in the case of several test-duties being carried out in the same testing station during one occupation, the restrictions given in the previous paragraph may cause economic constraints. Under these circumstances, it is allowed to use up to two test specimens for the performance of all the above-mentioned tests. In such a case, full identification of the two test specimens according to 6.1.2 of IEC 60694 shall be carried out; in addition, the mechanical travel characteristics of the two specimens shall be within the tolerances given in 6.101.1.1.

As a further allowance limited to circuit-breakers having independent operating mechanisms for each pole, tested single phase and full pole, in addition to the two test specimens, supplementary interrupting units of up to two poles may be used.

If tests are carried out as unit tests on one or more units of a pole, the total number of units involved in the individual test, taking the provisions of 6.102.4.2.3 into account, is considered as one test specimen. In this case, two test specimens with their associated operating mechanisms and up to two additional test specimens (appropriate interrupting units) may be used.

In figure 21 the permitted number of test specimens for making, breaking and switching tests is illustrated, and in figure 22 the definition of a test specimen in accordance with 3.2.2 of IEC 60694 is illustrated.

The additional allowance is permitted, provided that inspection of the equipment after the tests shows that there is no undue damage to the non-renewable parts which could impair the capability of the circuit-breaker to withstand the complete series of type tests without change of its non-renewable parts. Should this not be the case, the tests shall be repeated using the same specimen with only replacement of the renewable parts as declared by the manufacturer.

Where additional non-mandatory tests are performed, the use of additional test specimens, exceeding the number specified above, is allowed (see table 7).

6.102.3 Arrangement of circuit-breaker for tests

6.102.3.1 General

The circuit-breaker under test shall be mounted on its own support or on an equivalent support. A circuit-breaker supplied as an integral part of an enclosed unit shall be assembled on its own supporting structure and enclosure, complete with any disconnecting features, with vent outlets forming part of the unit and, where practicable, with main connections and busbars.

Its operating device shall be operated in the manner specified and in particular, if it is electrically or spring operated, closing solenoid or shunt closing releases and shunt opening releases shall be supplied at their respective minimum voltages guaranteeing successful operation (85 % of the rated voltage for the closing solenoid or shunt closing releases, 85 % of the rated voltage if a.c. or 70 % if d.c. for the opening release). To facilitate consistent control of the opening and closing operation, the releases shall be supplied at the maximum operating voltage for test-duty T100a, capacitive current switching tests and the single-phase test specified in 6.108. For pneumatically or hydraulically operated devices, it shall be operated at the minimum functional pressure for operation, as per 3.7.157, at commencement of the rated operating sequence, as per 4.104, unless otherwise specified in the relevant clauses. In cases where test-duty or test station limitations allow for operating sequences consisting of separate O operations, CO and O - *t* - CO operating sequences, the following procedure applies:

a) before performing making, breaking and switching tests and starting from the minimum functional pressure for operation as per 3.7.157, all the pressures during the rated operating sequence carried out at no-load shall be recorded;
b) the recorded values shall be compared with the minimum values declared by the manufacturer as guaranteeing successful operations as separate O, CO and O - *t* - CO;
c) tests shall be carried out at the pressure for operation set at the minimum value resulting from a) and b) above, whatever is the lower, for the corresponding operation in the test-duty; the pressure values shall be reported in the test report.

Interlocking devices associated with pressure interlocks shall be made inoperative during the tests, if they interfere with the intent of the test.

It shall be shown that the circuit-breaker will operate satisfactorily under the above conditions at no-load as specified in 6.102.6. The pressure of the compressed gas for interruption, if any, shall be set at its minimum functional value according to 3.7.157.

The circuit-breaker shall be tested according to its type as specified in 6.102.3.2 and 6.102.3.3.

6.102.3.2 Common enclosure type

A three-pole circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole circuit-breaker in three-phase circuits, taking IEC 61633 into account.

The reasons are as follows:

- possibility of disruptive discharge between poles or to earth due to the influence of exhaust gases;
- possible differences in the conditions of the extinguishing medium (pressures, temperatures, pollution levels, etc.);
- greater influence between phases due to electrodynamic forces in the case of a three-phase fault;
- possible different stresses on the operating mechanism.

6.102.3.3 Multi-enclosure type

A three-pole circuit-breaker consisting of three independent single-pole switching devices can be tested single-phase according to 6.102.4.1. The manufacturer shall give testing evidence to show compliance with 5.101.

A three-pole circuit-breaker not having completely independent switching devices should be tested as a complete three-pole circuit-breaker. However, owing to limitation of available testing facilities, one single-pole of the circuit-breaker may be tested, provided that it is with regard to the mechanical and electrical conditions applied during the tests equivalent to, or not in a more favourable condition than, the complete three-pole circuit-breaker over the range of tests in respect of

- mechanical travel characteristics in a making operation (for the evaluation method, see 6.102.4.1);
- mechanical travel characteristics in a breaking operation (for the evaluation method, see 6.102.4.1);
- availability of arc-extinguishing medium;
- power and strength of closing and opening devices;
- rigidity of structure.

6.102.3.4 Self-tripping circuit-breakers

For self-tripping circuit-breakers, subject to the provisions of 6.103.4, the over-current release shall be inoperative during making, breaking and switching tests and the over-current release or the current transformers shall be connected to the live side of the test circuit.

6.102.4 General considerations concerning testing methods

6.102.4.1 Single-phase testing of a single pole of a three-pole circuit-breaker

According to this method, a single-pole of a three-pole circuit-breaker is tested single-phase, applying to the pole the same current and substantially the same power-frequency voltage which would be impressed upon the most highly stressed pole during three-phase making and breaking by the complete three-pole circuit-breaker under corresponding conditions.

In those cases where the circuit-breaker design permits single-pole testing to simulate three-phase conditions and the circuit-breaker is equipped with one operating mechanism for all poles a complete three-pole assembly shall be supplied for the tests.

For short-circuit tests in order to establish whether the circuit-breaker permits single-phase tests to simulate three-phase conditions, verification tests consisting of an asymmetrical and a symmetrical making operation and a breaking operation shall be performed. Furthermore, it shall be checked that the operating characteristics of the circuit-breaker to be single-phase tested correspond to the provisions of 6.101.1.1.

The verification test for breaking consists of performing a three-phase short-circuit breaking test at the same current level as prescribed for test-duty T100s, without TRV with any convenient test voltage, and with the longest expected arcing time in the last-pole-to-clear.

The verification test for making consists of two three-phase making operations under the same conditions as given in 6.104.2. In one making operation full symmetrical current and the maximum prearcing time shall be achieved in one pole. In the other making operation the maximum asymmetry shall be achieved in one pole; in this case the making operation may be performed at a convenient reduced voltage.

During these verification tests for making and breaking, the course of the contact travel is recorded. It shall be used as a reference for the following procedure (see figure 23a). The sensor for picking up the course of the contact travel shall be mounted at a suitable location making it possible for providing the course of the contact travel at best, either directly or indirectly.

From this reference course, two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel. The distance of the two envelopes from the original course shall be ±5 % of the total travel evaluated from the three-phase verification test (see figure 23b).

During a single-phase test under the same conditions (test-duty T100s with the longest arcing time and the longest pre-arcing time) the course of the contact travel shall be recorded. If the course of the contact travel in the single-phase test is within the envelopes of the mechanical travel characteristics from the instant of contact separation to the end of the contact travel for the opening operation and from the instant of contact touch to the end of the contact travel for the closing operation of the three-phase tests, single-phase tests for representing three-phase conditions are valid.

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the reference contact travel curve of –0 %, +10 % and +0 %, –10 % respectively (see figures 23c and 23d). The displacement of the envelope can be done only once for the complete procedure in order to get a maximum total deviation from the reference curve of 10 %.

NOTE To achieve the correct contact travel characteristics of the individual poles, depending on the design (single-phase or three-phase operated), it may be necessary to make adjustments, for example by using transfer functions.

Special attention should be paid to the emission of arc products. If it is considered that such emission would, for example, be likely to impair the insulation distance to adjacent poles, then this shall be checked, using earthed metallic screens (see 6.102.8).

6.102.4.2 Unit testing

Certain circuit-breakers are constructed by assembling identical breaking or making units in series, the voltage distribution between the units of each pole often being improved by the use of parallel impedances.

This type of design enables the breaking or making performance of a circuit-breaker to be tested by carrying out tests on one or more units.

The requirements of 6.101.1.1, 6.102.3 and 6.102.4.1 also apply for unit testing. Since therefore at least a complete pole assembly has to be made available for the verification tests on one or more units, the test results relate only to this specific pole design.

The following situations can be distinguished

a) The circuit-breaker pole consists of units (or assemblies of units) which are separately operated and which have no mutual connections for the arc extinguishing medium.

   In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the units and the arc in the units should be taken into account (see figure 24). This may be done by substitution of the second interrupter unit by a conductor with equivalent shape.

b) The circuit-breaker pole consists of units (or assemblies of units) which are separately operated but which have a mutual connection for the arc extinguishing medium.

   In this case, unit testing is only acceptable if the units not under test arc during the test (e.g. used as auxiliary circuit-breaker in synthetic tests).

c) The circuit-breaker pole consists of units (or assemblies of units) which are not separately operated.

   In this case, unit testing is only acceptable if the mechanical travel characteristics for the single-unit testing and for full-pole testing are the same. The procedure as given in 6.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. Moreover, the influence of electrodynamic forces (see also item a) above) shall be covered.

   However, if the units not under test arc during the test (for example, used as auxiliary circuit-breaker in synthetic tests), the requirements related to the mechanical travel characteristics are considered to be covered. In this case, the requirement for circuit-breakers, which have mutual connections for the extinguishing medium between units (see also item b) above) is covered at the same time.

d) For test currents equal to or less than 60 % of the rated short-circuit current, single-unit testing is permissible if the arc extinguishing medium volume of the single unit under test is proportional to the applicable part of one assembly of units having the same arc extinguishing medium.

   The mechanical travel characteristics for single-unit testing and for full-pole testing shall be the same. The procedure given in 6.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly.

When carrying out unit tests it is essential that the units are identical and that the static voltage distribution for the type of test (for example terminal faults, short-line fault, out-of-phase, etc.) is known.

6.102.4.2.1 Identical nature of the units

The units of the circuit-breaker shall be identical in their shape, in their dimensions and in their operating conditions; only the devices for controlling the voltage distribution among units may be different. In particular, the following conditions shall be fulfilled.

a) *Operation of contacts*

The opening, in breaking tests, or the closing, in making tests, of the contacts of one pole shall be such that the time interval between the opening or closing of the contacts of the unit which is first to operate and the contacts of the unit which is last to operate is not more than one-eighth of a cycle of rated frequency. Rated operating pressures and voltages shall be used to determine this time interval.

b) *Supply of the arc-extinguishing medium*

For a circuit-breaker using a supply of arc-extinguishing medium from a source external to the units, the supply to each unit shall, for all practical purposes, be independent of the supply to the other units, and the arrangement of the supply pipes shall be such as to ensure that all units are fed essentially together and in an identical manner.

6.102.4.2.2 Voltage distribution

The test voltage is determined by analysing the voltage distribution between the units of the pole.

The voltage distribution between units of a pole, as affected by the influence of earth, shall be determined for the relevant test conditions laid down for tests on one pole:

– for terminal fault conditions see items c) and d) of 6.103.3 and figures 27a, 27b, 28a and 28b;

NOTE 1 The test circuit shown in figures 27b and 28b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in IEC 61633.

– for short-line fault conditions see 6.109.3;

– for out-of-phase conditions see 6.110.1 and figures 51, 52 and 53;

– for capacitive current switching conditions see 6.111.3, 6.111.4 and 6.111.5.

Where the units are not symmetrically arranged, the voltage distribution shall be determined also with reverse connections.

The voltage distribution is determined either by measurement or by calculation. Values used in the calculations shall be supported by measurements of the stray capacitances of the circuit-breaker. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

If the circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the equivalent frequency involved in the TRV.

NOTE 2 The equivalent frequency is considered to be $1/(2t_1)$ in the case of four parameters or $1/(2t_3)$ in the case of two parameters (see figures 39 and 40).

For short-line fault unit tests, the voltage distribution shall be calculated or measured statically on the basis of a voltage on the line side at the fundamental frequency of the line oscillation and a voltage on the source side at the equivalent frequency of the TRV for terminal faults, the common point of the two voltages being at earth potential.

If only capacitors are used, the voltage distribution may be calculated or measured at power frequency.

The manufacturing tolerances for resistors and capacitors shall be taken into account. The manufacturer shall state the value of these tolerances.

NOTE 3 It may be taken into account that the voltage distribution is more favourable during the out-of-phase and capacitive current breaking tests than during the terminal or short-line fault tests. This also applies when, in exceptional cases, tests have to be performed under the conditions of unearthed faults in earthed neutral systems.

NOTE 4 The influence of pollution is not considered in determining voltage distribution. In some cases, pollution may affect this voltage distribution.

6.102.4.2.3 Requirements for unit testing

When testing a single unit, the test voltage shall be the voltage of the most highly stressed unit of the complete pole of the circuit-breaker, determined in accordance with 6.102.4.2.2. For short-line fault conditions, the unit referred to is that most highly stressed at the specified time of the first peak of the line side transient voltage.

When testing a group of units, the voltage appearing at the terminals of the most highly stressed unit of the group shall be equal to the voltage of the most highly stressed unit of the pole, both determined in accordance with 6.102.4.2.2.

During unit testing, the insulation to earth is not stressed with the full voltage occurring during a breaking operation of the complete circuit-breaker. For certain types of circuit-breakers, such as circuit-breakers in metal enclosures, it is therefore necessary to prove that the insulation to earth is capable of withstanding this full voltage, after interruption of the rated short-circuit current in all units with maximum arcing time. The influence of exhaust gases should also be taken into account.

IEC 61633 shall be taken into account.

6.102.4.3 Multi-part testing

If all TRV requirements for the given test-duty cannot be met simultaneously, the test may be carried out in two successive parts, as illustrated in figure 43.

In the first part the initial portion of the TRV shall not cross the straight line defining the delay time and shall meet the specified reference line up to the voltage u_1 and the time t_1.

In the second part, the voltage u_c and the time t_2 shall be attained.

The number of tests for each part shall be the same as the number required for the test-duty, and the arcing times for each part shall meet the requirements of 6.102.10. The arcing times in separate tests forming part of one multi-part test shall be the same with a margin of ±1 ms. Moreover if the minimum arcing time in one part differs from that established in the other part by more than 1 ms then the maximum arcing time associated with the longer of the two minimum arcing times shall be used for both parts.

The circuit-breaker may be re-conditioned between the first part and the second part in accordance with 6.102.9.5.

In rare cases, it may be necessary to perform the test in more than two parts. In such cases, the principles stated above shall be applied.

6.102.5 Synthetic tests

Synthetic testing methods can be applied for making, breaking and switching tests as required in 6.106 to 6.111. Synthetic testing techniques and methods are described in IEC 60427.

6.102.6 No-load operations before tests

Before commencing making and breaking tests, no-load operations and no-load operating sequences (O, CO and O - t - CO) shall be made and details of the operating characteristics of the circuit-breaker recorded. Details such as closing time and opening time shall be recorded.

In addition, it shall be demonstrated that the mechanical behaviour of the circuit-breaker, or sample under test, conforms to that of the reference mechanical travel characteristics required in 6.101.1.1. For this test the operational conditions stated in 6.101.1.1 apply. After a change of contacts or any kind of maintenance, these mechanical travel characteristics shall be reconfirmed by repeating these no-load tests.

For a circuit-breaker fitted with a making current release, it shall be shown that this does not operate on no-load.

The pressure of the fluid for interruption shall be set at its minimum functional value according to 3.7.158.

For electrically or spring-operated circuit-breakers, operations shall be made with the closing solenoid or shunt-closing releases energised at 100 % and 85 % of the rated supply voltage of the closing device and with the shunt-opening release energised at 100 % and 85 % in the case of a.c., and 100 % and 70 % in the case of d.c. of the rated supply voltage.

For pneumatic or hydraulic operating devices, the operations shall be made under the following conditions:

a) pressure of the fluid for operation set at its minimum functional value as per 3.7.157 with the shunt opening releases energised at 85 % in case of a.c., 70 % in case of d.c. and with the shunt closing releases energised at 85 % of the rated supply voltage.
b) pressure of the fluid for operation set at its rated value as per 4.10 with the shunt releases energised at the rated supply voltage.

6.102.7 Alternative operating mechanisms

If the circuit-breaker is designed for use with alternative operating mechanisms, a separate series of short-circuit test-duties shall be made for each type of mechanism, unless it can be shown that the change of mechanism does not affect the performance of the common portion, particularly with regard to the opening and closing characteristics of the circuit-breaker.

If this can be satisfactorily shown, only a single complete series of short-circuit test-duties is required using one of the alternative mechanisms, but terminal fault T100s shall be repeated with all other alternative mechanisms.

Evidence of the equivalence of an alternative operating mechanism shall be produced by use of the following verification tests.

a) On each of the circuit-breakers (with an original operating mechanism and with an alternative operating mechanism) a no-load close-open operating cycle shall be performed. For each of the tests the course of the contact stroke shall be recorded. The course of the contact stroke during the test with the original mechanism shall be used as the reference (see figure 23a). The curves obtained during opening and closing with the alternative operating mechanism shall be within the two envelope curves as described in 6.101.1.1 from the instant of contact separation or contact touch respectively to the end of the contact travel.
b) On each of the circuit-breakers a breaking operation according to test-duty T100s, without TRV at any convenient test voltage, and with the longest arcing time shall be performed. The test shall be evaluated according to the method prescribed under a) above.

NOTE It is sufficient to perform the verification test under b) with one frequency (50 Hz or 60 Hz).

6.102.8 Behaviour of circuit-breaker during tests

During making and breaking tests, the circuit-breaker shall not

– show signs of distress;
– show harmful interaction between poles;
– show harmful interaction with adjacent laboratory equipment;
– exhibit behaviour which could endanger an operator.

For circuit-breakers which are designed to have discharge of interrupting medium to atmosphere during the making and breaking tests, the above requirements are considered to have been met, provided

– for oil circuit-breakers, there is no outward emission of flame, and the gases produced, together with the oil carried with the gases, shall be conducted from the circuit-breaker and directed away from all live conductors and locations where persons may be present;
– for other types of circuit-breakers, such as air blast or air break, there is an outward emission of flame, gas and/or metallic particles. If such emissions are appreciable it may be required that the tests shall be made with metallic screens placed in the vicinity of the live parts and separated from them by a safety clearance distance which the manufacturer shall specify. The screens shall be insulated from earth but connected thereto by a suitable device to indicate any significant leakage current to earth. There shall be no indication of significant leakage currents to the circuit-breaker earthed structure, or screens when fitted, during the tests.

NOTE 1 If no other devices are available, the earthed parts, etc. should be connected to earth through a fuse consisting of a copper wire of 0,1 mm diameter and 5 cm long. No significant leakage is assumed to have occurred if this fuse wire is intact after the test.

If faults occur which are not persistent or due to defect in design, but rather are due to errors in assembly or maintenance, the faults can be rectified and the circuit-breaker subjected to the repeated test-duty concerned. In those cases, the test report shall include reference to the invalid tests.

Non-sustained disruptive discharges (NSDD, for vacuum circuit-breakers only, see 3.1.126) may occur during the recovery voltage period following a breaking operation. Discharges during the TRV period are not considered to be a NSDD. Discharges are considered NSDD(s) if they occur later than one-quarter of a cycle of the power frequency after current interruption in the last two poles to clear. Earlier discharges are considered to form part of the arc extinguishing process.

During capacitive current switching tests in a three-phase test circuit with isolated neutral, a discharge which occurs later than one-quarter of a cycle and up to one half-cycle of the power frequency after current interruption will be treated as a restrike and is not considered to be a NSDD.

NOTE 2 An explanatory note is given in I.3.

If a NSDD occurs

– a maximum of three occurrences of NSDDs are permitted during the entire type test series of short-circuit tests including any test-duties which are repeated or restarted.
– in case of capacitive current switching tests a maximum number of NSDDs corresponding to one-ninth of the number of breaking operations is permitted during the individual test series, for example line-charging current switching tests;
– in any case, when there are multiple occurrences of the phenomenon during one test, they shall be counted individually;
– resumption of the power frequency current triggered by a NSDD is not allowed, even though it may only result in a single loop of current flow;
– the test report shall include reference to the NSDDs and test-duty in which they occurred.

6.102.9 Condition of circuit-breaker after tests

6.102.9.1 General

The circuit-breaker may be inspected after any test-duty. Its mechanical parts and insulators shall be in essentially the same condition as before the test-duty. Visual inspection is usually sufficient for verification of the insulating properties. In case of doubt, the condition checking test according to 6.2.11 is sufficient to prove the insulation properties.

For circuit-breakers with sealed-for-life interrupter units, the condition checking test is mandatory, except as stated in 6.102.9.4.

6.102.9.2 Condition after a short-circuit test-duty

After each short-circuit test-duty, the circuit-breaker shall be capable of making and breaking its rated normal current at the rated voltage, although its short-circuit making and breaking performance may be impaired. After test-duty L_{90} a condition checking test according to 6.2.11 shall be performed. If test-duty L_{90} is not performed, the condition checking test shall be carried out after test-duty T100s.

The main contacts shall be in such a condition, in particular with regard to wear, contact area, pressure and freedom of movement, that they are capable of carrying the rated normal current of the circuit-breaker without their temperature rise exceeding by more than 10 K the values specified for them in table 3 of IEC 60694.

NOTE Experience shows that an increase of the voltage drop across the circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

Contacts shall be considered as "silver-faced" only if there is still a layer of silver at the contact points after any of the short-circuit test-duties; otherwise, they shall be treated as "not silver-faced" (see 4.4.3, point 6 of IEC 60694).

In order to check the operation of the circuit-breaker after testing, no-load operations shall be made, if change of contacts or other kinds of maintenance are intended to be performed after the test-duty. These shall be compared with the corresponding operations made in accordance with 6.102.6 and shall show no significant change.

6.102.9.3 Condition after a short-circuit test series

In order to check the operation of the circuit-breaker after test, no-load closing and opening operations shall be made at the completion of the entire series of short-circuit tests. These shall be compared with the corresponding operations made in accordance with 6.102.6 and shall show no significant change. The requirements of 6.101.1.1 shall be fulfilled. The circuit-breaker shall close and latch satisfactorily.

It is recognised that the rated short-circuit current making, breaking and carrying capability will have been impaired, but degradation of the components in the current-carrying path shall not reduce the integrity of the insulating or the mechanically supporting components of the circuit-breaker. With regard to the main contacts the relevant provisions of 6.102.9.2 apply.

No criteria can be given for the acceptable level of degradation for the fluid insulation (gas, oil, air etc.) as their required strength is linked to the design criteria of each individual type of circuit-breaker.

6.102.9.4 Condition after a capacitive current switching test series

The circuit-breaker shall, after performing the line-charging, cable-charging and capacitor bank current switching test series specified in 6.111.9, and before reconditioning, be capable of operating satisfactorily at any making and breaking current up to its rated short-circuit making and breaking current at rated voltage.

In addition the circuit-breaker shall be capable of carrying its rated normal current with a temperature rise not in excess of the temperature rise permitted by table 3 of IEC 60694. In case of class C2 circuit-breakers the temperature rise shall not exceed the values permitted by table 3 of IEC 60694 by more than 10 K.

There shall be no evidence of puncture, flashover or tracking of the internal insulating materials, except that moderate wear of the parts of arc control devices exposed to the arc is permissible.

Degradation of the components in the current carrying path shall not reduce the integrity of the normal current carrying path.

If, during the capacitive current switching tests, one restrike occurred, the dielectric condition checking test according to 6.2.11 shall be performed before visual inspection, provided that the tested peak recovery voltage during the capacitive current switching tests is lower than the peak voltage of the specified dielectric condition checking test. The subsequent visual inspection shall demonstrate that the restrike occurred between the arcing contacts only. There shall be no evidence of puncture, flashover or permanent tracking of internal insulating materials. Wear of the parts of arc control devices exposed to the arc is permissible as long as it does not impair the breaking capability. Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a restrike.

If no restrike occurred during the capacitive current switching tests visual inspection is sufficient. The dielectric condition checking test according to 6.2.11 shall not be performed.

Where further tests are performed on the same pole, the dielectric condition checking test shall be performed after the capacitive current switching test. If no restrike occurred during the capacitive current switching test, this dielectric condition checking test need not be performed, and the condition checking test may be performed after the additional tests.

NOTE If the circuit-breaker fails during the additional tests, this procedure may make the capacitive current switching tests invalid.

For circuit-breakers with sealed-for-life interrupter units, the dielectric condition checking test according to 6.2.11 shall be performed, whether a restrike occurs during testing or not, provided that the tested peak recovery voltage during the capacitive current switching tests is lower than the peak voltage of the specified dielectric condition checking test.

6.102.9.5 Reconditioning after a short-circuit test-duty and other test series

It may be necessary to carry out maintenance work on the circuit-breaker after performing a short-circuit test-duty or other test series in order to restore it to the original condition specified by the manufacturer. For example, it may be necessary to

a) repair or replace the arcing contacts and any other renewable parts recommended by the manufacturer;
b) renew or filter of the oil, or any other extinguishing medium, and add any quantity of the medium necessary to restore its normal level or density;
c) remove deposit, caused by the decomposition of the extinguishing medium, from internal insulation.

A class E2 circuit-breaker shall not be reconditioned during the basic short-circuit test-duties, given in 6.106.

6.102.10 Demonstration of arcing times

It is preferred that the sequence for performing the three valid breaking operations is such that the last breaking operation results in a medium arcing time. The procedures described in this subclause are relevant for the adjustment of prospective arcing times. The actual arcing times may vary from the prospective ones. Tests are valid as long as the actual arcing times are within the tolerances given in annex B.

For circuit-breakers with the rated operating sequence CO - t'' - CO, one CO shall demonstrate the minimum arcing time and the other one shall demonstrate the maximum arcing time.

The terminal fault tests T100a in 6.102.10.1.2, 6.102.10.2.1.2 and 6.102.10.2.2.2 consist of three valid operations independent of the rated operating sequence. After the number of operations provided for in accordance with the rated operating sequence the circuit-breaker may be reconditioned in accordance with 6.102.9.5.

NOTE The arcing times prescribed in this subclause are adequate to cover the effect of the unintentional non-simultaneity of the circuit-breaker poles.

6.102.10.1 Three-phase tests

The procedures given below are for direct tests. Where synthetic tests are performed it is necessary to establish the minimum arcing time for the first phase to clear before starting the sequence. The method of establishing this minimum arcing time is given in 6.102.10.2.

6.102.10.1.1 Test-duty T10, T30, T60, T100s, T100s(b), OP1 and OP2

For these tests the tripping impulse shall be advanced by 40 electrical degrees (40°) between each opening operation. For T100s(b), see note in 6.106.

A graphical representation of the three valid breaking operations for the first-pole-to-clear factor 1,5 is given in figure 29 and for the first-pole-to-clear factor 1,3 in figure 30.

6.102.10.1.2 Test-duty T100a

Since the severity of the tests for this test-duty can vary widely depending on the moment of contact separation, a procedure has been developed in order to arrive at realistic stresses on the circuit-breaker under test. The intention is to arrive at a series of three valid tests. The initiation of the short-circuit changes 60° between tests in order to transfer the required d.c. component at the moment of contact separation from phase to phase.

Furthermore it is the intention to have, at least once during the test series, a first-phase-to-clear condition in the phase with the required d.c. component in order to comply with the TRV requirements. This test is valid if, in this phase, the current is interrupted after arcing during a full major loop, or the greatest possible part thereof. Since some circuit-breakers will not clear after a major loop, a test is still valid if arcing goes on during a subsequent minor loop. However, if the circuit-breaker clears in the phase with the required d.c. component after a foreshortened major loop, or after a minor loop without arcing during a preceding major loop, or the greatest possible part thereof, the test shall be considered invalid.

The procedure is as follows.

For the first valid operation the initiation of short circuit and the setting of the control of the tripping impulse shall be such that

- the required d.c. component at contact separation is obtained in one phase;
- arc extinction occurs in the phase with the required d.c. component after a major loop (or the greatest possible part of that loop) in the case of the first-phase-to-clear or after a major extended loop (or the greatest possible part of that loop) in the case of one of the last phases-to-clear.

For the second valid operation, the initiation of short circuit shall be advanced by 60° and the setting of the control of the tripping impulse shall be as follows:

- if the first operation was valid because the arc extinction occurred in the phase with the required d.c. component after a major loop, the setting of the control of the tripping impulse shall be advanced by 130° with respect to the first valid operation;
- if the first operation was valid because the arc extinction occurred in the phase with the required d.c. component after a major extended loop, then the setting of the control of the tripping impulse shall be advanced by 25° with respect to the first valid operation.

For the third operation, the procedure for the second operation may be repeated. The initiation of short-circuit shall be advanced by 60° with respect to the second operation and the setting of the control of the tripping impulse shall be as follows:

– if the second operation was valid because the arc extinction occurred in the phase with the required d.c. component after a major loop, the setting of the control of the tripping impulse shall be advanced by 130° with respect to the second operation;

– if the second operation was valid because the arc extinction occurred in the phase with the required d.c. component after a major extended loop, the setting of the control of the tripping impulse shall be advanced by 25° with respect to the second operation.

A graphical representation of the three valid breaking operations for the first-pole-to-clear factor 1,5 is given in figure 31 and for the first-pole-to-clear factor 1,3 in figure 32.

If the characteristics of the circuit-breaker are not constant, it may be necessary to use other procedures to achieve the three valid operations described above. If it is not possible to achieve the above requirements because of the characteristics of the circuit-breaker, the number of operations shall be extended to prove that, in this particular case, the most severe test conditions have been achieved. The circuit-breaker should not be subjected to more than six opening operations when attempting to meet the above requirements. The circuit-breaker may have its renewable parts replaced before the extended operations.

6.102.10.2 Single-phase tests in substitution for three-phase conditions

The procedures given below are partly derived from synthetic test methods. Where direct tests are performed the procedure for establishing a minimum arcing time might result in a valid test with maximum arcing time or with an arcing time in excess of the maximum arcing time.

The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear and the last pole-to-clear for each test-duty in one test circuit.

The following procedures are applicable if all operations of the rated operating sequence fulfil the requirements of 5.101. If not, caution shall be exercised when using the following tables 10, 11 and 12.

6.102.10.2.1 Systems other than solidly earthed

6.102.10.2.1.1 Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2

The first valid breaking operation shall demonstrate interruption with an arcing time as small as possible. The resultant arcing time is known as the minimum arcing time ($t_{\mathrm{arc\,min}}$). This is established when any extra delay in the contact separation with respect to the current waveform results in interruption at the next current zero. This minimum arcing time is found by changing the setting of the tripping impulse by steps of 18° (dα).

The second valid breaking operation shall demonstrate interruption with the maximum arcing time. The required maximum arcing time is known as $t_{\mathrm{arc\,max}}$ and is determined by:

$$t_{\mathrm{arc\,max}} \geq t_{\mathrm{arc\,min}} + T\,\frac{150° - \mathrm{d}\alpha}{360°}$$

where

$t_{\mathrm{arc\,min}}$ is the minimum arcing time obtained from the first valid operation;

dα = 18°;

T is one period of the power frequency.

This is normally achieved by setting the tripping impulse at least (150° – dα) earlier than that of the first valid breaking operation.

The third valid breaking operation shall demonstrate interruption with an arcing time which is approximately equal to the average value of those of the first and second valid breaking operations. This arcing time is known as the medium arcing time ($t_{\text{arc med}}$) and is determined by

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

The tripping impulse for the third valid breaking operation shall be delayed by 75° (± 18°) from that of the second valid breaking operation.

Figure 33 gives a graphical representation of the three valid breaking operations.

6.102.10.2.1.2 Test-duty T100a

a) Arcing times

The first valid breaking operation shall demonstrate interruption at the end of the minor loop with an arcing time as small as possible. The resultant arcing time is known as the minimum arcing time ($t_{\text{arc min}}$). This is established when any extra delay in the contact separation with respect to the current waveform results in interruption at the next current zero which will be at the end of a major loop. This minimum arcing time is found by changing the setting of the tripping impulse by steps of 18° (dα).

The second valid breaking operation shall demonstrate interruption with the maximum arcing time. The required maximum arcing time $t_{\text{arc max}}$ is determined by:

$$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T\frac{30° + \mathrm{d}\alpha}{360°}$$

where the time interval Δt_1 is the duration of the major loop given in tables 10 and 11.

The time interval Δt_1 is a function of the system circuit time constant (τ), the rated frequency of the system and the opening time of the circuit-breaker. The time interval Δt_1 shall be equal to or greater than the duration of the subsequent major loop (on the appropriate asymmetrical current waveform) which will occur after a time made up of the sum of the relay time of the system protection and the opening time of the circuit-breaker.

Interruption shall occur after a major loop or after the subsequent minor loop if the circuit-breaker failed to interrupt after the required major loop. This is achieved by setting the tripping impulse later than that of the first valid breaking operation.

Tables 10 and 11 consider a relay time of one half-cycle of the rated frequency (10 ms at 50 Hz and 8,3 ms at 60 Hz). If the circuit-breaker fails to interrupt after the required major loop and interrupts after the subsequent minor loop, the required maximum arcing time is extended by the duration of the appropriate minor loop (Δt_2) given in tables 10 and 11.

The third valid breaking operation shall demonstrate interruption with an arcing time which is approximately equal to the average value of those of the first and second valid breaking operations. This arcing time is known as the medium arcing time ($t_{\text{arc med}}$) and is determined by

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

This interruption shall also occur after a major loop or after the subsequent minor loop if the circuit-breaker failed to interrupt after the required major loop.

The tripping impulse for the third valid breaking operation shall be delayed from that of the second valid breaking operation in order to achieve this arcing time.

Figure 34 gives a graphical representation of the three valid breaking operations.

b) Short-circuit current during arcing interval

If the time constant of the test circuit is different from the specified time constant, breaking operations are valid if the following conditions are met:

– the prospective peak short-circuit current during the last loop prior to the interruption shall be between 90 % and 110 % of the required value;

– the prospective duration of the short-circuit current loop prior to the interruption shall be between 90 % and 110 % of the required value.

Tables 10 and 11 give required values of the peak short-circuit current and loop durations that should be attained by the last loop prior to the interruption.

Table 10 – Current peak values and current loop durations during the arcing period for 50 Hz operation in relation with short-circuit test-duty T100a

	Opening time	τ = 45 ms		τ = 60 ms		τ = 75 ms		τ = 120 ms	
	ms	$\hat{I}$ p.u.	Δt_1 ms	$\hat{I}$ p.u.	Δt_1 ms	$\hat{I}$ p.u.	Δt_1 ms	$\hat{I}$ p.u.	Δt_1 ms
Major loop	$0 < t \leq 12{,}5$	1,51	13,5	1,61	14,0	1,67	15,0	1,78	15,5
	$12{,}5 < t \leq 33{,}0$	1,33	12,5	1,44	13,0	1,51	13,5	1,66	14,5
	$33{,}0 < t \leq 53{,}5$	1,21	11,5	1,31	12,0	1,39	12,5	1,56	14,0
	ms	$\hat{I}$ p.u.	Δt_2 ms	$\hat{I}$ p.u.	Δt_2 ms	$\hat{I}$ p.u.	Δt_2 ms	$\hat{I}$ p.u.	Δt_2 ms
Minor loop	$0 < t \leq 12{,}5$	0,36	5,5	0,28	5,0	0,23	4,5	0,16	3,5
	$12{,}5 < t \leq 33{,}0$	0,59	7,0	0,49	7,0	0,41	6,0	0,28	5,0
	$33{,}0 < t \leq 53{,}5$	0,74	8,5	0,63	8,0	0,55	6,5	0,40	6,0

$\hat{I}$ p.u. value of the peak current related to the peak value of the short-circuit current.

Δt_1 duration of major loop (rounded to 0,5 ms).

Δt_2 duration of minor loop (rounded to 0,5 ms).

τ system circuit time constant.

All values in table 10 have been calculated with a protection relay time of 10 ms.

Table 11 – Current peak values and current loop durations during the arcing period for 60 Hz operation in relation with short-circuit test-duty T100a

	Opening time ms	τ = 45 ms		τ = 60 ms		τ = 75 ms		τ = 120 ms	
		$\hat{I}$ p.u.	Δt_1 ms	$\hat{I}$ p.u.	Δt_1 ms	$\hat{I}$ p.u.	Δt_1 ms	$\hat{I}$ p.u.	Δt_1 ms
Major loop	$0 < t \leq 10{,}0$	1,57	11,0	1,66	12,0	1,72	12,5	1,81	13,5
	$10{,}0 < t \leq 27{,}5$	1,39	10,0	1,50	11,0	1,57	11,5	1,70	12,5
	$27{,}5 < t \leq 44{,}5$	1,27	9,5	1,38	10,5	1,46	11,0	1,61	12,0
	ms	$\hat{I}$ p.u.	Δt_2 ms	$\hat{I}$ p.u.	Δt_2 ms	$\hat{I}$ p.u.	Δt_2 ms	$\hat{I}$ p.u.	$\Delta t2$ ms
Minor loop	$0 < t \leq 10{,}0$	0,31	5,0	0,24	4,0	0,20	3,5	0,13	2,5
	$10{,}0 < t \leq 27{,}5$	0,52	6,0	0,42	5,0	0,36	4,5	0,24	3,5
	$27{,}5 < t \leq 44{,}5$	0,67	6,5	0,57	6,0	0,49	6,0	0,34	4,5

$\hat{I}$ p.u. value of the peak current related to the peak value of the short-circuit current.

Δt_1 duration of major loop (rounded to 0,5 ms).

Δt_2 duration of minor loop (rounded to 0,5 ms).

τ system circuit time constant.

All values in table 11 have been calculated with a protection relay time of 8,3 ms.

NOTE The system circuit time constant τ = 45 ms is the standard time constant, τ = 60 ms, 75 ms and 120 ms are the special case time constants according to 4.101.2.

6.102.10.2.2 Solidly earthed neutral systems including short-line fault tests

6.102.10.2.2.1 Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2, L_{90}, L_{75} and L_{60}

The procedure to obtain the three valid breaking operations is the same as the one described for isolated neutral systems, with the following modifications:

The required maximum arcing time shall be:

$$t_{\text{arc max}} \geq t_{\text{arc min}} + T\,\frac{180° - \text{d}\alpha}{360°}$$

This is normally achieved by having the tripping impulse at least (180° – dα) earlier than that of the first valid breaking operation.

The third valid breaking operation shall demonstrate interruption with an arcing time which is approximately equal to the average value of those of the first and second valid breaking operations. This arcing time is determined by

$$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}})/2$$

The third valid breaking operation is achieved by having the tripping impulse 90° (±18°) later than that of the second valid breaking operation.

Figure 35 gives the graphical representation of the three valid breaking operations.

6.102.10.2.2.2 Test-duty T100a

The procedure to obtain the three valid breaking operations is the same as the one described for isolated neutral systems, with the following modifications.

The required maximum arcing time shall be

$$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times \frac{\mathrm{d}\alpha}{360°}$$

where Δt_1 is given in tables 10 and 11.

Figure 36 gives the graphical representation of the three valid breaking operations.

6.102.10.2.3 Modified procedure in cases where the circuit-breaker failed to interrupt during a test with a medium arcing time

6.102.10.2.3.1 Breaking test with symmetrical current

If the circuit-breaker does not interrupt at the expected current zero during a breaking test with symmetrical current with a medium arcing time then it is necessary to perform one or two additional tests.

a) Direct tests

Two cases shall be considered:

– For k_{pp} = 1,3 (systems with solidly earthed neutral)

If the circuit-breaker does not interrupt with the prospective medium arcing time but at a subsequent current zero, the arcing time on such a test would be known as the "ultimate maximum arcing time" $t_{\text{arc ult max}}$. This test is valid if the circuit-breaker is able to interrupt during an additional test with the "new minimum arcing time", which shall be 18° longer than the prospective medium arcing time. In this case this single additional test is sufficient with the setting of the tripping impulse advanced by 18°.

– For k_{pp} = 1,5 (systems with non-solidly earthed neutral)

If the circuit-breaker has not interrupted with the prospective medium arcing time and at the subsequent current zero, two additional tests are necessary:

i) one with the "new minimum arcing time" $t_{\text{arc new min}}$, which shall be 18°longer than the prospective medium arcing time,

ii) another one with the "new maximum arcing time", which shall be 150° longer than the "new minimum arcing time". This test may necessitate a forced re-ignition circuit at the preceding current zero crossing.

b) Synthetic tests

The first valid additional test shall demonstrate interruption at the "new minimum arcing time" $t_{\text{arc new min}}$. This is found when any extra advancement in contact separation with respect to the current waveform from that for the test at medium arcing time results in a successful interruption. The "new minimum arcing time" is found by changing the setting of the tripping impulse by steps of 18° (dα).

The second valid breaking operation shall demonstrate interruption with the "ultimate maximum arcing time" $t_{\text{arc ult max}}$ which is:

$$t_{\text{arc ult max}} \geq t_{\text{arc new min}} + T\frac{150° - \mathrm{d}\alpha}{360°} \quad \text{if } k_{\text{pp}} = 1{,}5$$

$$t_{\text{arc ult max}} \geq t_{\text{arc new min}} + T\frac{180° - \mathrm{d}\alpha}{360°} \quad \text{if } k_{\text{pp}} = 1{,}3 \text{ or } 1{,}0$$

where

$t_{arc\ new\ min}$ is the "new“ minimum arcing time;

$t_{arc\ ult\ max}$ is the "ultimate“ maximum arcing time;

$d\alpha$ = 18°.

If the circuit-breaker fails during the second additional test, it is permissible to carry out maintenance work on the circuit-breaker according to 6.102.9.5 and repeat the test-duty by starting with a minimum arcing time which is greater than the failed medium arcing time.

6.102.10.2.3.2 Breaking test with asymmetrical current

If the circuit-breaker does not interrupt at the expected current zero after a major loop, during a breaking test with asymmetrical current (test-duty T100a) and with a medium arcing time, then it shall interrupt after the subsequent minor loop.

6.102.10.2.4 Tests combining the conditions for isolated and earthed neutral systems

Both conditions, isolated neutral systems (6.102.10.2.1) and earthed neutral systems (6.102.10.2.2), may be combined in one test series. The transient and power frequency voltages to be used shall be those applicable to an isolated neutral system and the arcing times shall be those applicable to an earthed neutral system.

6.102.10.2.5 Splitting of test-duties in test series taking into account the associated TRV for each pole-to-clear

It is recognised that single-phase tests in substitution of three-phase conditions are more severe than three-phase tests because the arcing time of the last-pole-to-clear is used together with the TRV of the first-pole-to-clear. As an alternative, the manufacturer may choose to split each test-duty into two or three separate test series, each test series demonstrating a successful interruption with the minimum, maximum and medium arcing time for each pole-to-clear with its associated TRV. The standard multipliers for the TRV values for the second and third clearing poles for rated voltages above 72,5 kV are given in table 2.

Reconditioning of the circuit-breaker after each test series is permitted and shall comply with the requirements of 6.102.9.5.

Assuming that the simultaneity of poles during all operations of the rated operating sequence is within the tolerances of 5.101, for tests with symmetrical current the interrupting window for each phase is within the band stated in table 12, if the instant of interruption for the first clearing pole with the minimum arcing time is taken as reference. A graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, is given in figure 37 for systems with a first-pole-to-clear factor of 1,3 and in figure 38 for systems with a first-pole-to-clear factor of 1,5.

Table 12 – Interrupting window for tests with symmetrical current

First-pole-to-clear factor	First clearing pole °	Second clearing pole °	Third clearing pole °
1,5	0 – 42	90 – 132	90 – 132
1,3	0 – 42	77 – 119	120 – 162

6.103 Test circuits for short-circuit making and breaking tests

6.103.1 Power factor

The power factor in each phase shall be determined in accordance with one of the methods described in annex D.

The power factor of a three-phase circuit shall be taken as the average of the power factors in each phase.

During the tests, this average value shall not exceed 0,15.

The power factor of any phase shall not vary from the average by more than 25 % of the average.

6.103.2 Frequency

Circuit-breakers shall be tested at rated frequency with a tolerance of ±8 %.

However, for convenience of testing, some deviations from the above tolerance are allowable; for example, when circuit-breakers rated at 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the results, taking into account all significant facts such as the type of the circuit-breaker and the type of test performed.

6.103.3 Earthing of test circuit

The connections to earth of the test circuit for short-circuit making and breaking tests shall be in accordance with the following requirements and shall, in all cases, be indicated in the diagram of the test circuit included in the test report (see item g) of C.2.4).

a) Three-phase tests of a three-pole circuit-breaker, first-pole-to-clear factor 1,5:

   The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in figure 25a, or vice versa as shown in figure 25b, if the test can only be made in the latter way.

   These test circuits give a first-pole-to-clear factor of 1,5.

   In accordance with figure 25a, the neutral of the supply source may be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U/10$, where U is the numerical value in volts of the voltage between lines of the test circuit.

   When a test circuit according to figure 25b is used, it is recognised that in case of an earth fault at one terminal of the test circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through an appropriate impedance.

b) Three-phase tests of a three-pole circuit-breaker, first-pole-to-clear factor 1,3:

   The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply connected to earth by an appropriate impedance and the short-circuit point earthed as shown in figure 26a, or vice versa as shown in figure 26b, if the test can only be made in the latter way.

   The impedance in the neutral connection shall be selected appropriate to a first-pole-to-clear factor of 1,3. Assuming $Z_0 = 3{,}25 \cdot Z_1$ the appropriate value of the impedance in the neutral connection is 0,75 times the phase impedance.

NOTE 1 For circuit-breakers to be used in systems with a first-pole-to-clear factor lower than 1,3, it may be necessary to lower the value of the impedance between the neutral point and the earth to satisfy the breaking current conditions in the second and third pole-to-clear. Care should be taken for the TRVs for all three poles.

NOTE 2 The test circuit shown in figure 26b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in IEC 61633.

c) Single-phase tests of a single pole of a three-pole circuit-breaker with a first-pole-to-clear factor 1,5:

   The test circuit and the circuit-breaker structure shall be connected as in figure 27a, so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in figure 25a.

   The preferred test circuit is shown in figure 27a. Where there are limitations on test station equipment, then the circuit shown in figure 27b may be used.

NOTE 3 The test circuit shown in figure 27b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in IEC 61633.

d) Single-phase tests of a single pole of a three-pole circuit-breaker with a first-pole-to-clear factor 1,3:

   The test circuit and the circuit-breaker structure shall be connected as in figure 28a, so that the voltage conditions between live parts and the structure after arc extinction are approximately the same as those that would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in figure 26a.

   The preferred test circuit is shown in figure 28a. Where there are limitations on test station equipment, then the circuit shown in figure 28b may be used.

NOTE 4 The test circuit shown in figure 28b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in IEC 61633.

e) Single-phase tests of a single-pole circuit-breaker:

   The test circuit and the circuit-breaker structure shall be connected so that the voltage conditions between live parts and earth within the circuit-breaker after arc extinction reproduce the service voltage conditions. The connections used shall be indicated in the test report.

6.103.4 Connection of test circuit to circuit-breaker

Where the physical arrangement of one side of the circuit-breaker differs from that of the other side, the live side of the test circuit shall be connected for testing to that side of the circuit-breaker which gives the more severe conditions with respect to voltage to earth, unless the circuit-breaker is especially designed for feeding from one side only.

Where it cannot be demonstrated satisfactorily which connection gives the more severe conditions, test-duties T10 and T30 (6.106.1 and 6.106.2) shall be made with opposite connections, and likewise for test-duties T100s and T100a. If test-duty T100a is omitted, test-duty T100s shall be made with each of the two connections.

6.104 Short-circuit test quantities

6.104.1 Applied voltage before short-circuit making tests

For the short-circuit making tests of 6.106.4, the applied voltage shall be as follows.

a) For three-phase tests on a three-pole circuit-breaker, the average value of the applied voltages phase-to-phase shall not be less than the rated voltage U_r and shall not exceed this value by more than 10 % without the consent of the manufacturer.

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

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

NOTE With the manufacturer's consent it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

   Where the circuit-breaker can be arranged for a single-pole reclosing cycle and the maximum time difference between the contacts touching in a subsequent three-pole closing operation exceeds one-quarter of a cycle of rated frequency (compare with the note of 5.101), the applied voltage shall be the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

c) For a single-pole circuit-breaker, the applied voltage shall not be less than the rated voltage and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   When performing synthetic tests IEC 60427 applies, see also 6.106.4.1 a), 6.106.4.2 a) and 6.106.4.3.

6.104.2 Short-circuit making current

6.104.2.1 General

The ability of the circuit-breaker to make the rated short-circuit making current is proven in test-duty T100s (see 6.106.4).

The circuit-breaker shall be able to make the current with pre-strike of the arc occurring at any point on the voltage wave. Two extreme cases are specified as follows (see figure 1):

– making at the peak of the voltage wave, leading to a symmetrical short-circuit current and the longest pre-striking arc;
– making at the zero of the voltage wave, without pre-striking, leading to a fully asymmetrical short-circuit current.

The test procedure as outlined below aims to demonstrate the ability of the circuit-breaker to fulfil the following two requirements:

a) the circuit-breaker can close against a symmetrical current as a result of the pre-arcing commencing at a peak of the applied voltage. This current shall be the symmetrical component of the rated short-circuit breaking current (see 4.101);
b) the circuit-breaker can close against a fully asymmetrical short-circuit current. This current shall be the rated short-circuit making current (see 4.103).

   A circuit-breaker shall be able to operate at voltages below its rated voltage (see item a) of 4.101) at which it actually makes with a fully asymmetrical current. The lower limit of voltage, if any, shall be stated by the manufacturer.

NOTE 1 The short-circuit current is considered to be symmetrical, if the current flow commences within ± 15 ° of the peak value of the applied voltage.

NOTE 2 For circuit-breakers having a pre-arcing time exceeding 10 ms, more than two making operations may be necessary to meet the most onerous condition.

NOTE 3 Due to unintentional non-simultaneity of poles, the instants of contact touching during closing may differ such as to provoke an even higher peak making current in one pole (see also 5.101). This is particularly the case if, in one pole, the current begins to flow about one-quarter of a cycle later than in the other two poles, provided that there is no pre-arcing. Failure of the circuit-breaker during such an event is considered a failure of a circuit-breaker to satisfy the test-duty.

6.104.2.2 Test procedure

6.104.2.2.1 Three-phase tests

For three-phase tests on a three-pole circuit-breaker it is assumed that the requirements outlined in a) and b) above are adequately demonstrated during the test-duty T100s.

The control of the timing shall be such that at least in one of the two close-open (CO) cycles of test-duty T100s the rated short-circuit making current is obtained.

Where a circuit-breaker exhibits pre-arcing to such an extent that the rated short-circuit making current is not attained during the first CO operating cycle of test-duty T100s and, even after adjustment of the timing, the rated short-circuit making current is not achieved during the second CO operating cycle, a third CO operating cycle shall be carried out at reduced voltage. Before this operating cycle, the circuit-breaker may be reconditioned.

6.104.2.2.2 Single-phase tests

For single-phase tests, test-duty T100s or T100s(a) shall be carried out in such a way that the requirement outlined in a) of 6.104.2.1 is met in one and that of b) of 6.104.2.1 in the other closing operation. The sequence of these operations is not specified. If during test-duty T100s or T100s(a) (see note at 6.106) one of the requirements outlined in a) and b) has not been adequately demonstrated, an additional CO operating cycle is necessary. Before this operating cycle the circuit-breaker may be reconditioned.

The additional CO operating cycle shall, depending on the results obtained during the normal test-duty T100s or T100s(a), demonstrate either

– requirements in a) or b) of 6.104.2.1, or
– evidence that the short-circuit making currents attained are representative of the conditions to be met in service due to the pre-arcing characteristics of the circuit-breaker.

If, during the test-duty T100s or T100s(a), the rated short-circuit making current has not been attained due to the characteristics of the circuit-breaker, the additional CO test may be made at a lower applied voltage.

If during the test-duty T100s or T100s(a) no symmetrical current has been obtained, as required in a) above, the additional CO test may be made at an applied voltage within the margins stated in 6.104.1.

6.104.3 Short-circuit breaking current

The short-circuit current to be interrupted by a circuit-breaker shall be determined at the instant of contact separation in accordance with figure 8, and shall be stated in terms of the following two values:

– the average of the r.m.s. values of the a.c. components in all phases;
– the percentage value of the maximum d.c. component in any phase.

The r.m.s. value of the a.c. component in any phase shall not vary from the average by more than 10 %.

Although the short-circuit breaking current is measured at the instant corresponding to contact separation, the breaking performance of the circuit-breaker is determined, among other factors, by the current which is finally interrupted in the last loop of arcing. The decrement of the a.c. component of the short-circuit current is therefore very important, particularly when testing those circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the a.c. component of the short-circuit current should be such that at a time corresponding to the final extinction of the main arc in the last pole to clear, the a.c. component of the prospective current is not less than 90 % of the appropriate value for the test-duty. This shall be proven by a record of the prospective current before commencing the tests.

If the characteristics of the circuit-breaker are such that it reduces the short-circuit current value below the prospective breaking current, or if the oscillogram is such that the current wave envelope cannot be drawn successfully, the average prospective short-circuit breaking current in all phases shall be used as the short-circuit breaking current and shall be measured from the oscillogram of prospective current at a time corresponding to the instant of contact separation.

The instant of contact separation can be determined according to the experience of the testing station and the type of apparatus under test by various methods, for instance, by recording the contact travel during the test, by recording the arc voltage or by a test on the circuit-breaker at no-load.

6.104.4 DC component of short-circuit breaking current

For circuit-breakers which operate in opening times preventing the control of the d.c. component, for example self-tripping circuit-breakers when in a condition for test as set out in 6.102.3, the d.c. component may be greater than that specified for test-duties T10, T30, T60 and T100s of 6.106.

Circuit-breakers shall be considered to have satisfied test-duty T100a, even if the percentage d.c. component in one opening operation is less than the specified value, provided that the average of the percentage d.c. components of the opening operations of the test-duty exceeds the specified percentage d.c. component. In any one test of the test-duty, the d.c. component shall not be less than 90 % relative to the specified value.

If the oscillogram of any breaking operation is such that the current wave envelope cannot be drawn successfully, then provided that the instants of initiation of short-circuits are comparable, the prospective percentage d.c. component shall be taken as the percentage d.c. component at contact separation during the test. The percentage d.c. component shall be measured from the oscillogram of the prospective current at a time corresponding to the instant of contact separation.

6.104.5 Transient recovery voltage (TRV) for breaking tests

6.104.5.1 General

The prospective TRV of the test circuits shall be determined by such a method as will produce and measure the TRV wave without significantly influencing it. It shall be measured at the terminals to which the circuit-breaker will be connected with all necessary test-measuring devices, such as voltage dividers. Suitable methods are described in annex F (see also 6.104.6). In such cases where a measurement is not possible, for instance in certain synthetic test circuits, a calculation of the prospective TRV is allowed. Guidance is given in annex F.

For three-phase circuits, the prospective TRV refers to the first-pole-to-clear, i.e. the voltage across one open pole with the other two poles closed, with the appropriate test circuit arranged as specified in 6.103.3.

The prospective TRV for the test is represented by its envelope drawn as shown in annex E and by its initial portion.

The TRV specified for the test is represented by a reference line, a delay line and initial transient recovery voltage (ITRV) envelope in the same manner as the TRV related to the rated short-circuit breaking current in accordance with 4.102.2 and figures 10, 11 and 12.

TRV parameters are defined as follows as a function of the rated voltage (U_r), the first-pole-to-clear factor (k_{pp}) and the amplitude factor (k_{af}). The actual values of k_{pp} and k_{af} are stated in tables 1a, 1b, 1c, 13 and 14.

a) *For rated voltages below 100 kV*

A representation by two parameters of the prospective TRV is used for all test-duties.

- TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{2}/\sqrt{3}$ where k_{af} (amplitude factor) is equal to 1,4 for test-duty T100 and the supply side circuit for short-line fault, 1,5 for test-duties T60, T30 and T10, 1,25 for out-of-phase breaking.
- Time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.
- Time delay t_d for test-duty T100 is 0,15 t_3 for rated voltages lower than 48,3 kV, and 0,05t_3 for rated voltages 48,3 kV, 52 kV and 72,5 kV and for the supply side circuit for short-line fault. Time delay t_d is 0,15 t_3 for test-duties T60, T30 and T10 and for out-of-phase breaking.
- Voltage $u' = u_c/3$.
- Time t' is derived from u', u_c/t_3 and t_d according to figure 11.

b) *For rated voltages from 100 kV to 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100, T60, T30, L_{90}, L_{75}, OP1 and OP2, and by two parameters for test-duty T10.

- First reference voltage $u_1 = k_{pp} \times U_r \times \sqrt{2}/\sqrt{3}$.
- Time t_1 is derived from u_1 and the specified value of the rate of rise u_1/t_1.
- TRV peak value $u_c = k_{af} \times u_1$.where k_{af} (amplitude factor) is equal to 1,4 for test-duty T100 and for the supply side circuit for short-line fault, 1,5 for test-duty T60 and T30, 1,7×0,9 for test-duty T10 (a factor 0,9 is introduced to recognise that only 90 % (approximately) of the circuit voltage appears across the transformer assumed to supply the total short-circuit current at this level), 1,25 for out-of-phase breaking.
- Time t_2 is equal to 3t_1 for test-duty T100, for the supply side circuit for short-line fault and for out-of-phase breaking. Time t_2 is equal to 4,5t_1 for T60 and equal to 7,5t_1 for test-duty T30.
- For test-duty T10, time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3.
- Time delay t_d is between 2 μs and 0,21t_1 for test-duty T100, between 2 μs and 0,225t_1 for test-duty T60, between 5 μs and 0,225t_1 for test-duty T30 and 0,15t_3 for test-duty T10. For the supply side circuit for short-line fault the time delay is equal to 2 μs. For out-of-phase breaking the time delay is 0,1875t_1. The relevant value of t_d to be used for testing is given in 6.104.5.2 to 6.104.5.5.
- Voltage $u' = u_1/2$ for test-duties T100, T60, T30, for the supply side circuit for short-line fault and for out-of-phase breaking, and $u_c/3$ for test-duty T10.

– Time t' is derived from u', u_1/t_1 and t_d for test-duties T100, T60 and T30, for the supply side circuit for short-line fault and for out-of-phase breaking according to figure 10, and from u', u_c/t_3 and t_d for test-duty T10 according to figure 11.

The prospective transient recovery voltage wave of the test circuit shall comply with the following two requirements:

– Requirement a)

Its envelope shall at no time be below the specified reference line.

NOTE 1 It is stressed that the extent by which the envelope may exceed the specified reference line requires the consent of the manufacturer (see 6.104); this is of particular importance in the case of two-parameter envelopes when four-parameter reference lines are specified, and in the case of four-parameter envelopes when two-parameter reference lines are specified.

NOTE 2 For convenience of testing, test-duties T100, T60 and T30 for rated voltages 100 kV and above are allowed to be carried out with a two parameter TRV, provided that the rate of rise of the recovery voltage corresponds to the standard value u_1/t_1 and the voltage peak value to the standard value u_c. This procedure requires the consent of the manufacturer.

– Requirement b)

Its initial portion shall fulfil the specified ITRV requirements. The ITRV shall be handled like a short-line fault. Consequently it is necessary to measure the ITRV circuit independently of the source side in an inherent way. The ITRV is defined by the peak value u_1 and the time co-ordinate t_i (figure 12b). The inherent waveshape shall mostly follow a straight reference line drawn from the beginning of the ITRV to the point defined by u_i and t_i. The inherent ITRV waveshape shall follow this reference line from 20 % to 80 % of the required ITRV peak value. Deviations from the reference line are permitted for an ITRV amplitude below 20 % and 80 % of the specified ITRV peak value. It shall not be significantly higher than the above mentioned reference line. If 80 % of the value cannot be reached without significant increase of the rate of rise of the ITRV, it is preferred to raise the peak value u_i above the specified value in order to reach the 80 % point. The rate of rise of the ITRV shall not be increased, because this would be associated with a change of the impedance and thus to an essential change of the severity of the test.

Testing under ITRV conditions is necessary for T100a, T100s and L_{90}. 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).

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

These requirements are illustrated in figures 39 to 42.

6.104.5.2 Test-duties T100s and T100a

For rated voltages up to and including 72,5 kV, the specified standard values are given in table 13.

For rated voltages of 100 kV and above, the specified standard values are given in table 14.

The specific reference lines, delay lines and ITRV are given by the standard values in tables 1a, 1b, 1c, 2 and 3.

With reference to ITRV, if a test is made with a TRV following the straight reference line specified in requirement b) of 6.104.5.1 and shown in figure 12 b, it is assumed that the effect on the circuit-breaker is similar to that of any ITRV defined in requirement b) of 6.104.5.1 and figure 12 b.

Owing to limitations of the testing station, it may not be feasible to comply with the requirement of item b) of 6.104.5.1 with respect to the time delay t_d as specified in tables 1a, 1b or 1c. Where short-line fault duties are also to be performed, any such deficiency of the TRV of the supply circuit shall be compensated by an increase of the voltage excursion to the first peak of the line-side voltage (see 6.109.3). The time delay of the supply circuit shall be as small as possible, but shall in any case not exceed the values given in brackets in table 13 or table 14.

Where short-line fault duties are also to be performed, it may be convenient to combine the ITRV and SLF requirements in the line side circuit. When the ITRV is combined with the transient voltage of a short line having a time delay t_{dL} as specified in table 4, the total stress is, for practical considerations, equal to the stress of a short line with insignificant time delay. Therefore, the ITRV requirements for test-duties T100s and T100a are considered to be covered when the short-line fault duties are performed using a short line with insignificant time delay t_{dL} (see 6.109.3) unless both terminals are not identical from an electrical point of view (for instance, where an additional capacitance is used as mentioned in note 4 of 6.109.3).

6.104.5.3 Test-duty T60

For rated voltages up to and including 72,5 kV, the specified standard values are given in table 13.

For rated voltages of 100 kV and above, the specified standard values are given in table 14.

6.104.5.4 Test-duty T30

For rated voltages up to and including 72,5 kV, the specified standard values are given in table 13. For rated voltages of 100 kV and above, the specified standard values are given in table14.

In direct testing, it may be difficult to meet the small values of time t_3. The shortest time which can be met should be used but not less than the values specified. The values used shall be stated in the test report.

NOTE In view of the fact that the contribution of transformers to the short-circuit current is relatively larger at smaller values of short-circuit current, and even in earthed neutral systems of rated voltages of 100 kV to 170 kV, a comparatively large number of transformers with unearthed neutral are in service, the TRV specified for test-duties T30 and T10 are based on a first-pole-to-clear factor 1,5 for rated voltages of 100 kV to 245 kV. The same applies for test-duty T10 for rated voltages of 300 kV and above.

6.104.5.5 Test-duty T10

For rated voltages up to and including 72,5 kV, the specified standard values are given in table 13. For rated voltages of 100 kV and above, the specified standard values are given in table 14. The time t_3 is a function of the natural frequency of transformers.

In direct testing, it may be difficult to meet the small values of time t_3. The shortest time which can be met should be used but not less than the values specified. The values used shall be stated in the test report.

6.104.6 Measurement of transient recovery voltage during test

During a short-circuit test, the circuit-breaker characteristics such as arc voltage, post-arc conductivity and presence of switching resistors (if any) will affect the transient recovery voltage. Thus, the test transient recovery voltage will differ from the prospective TRV-wave of the test circuit upon which the performance requirements are based to a degree depending upon the characteristics of the circuit-breaker.

Unless the modifying effect of the circuit-breaker is not significant and the breaking current does not contain a significant d.c. component, records taken during tests should not be used for assessing the prospective transient recovery voltage characteristics of the circuit; rather, this should be done by other means, as described in annex F.

The transient recovery voltage during the test shall be recorded.

Table 13 – Standard values of prospective transient recovery voltage – Rated voltages below 100 kV – Representation by two parameters

Rated voltage U_r kV	Test-duty	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 (see note) t_d µs	Voltage u' kV	Time (see note) t' µs	Rate-of-rise u_c/t_3 kV/µs
3,6	T100	1,5	1,4	6,2	41	6	2,1	20	0,15
	T60	1,5	1,5	6,6	17	3	2,2	9	0,39
	T30	1,5	1,5	6,6	9	1	2,2	4	0,77
	T10	1,5	1,5	6,6	9	1	2,2	4	0,77
4,76[a]	T100	1,5	1,4	8,2	51	8	2,7	24	0,16
	T60	1,5	1,5	8,7	31	5	2,9	15	0,28
	T30	1,5	1,5	8,7	20	3	2,9	10	0,44
	T10	1,5	1,5	8,7	20	3	2,9	10	0,44
7,2	T100	1,5	1,4	12,3	51	8	4,1	25	0,24
	T60	1,5	1,5	13	22	3	4,4	11	0,60
	T30	1,5	1,5	13	11	2	4,4	6	1,20
	T10	1,5	1,5	13	11	2	4,4	6	1,20
8,25[a]	T100	1,5	1,4	14,1	59	9	4,7	29	0,24
	T60	1,5	1,5	15,1	35	5	5,0	17	0,43
	T30	1,5	1,5	15,1	24	4	5,0	12	0,63
	T10	1,5	1,5	15,1	24	4	5,0	12	0,63
12	T100	1,5	1,4	20,6	61	9	6,9	29	0,34
	T60	1,5	1,5	22	26	4	7,3	13	0,85
	T30	1,5	1,5	22	13	2	7,3	6	1,70
	T10	1,5	1,5	22	13	2	7,3	6	1,70
15[a]	T100	1,5	1,4	25,7	76	11	8,6	36	0,34
	T60	1,5	1,5	27,6	46	7	9,2	22	0,60
	T30	1,5	1,5	27,6	30	5	9,2	15	0,92
	T10	1,5	1,5	27,6	30	5	9,2	15	0,92
17,5	T100	1,5	1,4	30	71	11	10	35	0,42
	T60	1,5	1,5	32	31	5	11	16	1,04
	T30	1,5	1,5	32	15	2	11	7	2,14
	T10	1,5	1,5	32	15	2	11	7	2,14
24	T100	1,5	1,4	41	87	13	14	43	0,47
	T60	1,5	1,5	44	38	6	15	18	1,16
	T30	1,5	1,5	44	19	3	15	9	2,32
	T10	1,5	1,5	44	19	3	15	9	2,32
25,8[a]	T100	1,5	1,4	44	105	16	15	52	0,42
	T60	1,5	1,5	47	63	9	16	30	0,75
	T30	1,5	1,5	47	42	6	16	20	1,12
	T10	1,5	1,5	47	42	6	16	20	1,12
36	T100	1,5	1,4	62	109	16	21	53	0,57
	T60	1,5	1,5	66	46	7	22	23	1,44
	T30	1,5	1,5	66	23	3	22	10	2,88
	T10	1,5	1,5	66	23	3	22	10	2,88

Table 13 *(continued)*

Rated voltage U_r kV	**Test-duty**	**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 (see note)** t_d µs	**Voltage** u' kV	**Time (see note)** t' µs	**Rate-of-rise** u_c/t_3 kV/µs
38[a]	T100	1,5	1,4	65	125	19	22	61	0,52
	T60	1,5	1,5	70	75	11	23	36	0,93
	T30	1,5	1,5	70	50	8	23	24	1,40
	T10	1,5	1,5	70	50	8	23	24	1,40
48,3[a]	T100	1,5	1,4	83	122	6 (18)	27	47 (59)	0,68
	T60	1,5	1,5	89	73	17	30	36	1,22
	T30	1,5	1,5	89	48	7	30	23	1,85
	T10	1,5	1,5	89	48	7	30	23	1,85
52	T100	1,5	1,4	89	131	7 (20)	30	51 (64)	0,68
	T60	1,5	1,5	96	57	9	32	28	1,68
	T30	1,5	1,5	96	28	4	32	13	3,41
	T10	1,5	1,5	96	28	4	32	13	3,41
72,5	T100	1,5	1,4	124	165	8 (25)	41	63 (80)	0,75
	T60	1,5	1,5	133	72	11	44	35	1,85
	T30	1,5	1,5	133	36	5	44	17	3,70
	T10	1,5	1,5	133	36	5	44	17	3,70

NOTE Where two values of times t_d and t' are given, separated by brackets (T100), the one in brackets can be used if short-line fault tests are also made. If this is not the case, the times before the brackets apply.

[a] Used in North America.

Table 14 – Standard values of prospective transient recovery voltage – Rated voltages from 100 kV to 800 kV Representation by four parameters (T100, T60, T30) or two parameters (T10)

Rated voltage U_r kV	Test-duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	First reference voltage u_1 kV	Time t_1 µs	TRV peak value u_c kV	Time t_2 or t_3 µs	Time delay (see note) t_d µs	Voltage u' kV	Time (see note) t' µs	Rate of rise u_1/t_1 u_c/t_3 kV/µs
100	T100	1,3	1,4	106	53	149	159	2 (11)	53	29 (38)	2,0
		1,5	1,4	122	61	171	183	2 (13)	61	33 (44)	2,0
	T60	1,3	1,5	106	35	159	158	2 – 8	53	20 – 26	3,0
		1,5	1,5	122	41	184	185	2 – 9	61	22 – 30	3,0
	T30	1,5	1,5	122	24	184	180	5 – 6	61	17 – 18	5,0
	T10	1,5	0,9x1,7	-	-	187	34	5	62	16	5,5
123	T100	1,3	1,4	131	65	183	195	2 (14)	65	35 (47)	2,0
		1,5	1,4	151	75	211	225	2 (16)	75	40 (54)	2,0
	T60	1,3	1,5	131	44	196	198	2 – 10	65	24 – 32	3,0
		1,5	1,5	151	50	226	225	2 – 11	75	27 – 36	3,0
	T30	1,5	1,5	151	30	226	225	5 – 7	75	20 – 22	5,0
	T10	1,5	0,9x1,7	-	-	230	40	6	77	19	5,8
145	T100	1,3	1,4	154	77	215	231	2 (16)	77	41 (55)	2,0
		1,5	1,4	178	89	249	267	2 (19)	89	47 (64)	2,0
	T60	1,3	1,5	154	51	231	230	2 – 12	77	28 – 38	3,0
		1,5	1,5	178	59	266	266	2 – 13	89	32 – 43	3,0
	T30	1,5	1,5	178	36	266	270	5 – 8	89	23 – 26	5,0
	T10	1,5	0,9x1,7	-	-	272	45	7	91	22	6,0
170	T100	1,3	1,4	180	90	253	270	2 (19)	90	47 (64)	2,0
		1,5	1,4	208	104	291	312	2 (22)	104	54 (74)	2,0
	T60	1,3	1,5	180	60	271	270	2 – 14	90	32 – 44	3,0
		1,5	1,5	208	69	312	311	2 – 16	104	37 – 51	3,0
	T30	1,5	1,5	208	42	312	315	5 – 9	104	26 – 30	5,0
	T10	1,5	0,9x1,7	-	-	319	51	8	106	25	6,2
245	T100	1,3	1,4	260	130	364	390	2 (27)	130	67 (92)	2,0
	T60	1,3	1,5	260	87	390	392	2 – 20	130	45 – 63	3,0
	T30	1,5	1,5	300	60	450	450	5 – 14	150	35 – 44	5,0
	T10	1,5	0,9x1,7	-	-	459	66	10	153	32	7,0
300	T100	1,3	1,4	318	159	446	477	2 (33)	159	82 (113)	2,0
	T60	1,3	1,5	318	106	478	477	2 – 24	159	55 – 77	3,0
	T30	1,3	1,5	318	64	478	480	5 – 14	159	37 – 46	5,0
	T10	1,5	0,9x1,7	-	-	562	73	11	187	35	7,7
362	T100	1,3	1,4	384	192	538	576	2 (40)	192	98 (136)	2,0
	T60	1,3	1,5	384	128	576	576	2 – 29	192	66 – 93	3,0
	T30	1,3	1,5	384	77	576	578	5 – 17	192	43 – 55	5,0
	T10	1,5	0,9x1,7	-	-	678	82	12	226	39	8,3

Table 14 *(continued)*

Rated voltage U_r kV	Test-duty	First-pole-to-clear factor k_{pp} p.u.	Amplitude factor k_{af} p.u.	First reference voltage u_1 kV	Time t_1 µs	TRV peak value u_c kV	Time t_2 or t_3 µs	Time delay (see note) t_d µs	Voltage u' kV	Time (see note) t' µs	Rate of rise u_1/t_1 u_c/t_3 kV/µs
420	T100	1,3	1,4	446	223	624	669	2 (47)	223	114 (159)	2,0
	T60	1,3	1,5	446	149	669	671	2 – 33	223	76 – 107	3,0
	T30	1,3	1,5	446	89	669	668	5 – 20	223	50 – 65	5,0
	T10	1,5	0,9x1,7	-	-	787	88	13	262	42	8,9
550	T100	1,3	1,4	584	292	817	876	2 (61)	292	148 (207)	2,0
	T60	1,3	1,5	584	195	876	878	2 – 44	292	99 – 141	3,0
	T30	1,3	1,5	584	117	876	878	5 – 26	292	63 – 84	5,0
	T10	1,5	0,9x1,7	-	-	1 031	100	15	344	48	10,3
800	T100	1,3	1,4	849	424	1 189	1 272	2 (89)	424	214 (301)	2,0
	T60	1,3	1,5	849	283	1 274	1 274	2 – 64	424	143 – 205	3,0
	T30	1,3	1,5	849	170	1 274	1 275	5 – 38	424	90 – 127	5,0
	T10	1,5	0,9x1,7	-	-	1 499	116	17	500	56	12,9

NOTE Where two values of times t_d and t' are given, separated by brackets (T100), the one in brackets can be used if short-line fault tests are also made. If this is not the case, the times before the brackets apply.

Where two values of times t_d and t' are given, separated by a dash (T30 and T60), those indicate the lower and the upper limits which should be used for testing. The values before the dash are the lower limits which should not be reduced and the values after the dash are the upper limits which should not be exceeded during tests.

6.104.7 Power frequency recovery voltage

The power frequency recovery voltage of the test circuit may be stated as a percentage of the power frequency recovery voltage specified below. It shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, details and tolerances are given in IEC 60427.

For the basic short-circuit test-duties of 6.106, the power frequency recovery voltage shall be as follows, subject to the 95 % minimum stated above:

a) For three-phase tests on a three-pole circuit-breaker, the average value of the power frequency recovery voltage shall be equal to the rated voltage U_r of the circuit-breaker divided by $\sqrt{3}$.

   The power frequency recovery voltage of any pole should not deviate by more than 20 % from the average value at the end of the time for which it is maintained.

   For an earthed neutral system, it shall be proved that the insufficient build-up of dielectric strength in one pole will not lead to prolonged arcing and possible failure. The single-phase test (6.108) shall be applied as a demonstration.

b) For single-phase tests on a three-pole circuit-breaker, the power frequency recovery voltage shall be equal to the product of the phase-to-earth value $U_r/\sqrt{3}$ and the first-pole-to-clear factor (1,3 or 1,5); the power frequency recovery voltage may be reduced to $U_r/\sqrt{3}$ after an interval of one cycle of rated frequency.

c) For a single-pole circuit-breaker, the power frequency recovery voltage shall be equal to the rated voltage U_r of the circuit-breaker.

The power frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its r.m.s. value shall be determined on the oscillogram within the time interval of one half-cycle and one cycle of test frequency after final arc extinction, as indicated in figure 44. The vertical distance (V_1, V_2 and V_3 respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by $2\sqrt{2}$ and multiplied by the appropriate calibration factor, gives the r.m.s. value of the power frequency recovery voltage recorded.

6.105 Short-circuit test procedure

6.105.1 Time interval between tests

The basic short-circuit tests and, if applicable, short-line fault tests, consist of the series of test-duties specified in 6.106 and 6.109.

The time intervals between individual operations of a test sequence shall be the time intervals of the rated operating sequence of the circuit-breaker, given in 4.104, subject to the following provision:

Due to test plant limitations, it may not be possible to achieve the 15 s, 1 min or 3 min time interval of the rated operating sequence. In such cases the time interval may be extended to 10 min without the test being disqualified; time intervals even longer than 10 min may be required. Prolonged time intervals shall not be due to faulty operation of the circuit-breaker. The actual time interval between operations shall be stated in the test report. If it is longer than 10 min the reason for such a delay shall be recorded in the test report.

For circuit-breakers with a rated operating sequence of O - t - CO - t' - CO rated for different time intervals of t', the test may be performed with the shortest time interval t'. This test is considered to cover all rated operating sequences with longer t' time intervals. This makes it possible to combine the testing for rated operating sequences according to 4.104 a) and b). The actual time interval shall be recorded.

6.105.2 Application of auxiliary power to the opening release – Breaking tests

Auxiliary power shall be applied to the opening release after the initiation of the short-circuit, but when due to test plant limitations this is impracticable the power may be applied before the initiation of the short-circuit (with the limitation that contacts shall not start to move before the initiation of the short-circuit).

6.105.3 Application of auxiliary power to the opening release – Make-break tests

In make-break tests, auxiliary power shall not be applied to the opening release before the circuit-breaker has reached the closed position. In the closing-opening operating cycles of test-duty T100s (see 6.106.4), the power shall not be applied until at least one half-cycle has elapsed from the instant of contact make. It is permissible to delay the circuit-breaker opening so that the permissible d.c. component is not exceeded.

6.105.4 Latching on short-circuit

A circuit-breaker is latched when the main current-carrying contacts have achieved a stationary, fully engaged position at closing and this position is maintained until intentionally released, either mechanically or electrically. Unless the circuit-breaker is fitted with a making current release, or equivalent device, it shall be verified that it latches satisfactorily without undue hesitation when there is negligible decrement of the a.c. component of the current during the closing period.

The ability of the circuit-breaker to latch on short-circuit making current may be verified in test-duty T100s (see 6.106.4) or in the verification test for making (see 6.102.4.1). During this test the following applies:

– for three-phase tests on a three-pole circuit-breaker, the closing angle should be chosen in order to stress the pole most remote from the drive with the peak making current;
– for single-phase tests on a three-pole circuit-breaker, the pole most remote from the mechanism shall be tested in series with the other two poles connected in parallel.

NOTE If a single-phase test is carried out, care should be taken to stress the pole most remote from the mechanism in the same way as during a three-phase test in respect to applied voltage across the pole, moment of pre-strike and current through the pole.

If the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of the applied voltage stated in 6.104.1, the test shall be repeated at reduced voltage using a test circuit which gives the rated short-circuit making current, with negligible decrement of the a.c. component.

Several methods may be used to establish whether a circuit-breaker has closed and latched, for example:

– by proper recording the auxiliary contacts or the contact travel;
– by visually checking the latching position after the performance of the making test;
– by recording the action of the device in order to detect latching (for example a micro-switch suitably fitted to the mechanism).

The method employed to prove satisfactory latching shall be recorded in the test report.

6.105.5 Invalid tests

In the case of an invalid test, it may become necessary to perform a greater number of short-circuit tests than are required by this standard. An invalid test is one where one or more of the test parameters demanded by the standard is not met. This includes, for example, current, voltage and time factors as well as point-on-wave requirements (if specified) and the additional features in synthetic testing such as correct auxiliary circuit-breaker operation and correct injection time.

The deviation from the standard could make the test less or more severe. Four different cases are considered in table 15.

The invalid part of the test-duty may be repeated without reconditioning of the circuit-breaker. However, in the case of a failure of the circuit-breaker during such additional tests, or at the discretion of the manufacturer, the circuit-breaker may be reconditioned and the complete test-duty repeated. In those cases the test report shall include reference to the invalid test.

NOTE In a rapid, auto-reclosing duty cycle, the O - *t* - CO is regarded as one part, and an ensuing CO is regarded as another part.

A class E2 circuit-breaker may be reconditioned, but in this event the entire test series shall be repeated.

If any record of an individual operation cannot be produced for technical reasons, this individual operation is not considered invalid, provided that evidence can be given in another manner that the circuit-breaker did not fail and the required testing values were fulfilled.

Table 15 – Invalid tests

Test conditions related to standard	Circuit-breaker	
	Passes	**Fails**
More severe	Test valid, result accepted	Test to be repeated with correct parameters Modification of the design of the circuit-breaker not required
Less severe	Test to be repeated with correct parameters Modification of the design of the circuit-breaker not required	Circuit-breaker failed the test. Modification of the design of the circuit-breaker required, aiming for improvement of the making, breaking or switching capability. Tests to be re-started on the modified circuit-breaker

6.106 Basic short-circuit test-duties

The basic short-circuit test series shall consist of test-duties T10, T30, T60, T100s and T100a, as specified below.

The breaking current may deviate from the specified values by not more than 20 % of the specified values for test-duties T10 and T30 and by not more than 10 % for test-duty T60.

The peak short-circuit current during the breaking-current tests of test-duties T100s, T100s(b) and T100a shall not exceed 110 % of the rated short-circuit making current of the circuit-breaker.

NOTE In the cases explained in 6.106.4, it may be necessary to separate the making and breaking tests of test-duty T100s. In this case, the part consisting of the making operations is designated T100s(a) and the part consisting of the breaking operations is designated T100s(b).

For test-duties T10, T30 and T60, it is permissible to omit the making operation before any breaking operation for convenience in testing. The time intervals between the individual breaking operations, shall be the time intervals of the rated operating sequence of the circuit-breaker (see 6.105.1).

6.106.1 Test-duty T10

Test-duty T10 consists of the rated operating sequence at 10 % of the rated short-circuit breaking current with a d.c. component of less than 20 % and a transient and power frequency recovery voltage as specified in 6.104.5.5 and 6.104.7 (see also tables 13 and 14).

6.106.2 Test-duty T30

Test-duty T30 consists of the rated operating sequence at 30 % of the rated short-circuit breaking current with a d.c. component of less than 20 % and a transient and power frequency recovery voltage as specified in 6.104.5.4, tables 13, 14 and 6.104.7.

6.106.3 Test-duty T60

Test-duty T60 consists of the rated operating sequence at 60 % of the rated short-circuit breaking current with a d.c. component of less than 20 % and a transient and power frequency recovery voltage as specified in 6.104.5.3, tables 13, 14 and 6.104.7.

6.106.4 Test-duty T100s

Test-duty T100s consists of the rated operating sequence at 100 % of the rated short-circuit breaking current, taking account of 6.104.3, and with a transient and power frequency recovery voltage as specified in tables 13 and 14 and in 6.104.7 and 100 % of the rated short-circuit making current, taking account of 6.104.2, and an applied voltage as specified in 6.104.1.

For this test-duty, the percentage d.c. component shall not exceed 20 % of the a.c. component.

When making single-phase tests on one pole of a three-pole circuit-breaker, or when the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of applied voltage in 6.104.1, making current in 6.104.2, breaking current in 6.104.3 and transient and power frequency recovery voltages in 6.104.5.2 and 6.104.7, taking account also of 6.105.3 and 6.105.4, the making and breaking tests in test-duty T100s may be made as follows:

6.106.4.1 Time constant of the d.c. component of the test circuit equal to the specified value

Where the time constant of the d.c. component of the test circuit is equal to the specified value as defined by 4.101.2, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

   The sequence C - t' - C or C - t'' - C shall be carried out for the rated operating sequence O - t - CO - t' - CO or CO - t'' - CO respectively, with the first closing operation against a symmetrical current equal to the rated short-circuit breaking current and the second closing operation against the rated short-circuit making current according to 6.104.2. The first closing operation shall be carried out at the applied voltage specified in 6.104.1;

b) breaking tests, test-duty T100s(b)

These closing operations detailed in a) shall be followed by O - t - CO - t' - CO or CO - t'' - CO for the rated operating sequence O - t - CO - t' - CO or CO - t'' - CO respectively, at 100 % of the rated short-circuit breaking current and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7.

During this test sequence, the following applies:

– no maintenance is allowed between a) and b);
– the second closing operation of a) can be omitted, provided that during b) one of the closing operations is such that the rated short-circuit making current is achieved;
– for synthetic testing IEC 60427 applies.

6.106.4.2 Time constant of the d.c. component of the test circuit less than the specified value

Where the time constant of the d.c. component of the test circuit is less than the specified value as defined by 4.101.2, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

A single closing operation against the rated short-circuit making current according to 6.104.2 shall be performed. This closing operation may be performed at reduced voltage with the limitations stated in 6.104.2;

b) breaking tests, test-duty T100s(b)

This closing operation shall be followed by O - t - CO - t' - CO or CO - t'' - CO for the rated operating sequence O - t - CO - t' - CO or CO - t'' - CO respectively, at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 6.104.1 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. In this second part, one of the closing operations shall be such that it closes against a symmetrical current equal to the rated short-circuit breaking current.

NOTE Due to the smaller time constant of the d.c. component of the test circuit with respect to the specified value used for the rated short-circuit breaking current, the symmetrical value of the current during a) will need to be greater than the rated value. During b), for the same reason, the current peak, already demonstrated during a), will be smaller than the rated short-circuit making current.

During this test sequence the following applies:

– no maintenance is allowed between a) and b);
– for synthetic testing IEC 60427 applies.

6.106.4.3 Time constant of the d.c. component of the test circuit greater than the specified value

Where the time constant of the d.c. component of the test circuit is greater than the specified value as defined by 4.101.2, the alternative for performing test-duty T100s described above is as follows:

a) The sequence O - t - CO - t' - CO or CO - t'' - CO shall be carried out for rated operating sequence O - t - CO - t' - CO or CO - t'' - CO respectively, at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 6.104.1 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. During this sequence, one of the closing operations shall be such that the circuit-breaker closes against a symmetrical current equal to the rated short-circuit breaking current, and the other one against a full asymmetrical current. Due to the larger time constant of the d.c. component of the test circuit with respect to the specified value as per 4.101.2, the current peak during the asymmetrical closing will be larger than the rated short-circuit making current. Therefore, the closing operation may be controlled by use of point on wave control to obtain the required rated short-circuit making current. The performance of the test procedure a) is, however, subject to the consent of the manufacturer;

NOTE 1 Because of the larger peak of the current during the asymmetrical closing, a separate closing operation against the rated short-circuit making current according to 6.104.2 is not required.

b) Alternatively the above sequence a) can be performed with the first closing operation against a symmetrical current equal to the rated short-circuit breaking current and the second closing operation at no load, i.e. O - t - CO - t' - O or CO - t'' - O for the rated operating sequence O - t - CO - t' - CO or CO - t'' - CO respectively, at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 6.104.1 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7.

   In this case evidence of the ability of the circuit-breaker to perform the rated operating sequence will be demonstrated by repeating the test sequence a), with relevant requirements, and with a symmetrical current smaller than the rated short-circuit breaking current in such a manner that the rated short-circuit making current is obtained in one of the closing operations. During this repeated duty, the closing operations may be performed at reduced voltage with the limitations stated in 6.104.2.

NOTE 2 Since the ability of the circuit-breaker to close against the rated short-circuit making current is proven during the repeated duty, a separate closing operation against the rated short-circuit making current according to 6.104.2 is not required.

During this test sequence the following applies:

– where sequence b) is adopted, maintenance before repetition of the rated operating sequence is permitted;
– for synthetic testing IEC 60427 applies.

6.106.4.4 Time constant of the a.c. component of the test circuit is small

Where the time constant of the a.c. component of the test circuit is small, it may be impossible to test the rated operating sequence without overstressing the circuit-breaker extensively. In such cases it is permitted to split the making and the breaking tests in test-duty T100s as follows:

a) Making tests, test-duty T100s(a)

   C – t' - C in case of a rated operating sequence O - t - CO – t' - CO,

   C - t'' - C in case of a rated operating sequence CO - t'' - CO

   with the making current as specified in 6.104.2 and the applied voltage as specified in 6.104.1. For the time interval between the individual tests 6.105.1 applies.

b) Breaking tests, test-duty T100s(b)

   The testing procedure depends upon the rated operating sequence.

   – In case of a rated operating sequence O - t - CO – t' - CO the closing operations of test-duty T100s(a) shall be followed by the testing sequence O - t - CO – t' - CO at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. For the time interval between the individual tests 6.105.1 applies.

The operating sequence O - t - CO (initial part of the rated operating sequence O - t - CO - t' - CO) may be demonstrated by two tests. In this case the following applies:

In the first test the first opening operation shall be tested at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. The subsequent closing and opening operations shall be tested with making current and applied voltage or breaking current and transient and power frequency recovery voltage respectively as close as possible to the values specified for test-duty T100s.

In the second test an additional CO operating cycle shall be performed with the opening operation at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. This CO operating cycle shall be preceded by a no-load opening operation to complete the operating sequence O - t - CO.

– In case of a rated operating sequence CO – t'' - CO the closing operations of test-duty T100s(a) shall be followed by the testing sequence CO – t'' - CO at 100 % of the rated short-circuit breaking current as specified in 6.104.3 and with a transient and power frequency recovery voltage as specified in 6.104.5.2 and 6.104.7. For the time interval between the individual tests 6.105.1 applies.
– Where a closing operation in test-duty T100s(b) fulfils the requirements given in a) above, the respective closing operation in test-duty T100s(a) may be omitted. In order to not overstress the circuit-breaker controlled closing may be necessary in test-duty T100s(b). For the closing operations the requirements specified in 6.104.1 and 6.104.2 may not be fulfilled.

No maintenance is allowed between the test-duties T100s(a) and T100s(b). When this testing procedure results in actual stresses exceeding the limits specified in table B.1 the consent of the manufacturer is necessary.

6.106.5 Test-duty T100a

Test-duty T100a shall be applied only to circuit-breakers having a time interval equal to the minimum opening time T_{op} of the circuit-breaker, as stated by the manufacturer, plus one half-cycle of rated frequency T_r, such that the d.c. component at the instant of contact separation is greater than 20 % (see 4.101.2).

Test-duty T100a consists of three opening operations at time intervals t' in accordance with 6.105.1 at 100 % of the rated short-circuit breaking current with a percentage d.c. component equal to the appropriate rated value specified in 4.101, and the prospective transient and power frequency recovery voltages as specified in 6.104.5.2 and 6.104.7 (see also 6.104.6). (For table references see 6.106.4).

Where the d.c. time constant of the test circuit is different from that specified for the circuit-breaker, T100a should be performed in accordance with IEC 62215.[3]

[3] To be published

6.107 Critical current tests

6.107.1 Applicability

These tests are short-circuit tests additional to the basic short-circuit test-duties covered by 6.106 and are applicable only to circuit-breakers which have a critical current. It shall 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. For three-phase tests the arcing times of all three phases shall be taken into account.

6.107.2 Test current

Where applicable, the behaviour of the circuit-breaker with respect to the critical current shall be tested in two test-duties.

The test currents for these two test-duties shall be equal to the average of the breaking current corresponding to the test-duty in which the prolonged arcing times occurred (see 6.107.1) and:

a) the breaking current corresponding to the next higher breaking current for one test-duty; and

b) the breaking current corresponding to the next lower breaking current for the other test-duty.

In the case of prolonged arcing times in test-duty T10, the critical current tests shall be performed at a current of 20 % of the rated short-circuit breaking current for one test-duty and at a current of 5 % of the rated short-circuit breaking current for the other one.

6.107.3 Critical current test-duty

The critical current test-duty consists of the rated operating sequence at the current according to 6.107.2 with a d.c. component less than 20 %. The transient and power frequency recovery voltage shall be that associated with the basic short-circuit test-duty having the breaking current the next higher to the critical current.

The critical current test-duty may be performed on a reconditioned circuit-breaker.

6.108 Single-phase and double-earth fault tests

6.108.1 Applicability

Circuit-breakers shall be capable of clearing single-pole the short-circuit currents which may occur in two different cases:

– in solidly earthed neutral systems in case of single-phase faults or,

– in non-solidly earthed neutral systems in case of double earth faults, i.e. earth faults on two different phases, one of which occurs on one side of the circuit-breaker and the other one on the other side.

Depending on the neutral earthing condition of the system in which the circuit-breaker is intended to be used, on the circuit-breaker operating mechanism design (single pole or three pole operated) and on whether the circuit-breaker was tested single-phase or three-phase in test-duty T100s, additional single-phase breaking tests may be necessary (see figure 45).

These tests are intended to demonstrate

– that the circuit-breaker is able to clear a single-pole fault current at relevant parameters;

– for circuit-breakers having a common operating mechanism for all three poles and being fitted with a common opening release, that the operation of the circuit-breaker is not adversely affected by unbalanced forces produced in the case of a single-phase fault current.

The test for single-phase fault shall be performed on an outer pole, while the test for double earth fault can be performed on any pole.

NOTE If two single-phase tests are carried out on a circuit-breaker with a three-pole common operating mechanism, the test may be carried out on two different poles to prevent overstressing of one pole.

6.108.2 Test current and recovery voltage

The breaking current and the recovery voltage for the additional single-phase breaking tests are as shown in figure 45.

The d.c. component of the breaking current shall not exceed 20 % of the a.c. component. The transient recovery voltage shall meet the requirements of items a) and b) of 6.104.5.1. Standard values are derived from u_1, t_1, u_c and t_3 of tables 1a, 1b and 1c. The values to be used for single-phase and double earth fault tests are given in table 16 marked by the index ($_{sp}$):

Table 16 – TRV-parameters for single-phase and double earth fault tests

System neutral	Rated voltage					
	U_r < 100 kV 2-parameter-TRV		$U_r \geq$ 100 kV 4-parameter-TRV			
	$u_{c,sp}$	$t_{3,sp}$	$u_{1,sp}$	$t_{1,sp}$	$u_{c,sp}$	$t_{2,sp}$
Solidly earthed	$1{,}4 \times U_r \frac{\sqrt{2}}{\sqrt{3}}$	t_3 x $u_{C,sp}/u_C$	$U_r \frac{\sqrt{2}}{\sqrt{3}}$	$t_1 \times u_{1,sp}/u_1$	$1{,}4 \times u_{1,sp}$	t_2
Non-solidly earthed	$1{,}4 \times U_r \sqrt{2}$		$U_r \sqrt{2}$			

The other parameters are related to $u_{1,sp}$, $u_{c,sp}$, $t_{1,sp}$ and $t_{3,sp}$ as defined in 6.104.5.1 for test-duty T100. Where necessary, advantage may be taken of the provisions of 6.104.5.2 concerning test plant limitations.

6.108.3 Test-duty

The test-duty for each of the two specified fault cases shall consist of one single breaking operation. The current shall be applied in that outer pole which gives the maximum stress on the inter-pole coupling mechanism.

The arcing time during the breaking operation shall not be shorter than the following value t_a:

$$t_a \geq t_{a100s} + 0{,}7 \times T/2$$

where

t_{a100s} – is the minimum of the arcing times of first-poles-to-clear during the three breaking operations of test-duty T100s, if terminal fault test-duty T100s is tested in three-phase;

– is the minimum arcing time of terminal fault test-duty T100s, if terminal fault test-duty T100s is tested in single-phase.

T is the duration of one period of power frequency

To reduce the amount of testing, it is allowed to replace the two applicable tests by one test, provided that both test conditions are met simultaneously. This allowance is permitted only with the consent of the manufacturer.

6.109 Short-line fault tests

6.109.1 Applicability

Short-line fault tests are short-circuit tests additional to the basic short-circuit test-duties covered by 6.106. These tests shall be made to determine the ability of a circuit-breaker to break short-circuit currents under short-line fault conditions characterised by a transient recovery voltage as a combination of the source and the line side components.

Short-line fault tests are applicable only to three-pole circuit-breakers designed for direct connection to overhead lines, having a rated voltage of 52 kV and above and a rated short-circuit breaking current exceeding 12,5 kA.

6.109.2 Test current

The test current shall take into account the source and line side impedances. The source side impedance shall be that corresponding to approximately 100 % rated short-circuit breaking current I_{sc} and the phase-to-earth value of the rated voltage U_r. Standard values of the line side impedance are specified corresponding to a reduction of the a.c. component of the rated short-circuit breaking current to 90 % (L_{90}) and 75 % (L_{75}) respectively.

In a test, the line length represented on the line side of a circuit-breaker may differ from the length of the line corresponding to currents equal to 90 % and 75 % of the rated short-circuit breaking current. Tolerances on these standardized lengths of –20 % and +0 % for tests at 90 % of the rated short-circuit breaking current and of ± 20 % for tests at 75 % of the rated short-circuit breaking current are permitted.

These tolerances for the line lengths give the following deviations of the short-circuit currents:

- L_{90} at 0 % deviation: I_L = 90 % of I_{sc}
- L_{90} at –20 % deviation: I_L = 92 % of I_{sc}
- L_{75} at +20 % deviation: I_L = 71 % of I_{sc}
- L_{75} at –20 % deviation: I_L = 79 % of I_{sc}

For the case stated in 6.109.4, item c) another test (L_{60}) at 60 % of the rated short-circuit breaking current is required. The tolerance on the corresponding standardized line length is ±20 %. This results in the following deviations of the short-circuit current:

– L_{60} at +20 % deviation: I_L = 55 % of I_{sc}

– L_{60} at –20 % deviation: I_L = 65 % of I_{sc}

For further information, see annex J.

6.109.3 Test circuit

The test circuit shall be single-phase and consists of a supply circuit and a line circuit (see figures 46, 47 and 48). The basic requirements are given in 4.105.

Regarding the time delays on the source side and on the line side and the ITRV (see 4.102.1), two main requirements are specified and shall be distinguished:

a) source side: with time delay *(t_d)* and without ITRV;
   line side: with time delay *(t_{dL})*;

b1) source side: with time delay *(t_d)* and with ITRV;
   line side: with time delay *(t_{dL})*;

b2) source side: with time delay *(t_d)* and without ITRV;
   line side: with insignificant time delay *(t_{dL}).*

The representation of the ITRV on the source side can be neglected if a line side oscillation without a time delay is used (see 6.104.5.2). A line side time delay not greater than 100 ns is considered as an insignificant time delay.

NOTE 1 If no ITRV on the source side and insignificant time delay on the line side is used, within the specified limits yet close to 100 ns, depending on the ratings of the circuit-breaker the voltage across the circuit-breaker at the time t_i may be lower to some extent than in the case of the source side with ITRV and the line side with time delay.

Taking this into account, three types of test circuits characterised by their time delays are applicable for testing:

- circuit SLF a): source side with time delay *(t_d)* and line side with time delay *(t_{dL})* (see A.4.1); circuit shown in figure 46.
- circuit SLF d1): source side with ITRV and line side with time delay *(t_{dL})* (see A.4.2); circuit shown in figure 47.
- Circuit SLF d2): source side with time delay *(t_d)* and line side with insignificant time delay *(t_{dL})* (see A.4.3); circuit shown in figure 48.

Circuit a) shall only be used in the case where no ITRV requirements apply. Circuit b2) can be used as a substitute for the circuit b1) unless both terminals are not identical from an electrical point of view (for instance where an additional capacitance is used as mentioned in note 4 of 6.109.3).

For the choice of test circuit, see flow chart diagram, figure 49.

Other characteristics of the source side and the load side of the test circuit shall be in line with the explanations and calculations given in annex A.

If the TRV requirements of the source side cannot be met due to testing station limitations, a deficiency of the time delay of the source side TRV can be compensated by an increase of the excursion of the line side voltage. The increased value $u_{L,mod}$* is calculated as follows (see also figure 16 and figure 50):

$$t_d < t'_d \leq t_L \qquad u_{L,mod}{}^* = u_L{}^* + L_f \times \text{RRRV} \times (t'_d - t_d)$$

$$t_d < t_L \leq t'_d \qquad u_{L,mod}{}^* = u_L{}^* + L_f \times \text{RRRV} \times (t_L - t_d)$$

where

RRRV is the required rate of rise of recovery voltage of the source side (kV/μs);

L_f is the SLF current factor I_L/I_{sc} (0,9 or 0,75 or 0,6);

t_d is the required time delay of the source side (μs);

t'_d is the actual time delay of the source side (μs);

t_L is the time to the peak voltage $u_L{}^*$ of the line side transient voltage (μs);

$u_L{}^*$ is the required peak voltage across the line (kV);

$u_{L,mod}{}^*$ is the adjusted peak voltage across the line (kV).

If the tests are carried out on a circuit-breaker with one terminal earthed, as may be the case during synthetic testing, measurements or calculations of voltage distribution factors of line and source side oscillations shall be carried out. The higher stressed unit from the line side oscillation is the lower stressed unit from the source side oscillation. It is recognised that the more significant stress is due to the line. The voltage distribution factors shall be as follows:

– unit tests: factors calculated or measured on the line side unit;
– multi-unit tests: factors calculated or measured on the multi-unit next to the line-side. Attention should be paid that the factors to be applied do not overstress the circuit-breaker because of the voltage distribution within the multi-unit. A new measurement or calculation may be required for the portion to be tested.

The measurement of the prospective TRV shall be carried out with the line connected to the actual circuit in order to take into account all the effects due to voltage dividers, stray capacitances and inductances of the test circuit.

An extra capacitance may be applied at the line side or at the source side of the circuit-breaker or across the circuit-breaker in order to adjust the time delays of the individual sections of the test circuit.

NOTE 2 The term 'actual' is used as distinct from the nominal value (90 %, 75 % or 60 %); the use of prospective short-circuit breaking current in accordance with 6.104.3 is not precluded.

NOTE 3 If an extra capacitance is applied in order to adjust the time delay of the line to the standard value given in table 4, the rate of rise of the line side TRV will reach its standard value ($du_L/dt = -s \times I_L$) after the decay of the delaying effect of this extra capacitance.

NOTE 4 Where the breaking capability of the circuit-breaker is not sufficient to interrupt a short-line fault, an additional capacitance at the line side of the circuit-breaker or parallel to the breaking unit(s) may be used, both during the test and in service. In this way, the stress on the circuit-breaker is facilitated. The value and the location of this additional capacitance used during the tests should be stated in the test report.

For a large additional capacitance, the surge impedance of the line and the line side time delay may seem to be reduced, caused by the effect of this additional capacitance. However, the correct value of the surge impedance of the line itself (in advance adjusted in accordance with the standard values given in table 4) remains unchanged. Since the period of the decay of the delaying effect of the additional capacitance may be longer than the time to the first peak of the line side TRV, the lower rate of rise at the rising slope of the TRV may be misinterpreted as a decreased surge impedance of the line. Therefore, the values of the time delay and the surge impedance evaluated for the line in connection with the additional capacitance are not relevant to the test.

The test report should show the specified transient recovery voltage appropriate to the rating of the circuit-breaker, and, for comparative purposes, the prospective transient recovery voltage of the test circuit used.

6.109.4 Test-duties

The short-line fault tests shall be single-phase tests. The series of test-duties is specified below. Each test-duty consists of the rated operating sequence. For convenience of testing, the closing operations may be performed as no-load operations.

The test circuit shall be in accordance with 6.109.3.

For these test-duties, the percentage d.c. component at the instant of contact separation shall be less than 20 % of the a.c. component.

The test-duties related to test currents according to 6.109.2 are as follows:

a) test-duty L_{90}

   at the current for L_{90} given in 6.109.2 and the appropriate prospective transient recovery voltage;

b) test-duty L_{75}

   at the current for L_{75} given in 6.109.2 and the appropriate prospective transient recovery voltage;

c) test-duty L_{60}

   at the current for L_{60} given in 6.109.2 and the appropriate prospective transient recovery voltage.

   This test-duty is mandatory only if the minimum arcing time obtained during test-duty L_{75} is a quarter of a cycle or more greater than the minimum arcing time determined during test-duty L_{90}.

6.109.5 Short-line fault tests with a test supply of limited power

When the maximum short-circuit power available at a testing plant is not sufficient to make the short-line fault tests on a complete pole of a circuit-breaker, it may be possible to make unit tests (see 6.102.4.2).

Short-line fault tests may also be made at reduced power frequency voltage, the provisions of 6.109.3 being relaxed. These provisions shall be met as well as possible and, for the transient recovery voltage at least up to three times the specified time of the first line side peak. This method is used if the basic short-circuit tests in 6.106 have been satisfactory, it being assumed that the dielectric strength of the circuit-breaker near the peak value of transient recovery voltage is independent of stresses applied immediately after current zero. The test method may also be used in combination with unit tests.

If short-line fault tests are performed at reduced power frequency voltage and in any one short-line fault test-duty the maximum arcing time according to 6.102.10.2.2.1 is more than 2 ms longer than the maximum arcing time achieved in test-duty T100s, a single opening operation with the maximum arcing time achieved in the short-line fault tests shall be performed, applying the test conditions of terminal fault T100s. The TRV parameters for this additional operation may be reduced to values corresponding to a first-pole-to-clear factor 1,0, as usual for short-line fault testing. The circuit-breaker is considered to have passed the short-line fault test only, if the current is interrupted successfully in this additional opening operation.

6.110 Out-of-phase making and breaking tests

6.110.1 Test circuit

The power factor of the test circuit shall not exceed 0,15.

Usually the tests are carried out in a single-phase test circuit. This subclause therefore concerns single-phase test procedures only.

NOTE Instead of single-phase tests, three-phase tests are permissible. Where three-phase tests are performed, the test procedure should be agreed upon between the manufacturer and user.

The test circuit should be so arranged that approximately one half of the applied voltage and of the recovery voltage is on each side of the circuit-breaker (see figure 51).

If it is not practicable to use this circuit in the testing station, it is permissible, with the agreement of the manufacturer, to use two identical voltages separated in phase by 120° instead of 180°, provided that the total voltage across the circuit-breaker is as stated in 6.110.2 (see figure 52).

Tests with one terminal of the circuit-breaker earthed are permissible, with the agreement of the manufacturer (see figure 53).

6.110.2 Test voltages

The applied voltage and the power frequency recovery voltage shall have one of the following values:

a) 2,0/√3 times the rated voltage for circuit-breakers intended to be used in earthed neutral systems;

b) 2,5/√3 times the rated voltage for circuit-breakers intended to be used in systems other than earthed neutral systems.

The transient recovery voltage shall be in accordance with 4.106.

6.110.3 Test-duties

The test-duties to be made are indicated in table 17.

For the opening operations of each test-duty, the d.c. component of the breaking current shall be less than 20 % of the a.c. component.

For the closing operation of the close-open cycle of test-duty OP2:

– the power frequency voltage shall be $2U_r/\sqrt{3}$;

– the making shall occur within ±15° of the peak value of the applied voltage.

The closing operation shall produce a symmetrical current with the longest pre-arcing time. The making current shall be equal to the rated out-of-phase making current. The d.c. component of the breaking current is not specified. For arcing times, see 6.102.10.2.1 and 6.102.10.2.2.

If the pre-arcing time when making at the peak value of the applied voltage is not significantly longer than a quarter of a cycle of the power frequency, due to possible limitations of the testing facilities it is allowed to replace the CO operating cycle of OP2 by the following sequence:

– C at full voltage and maximum making current available;
– CO with C at no-load;
– O - O.

Table 17 – Test-duties to demonstrate the out-of-phase rating

Test-duty	Operating sequence	Breaking current in per cent of the rated out-of-phase breaking current
OP1	O - O - O	30
OP2	CO - O - O or alternatively C* - C**O - O - O C* = C at full voltage C** = C at no-load	100
NOTE 1 For circuit-breakers fitted with closing resistors, the thermal capability of the closing resistors may be tested separately. NOTE 2 Test-duty OP1 may be omitted for those circuit-breakers whose arcing characteristics are such that critical current tests according to 6.107.1 at a current level lower than that one associated with terminal fault T10 are not required.		

6.111 Capacitive current switching tests

6.111.1 Applicability

Capacitive current switching tests are applicable to all circuit-breakers to which one or more of the following ratings have been assigned:

– 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.

NOTE 1 The determination of overvoltages when switching capacitor currents is not covered by this standard.

NOTE 2 An explanatory note on capacitive current switching is given in I.4.

6.111.2 General

Re-ignitions during the capacitive current switching tests are permitted. Two classes of circuit-breakers are defined according to their restrike performances:

– class C1: low probability of restrike during capacitive current breaking as demonstrated by specific type tests (6.111.9.2);
– class C2: very low probability of restrike during capacitive current breaking as demonstrated by specific type tests (6.111.9.1).

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

NOTE 2 Phenomena occurring after a restrike or a re-ignition event are not representative of service conditions as the test circuit does not adequately reproduce the post-event voltage conditions.

In laboratory tests the lines and cables may be partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors or resistors.

The test circuit frequency shall be the rated frequency with a tolerance of ± 2 %.

NOTE 3 Tests at 60 Hz may be considered to prove the breaking characteristics at 50 Hz.

NOTE 4 Tests at 50 Hz may be considered to prove the characteristics at 60 Hz, provided that the voltage across the circuit-breaker is not less during the first 8,3 ms than it would be during a test at 60 Hz with the specified voltage. If restrikes occur after 8,3 ms, due to the instantaneous voltage being higher than it would be during a test at 60 Hz with the specified voltage, the test-duty should be repeated at 60 Hz.

NOTE 5 The specification of the circuits may be replaced by a specification of the recovery voltage.

6.111.3 Characteristics of supply circuits

The test circuit shall fulfil the following requirements:

a) the characteristics of the test circuit shall be such that the power frequency voltage variation, when switching, shall be less than 2 % for test-duty 1 (LC1, CC1 and BC1) and less than 5 % for test-duty 2 (LC2, CC2 and BC2). Where the voltage variation is higher than the values specified, it is alternatively permissible to perform tests with the specified recovery voltage (6.111.10) or synthetic tests;
b) the impedance of the supply circuit shall not be so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker.

For line-charging, cable-charging or single capacitor bank current switching tests the prospective transient recovery voltage of the supply circuit shall be no more severe than the transient recovery voltage specified for short-circuit T100 in 6.104.5.2.

For back-to-back capacitor bank breaking current tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated capacitor bank inrush making current when testing with 100 % of the rated back-to-back capacitor bank breaking current.

NOTE 1 If a circuit-breaker is intended to be used in a system with appreciable lengths of cable on the supply side, a supply circuit incorporating appropriate additional capacitance should be used.

NOTE 2 For back-to-back capacitor bank switching current tests where separate making tests are performed, a lower capacitance of the supply circuit may be chosen for the breaking tests. The capacitance should, however, not be so low that the prospective transient recovery voltage of the supply side exceeds that specified for short-circuit in 6.104.5.2.

6.111.4 Earthing of the supply circuit

For single-phase laboratory tests, either terminal of the single-phase supply circuit can be earthed. However, when it is necessary to ensure that the correct voltage distribution exists between the units of the circuit-breaker, another point of the supply circuit may be connected to earth.

For three-phase tests the earthing shall be as follows:

a) for capacitor bank current switching tests, the neutral of the supply circuit shall be earthed. For capacitor banks with earthed neutral, the zero sequence impedance shall be no more than three times its positive sequence impedance. For isolated capacitor banks this ratio is not relevant;

b) for line-charging and cable-charging current switching tests, the earthing of the supply circuit shall, in principle, correspond to the earthing conditions in circuits for which the circuit-breaker is to be used:

   – for three-phase tests of a circuit-breaker intended for use in earthed neutral systems, the neutral point of the supply circuit shall be earthed and its zero sequence impedance shall be no more than three times its positive sequence impedance;

   – for three-phase tests of a circuit-breaker intended for use in isolated neutral and resonant earthed systems the neutral point of the supply side shall be isolated.

NOTE For convenience of testing, an alternative test circuit can be used as long as the testing authority can prove that equivalent values of the recovery voltage will be obtained, for example a test circuit with an earthed neutral system and an isolated capacitor bank can be replaced, in many cases, by a test circuit with an isolated neutral system and an earthed capacitor bank.

Moreover, attention should be given to the influence of TRV control capacitors on the values of the recovery voltage especially for low capacitive currents. Table 20 gives values of the required recovery voltage.

6.111.5 Characteristics of the capacitive circuit to be switched

The characteristics of the capacitive circuit shall, with all necessary measuring devices such as voltage dividers included, be such that the decay of the voltage across the circuit-breaker does not exceed 10 % at the end of an interval of 300 ms after final arc extinction.

Where the test circuit is unable to supply the recovery voltage for 300 ms, the withstand ability of the circuit-breaker shall be demonstrated in another way. This demonstration can be done by performing an additional test without current, applying the required recovery voltage one cycle of the power frequency after contact separation. The required recovery voltage can be obtained by applying, for example, a d.c. voltage at one terminal and an a.c. voltage to the other terminal for the required time duration. The number of voltage applications shall be the same as the number of opening operations in test-duty 1 (LC1, CC1 and BC1), evenly distributed among the two polarities. Where the capacitive current switching tests are performed three-phase, this additional dielectric test shall be carried out on each of the three phases.

6.111.5.1 Line-charging current switching tests

There are three possibilities:

a) three-phase tests, where it is permissible to use parallel lines or to partly, or fully, replace the real three-phase line with concentrated capacitor banks. The resulting positive sequence capacitance shall be approximately twice the zero sequence capacitance for rated voltages 52 kV and above, and three times the zero sequence capacitance for rated voltages less than 52 kV;
b) single-phase tests in a three-phase test circuit with two phases of the capacitive circuit connected directly to the three-phase supply circuit and one phase connected to the supply circuit through the circuit-breaker pole to be tested;
c) single-phase laboratory tests, where it is allowed to replace partly or fully the real lines by concentrated capacitor banks and to use any parallel connection of the conductors in the individual phases with the return current through earth or through a conductor.

When capacitors are used to simulate overhead lines a non-inductive resistor of a maximum value of 5 % of the capacitive impedance may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (for example LR)

may be used instead of the resistor, provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly from the specified values.

Caution is needed when using such alternative impedances, since this impedance can generate an overvoltage after re-ignition, which may lead to further re-ignitions or restrikes.

6.111.5.2 Cable-charging current switching tests

Capacitors may be used to simulate screened and belted cables. For three-phase tests representing three-core belted cables, the positive sequence capacitance shall be approximately twice the zero sequence capacitance.

When capacitors are used to simulate cables, a non-inductive resistor of a maximum value of 5 % of the capacitive impedance may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (for example LR) may be used instead of the resistor, provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly from the specified values.

Caution is needed when using such alternative impedances, since this impedance can generate an overvoltage after re-ignition, which may lead to further re-ignitions or restrikes.

NOTE A short overhead line may be used in series with a cable for the tests, provided the line charging current does not exceed 1 % of the cable charging current.

6.111.5.3 Capacitor bank current switching tests

The neutral of the capacitor shall be isolated except that, for rated voltages equal to or above 52 kV, the earthing conditions of the test capacitor shall be the same as for the capacitor when in service if the circuit-breaker is intended for use in earthed neutral systems.

6.111.6 Waveform of the current

The waveform of the current to be broken should, as nearly as possible, be sinusoidal. This condition is considered to be complied with if the ratio of the r.m.s. value of the current to the r.m.s. value of the fundamental component does not exceed 1,2.

The current to be interrupted shall not go through zero more than once per half-cycle of power frequency.

6.111.7 Test voltage

For direct three-phase tests and for single-phase tests with the capacitive circuit to be switched according to the arrangement in item b) of 6.111.5.1, the test voltage measured between the phases at the circuit-breaker location immediately prior to opening shall be not less than the rated voltage U_r of the circuit-breaker.

For direct single-phase laboratory tests, the test voltage measured at the circuit-breaker location immediately before the opening shall be not less than the product of $U_r/\sqrt{3}$ and the following capacitive voltage factor k_c:

a) **1,0** for tests corresponding to normal service in earthed neutral systems without significant mutual influence of adjacent phases of the capacitive circuit, typically capacitor banks with earthed neutral and screened cables.

b) **1,2** for tests on belted cables and for line-charging current switching tests according to item c) of 6.111.5.1 corresponding to normal service conditions in earthed neutral systems for rated voltages 52 kV and above.

c) **1,4** for tests corresponding to
   - breaking during normal service conditions in systems other than earthed neutral systems;
   - breaking of capacitor banks with isolated neutral.

   Moreover, the factor **1,4** will be applied for tests on belted cables and for line-charging current switching according to item c) of 6.111.5.1 corresponding to normal service conditions in earthed neutral systems for rated voltages less than 52 kV.

Where verification of capacitive current switching is required in presence of single or two-phase earth faults, the following factors apply (see also 6.111.9.3 for the test currents).

d) **1,4** for tests corresponding to breaking in the presence of single or two-phase earth faults in earthed neutral systems;

e) **1,7** for tests corresponding to breaking in systems other than earthed neutral systems in the presence of single or two-phase earth faults.

For unit tests, the test voltage shall be chosen to correspond to the most stressed unit of the pole of the circuit-breaker.

The power frequency test voltage and the d.c. voltage resulting from the trapped charge on the capacitive circuit shall be maintained for a period of at least 0,3 s after breaking.

NOTE 1 The voltage factors in b) to c) above are applicable to single circuit line construction. Switching test requirements for multiple circuit overhead line constructions may be greater than these factors.

NOTE 2 When the non-simultaneity of contact separation in the different poles of the circuit-breaker exceeds one sixth of the cycle of the rated frequency, it is recommended to raise further the voltage factor or to make only three-phase tests.

6.111.8 Test current

Preferred values of rated capacitive currents are specified in table 5.

6.111.9 Test-duties

The test-duties of each test series shall be performed on one specimen without any maintenance. The following abbreviations apply:

– line-charging current, test-duty 1 LC1
– line-charging current, test-duty 2 LC2
– cable-charging current, test-duty 1 CC1
– cable-charging current, test-duty 2 CC2
– capacitor bank current, test-duty 1 BC1
– capacitor bank current, test-duty 2 BC2

6.111.9.1 Test conditions for class C2 circuit-breakers

6.111.9.1.1 Class C2 test-duties

Capacitive current switching tests for class C2 circuit-breakers shall be made after performing test-duty T60 as a preconditioning test (T60 is related to the rated breaking capability of the circuit-breaker). The test arrangement should be such that no interference with the circuit-breaker between the tests is necessary. However, if this is not possible and local safety rules require depressurising to enter the test cell, it is allowed to decrease the pressure in the circuit-breaker provided that the gas is reused when refilling the circuit-breaker.

As an alternative, the preconditioning test may consist of the following:

– same current as test-duty T60;
– low voltage and no specified TRV;
– three opening operations;
– arcing time: as for T60 or expected T60 arcing time values given by the manufacturer;
– rated or lock-out conditions.

NOTE 1 For practical reasons, for circuit-breakers rated less than 52 kV, the manufacturer may choose to add other test-duties to the T60 preconditioning tests.

NOTE 2 If several capacitive current switching tests, for instance line-charging, cable-charging and capacitor bank current switching tests, are performed with the same circuit-breaker without reconditioning, the T60 preconditioning tests must be performed only once at the beginning of the capacitive current switching test.

The capacitive current switching tests shall consist of the test-duties as specified in table 18.

Table 18 – Class C2 test-duties

Test-duty	Operating voltage of the releases	Pressure for operation and interruption	Test current as percentage of the rated capacitive breaking current %	Type of operation or operating sequence
1: LC1, CC1 and BC1	Maximum voltage	Minimum functional pressure	10 to 40	O
2: LC2, CC2 and BC2	Maximum voltage	Rated pressure	Not less than 100	O and CO or CO

NOTE 1 The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control of the opening operation.

NOTE 2 For convenience of testing, CO operating cycles may be performed in test-duty 1 (LC1, CC1 and BC1).

For sealed-for-life fluid circuit-breakers, the minimum functional pressure is replaced by the rated pressure for interruption less the pressure drop due to leakage during life duration. For vacuum circuit-breakers the pressure conditions for interruption are not applicable.

For make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and the opening operations may need to be adjusted but shall remain as close as possible to the close-open time as defined in 3.7.143.

No appreciable charge shall remain on the capacitive circuits before the making operations.

For all capacitor bank making operations, the making shall occur within 15° of the peak value of applied voltage (on one phase for three-phase tests). When applicable, the making current shall be at least equal to the rated back-to-back capacitor bank inrush making current.

Where due to limitations of the test plant it is not possible to comply with the requirements during the CO operating cycles, then it is permitted to perform the requirements of test-duty 2 (LC2, CC2 and BC2) as a series of separate making tests followed by a series of CO tests.

The separate making tests of this test series shall comprise the following:

– the same number of operations;
– when applicable, the making current shall be equal to the rated back-to-back capacitor bank inrush making current;
– the test voltage shall be the same as for test-duty 2 (LC2, CC2 and BC2);
– closing shall occur within 15° of the peak value (on the same phase for three-phase tests).

After the separate making operations, the CO operating cycles, following the same procedure for the separate making tests described previously, shall be performed with no-load conditions on the closing.

NOTE 3 When switching capacitive currents, the opening operation in a CO operating cycle is not influenced by the pre-arc of the preceding closing operation but may be impacted by the actual behaviour of the fluid for interruption caused by the closing operation (for example, local differences in density, turbulence, fluid motion). Therefore, the closing and the opening operations may be separated as mentioned above with regard to the electrical stress but not with regard to the motion conditions of the fluid for interruption. A no-load closing operation prior to the opening operation is necessary for these reasons.

The prospective damping factor for the inrush current during back-to-back switching, i.e. the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0,75 for circuit-breakers having a rated voltage less than 52 kV and equal to or greater than 0,85 for circuit-breakers having a rated voltage equal to or greater than 52 kV.

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by periods of approximately 6°. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE 4 In order to obtain more consistent opening and closing times of the circuit-breaker, by agreement of the manufacturer voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time this is a valid test and shall be included in the count for the total requirement. In such an event, the following will be necessary:

– advance the setting of the control of the tripping impulse by 6° and repeat the test. The new setting shall be kept for other tests at minimum arcing time;
– make one less opening operation to retain the overall total count of tests.

The number of operations at minimum arcing time as stated in 6.111.9.1.2, 6.111.9.1.3, 6.111.9.1.4 and 6.111.9.1.5 shall be achieved, even if the specified total number of operations is exceeded.

A re-ignition followed by interruption at a later current zero shall be treated as a breaking operation with long arcing time.

The preferred order for the line-charging or cable-charging current switching tests is as follows:

– terminal fault T60 (mandatory at the beginning);
– capacitive current switching, test-duty 1 (LC1 or CC1);
– capacitive current switching, test-duty 2 (LC2 or CC2).

The mandatory order for capacitor bank (single or back-to-back) current switching tests is as follows:

– terminal fault T60;
– capacitive current switching, test-duty 2 (BC2);
– capacitive current switching, test-duty 1 (BC1).

Within each test-duty, the order of the operations as written in 6.111.9.1.2 to 6.111.9.1.5 is suggested but not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty 1 (LC1, CC1 and BC1) and test-duty 2 (LC2, CC2 and BC2).

Where the capacitive current switching tests are performed for a certain rating or type of application (e.g. line-charging current switching test) the test may be valid also for a different rating or another type of application (e.g. cable-charging current switching test) without additional testing, if the specified values are covered by these tests taking the stated tolerances into account.

6.111.9.1.2 Three-phase line-charging and cable-charging current switching tests

Each test-duty shall comprise a total of 24 operations or operating cycles as follows:

Test-duty 1 (LC1 and CC1):

- 4 O, distributed on one polarity (step: 15°);
- 6 O at minimum arcing time on one polarity;
- 4 O, distributed on the other polarity (step: 15°);
- 6 O at minimum arcing time on the other polarity;
- additional tests to achieve 24 O, distributed (step: 15°).

Test-duty 2 (LC2 and CC2):

- 4 CO, distributed on one polarity (step: 15°);
- 6 CO at minimum arcing time on one polarity;
- 4 CO, distributed on the other polarity(step: 15°);
- 6 CO at minimum arcing time on the other polarity;
- additional tests to achieve 24 CO, distributed (step: 15°).

During these tests, all minimum arcing times shall occur on the same phase.

The C operations may be no-load operations. In this case a series of separate making tests according to 6.111.9.1.1 shall be performed.

NOTE If the opening time of the circuit-breaker prevents accurate control of contact separation, the requirement for minimum arcing times to be on the same phase can be ignored.

6.111.9.1.3 Single-phase line-charging and cable-charging current switching tests

Each test-duty shall comprise a total requirement of 48 operations or operating cycles as follows:

Test-duty 1 (LC1 and CC1):

- 12 O, distributed on one polarity (step: 15°);
- 6 O at minimum arcing time on one polarity;
- 12 O, distributed on the other polarity (step: 15°);
- 6 O at minimum arcing time on the other polarity;
- additional tests to achieve 48 O, distributed (step:15°).

Test-duty 2 (LC2 and CC2):

- 6 O and 6 CO, distributed on one polarity (step 30°);
- 3 O and 3 CO at minimum arcing time on one polarity;
- 6 O and 6 CO, distributed on the other polarity (step: 30°);
- 3 O and 3 CO at minimum arcing time on the other polarity;
- additional tests to achieve 24 O and 24 CO, distributed (step:30°).

The C operations may be no-load operations. In this case a series of separate making tests according to 6.111.9.1.1 shall be performed.

6.111.9.1.4 Three-phase capacitor bank (single or back-to-back) current switching tests

Test-duty 1 (BC1) shall comprise a total of 24 O tests. Test-duty 2 (BC2) shall comprise a total of 80 CO tests as follows:

Test-duty 1 (BC1):

- 4 O, distributed on one polarity (step:15°);
- 6 O at minimum arcing time on one polarity;
- 4 O, distributed on the other polarity (step: 15°);
- 6 O at minimum arcing time on the other polarity;
- additional tests to achieve 24 O, distributed (step: 15°).

Test-duty 2 (BC2):

- 4 CO, distributed on one polarity (step 15°);
- 32 CO at minimum arcing time on one polarity;
- 4 CO, distributed on the other polarity (step: 15°);
- 32 CO at minimum arcing time on the other polarity;
- additional tests to achieve 80 CO, distributed (step:15°).

During these tests, all minimum arcing times shall be obtained on the same phase.

The C operations may be no-load operations. In this case a series of separate making tests according to 6.111.9.1.1 shall be performed.

NOTE If the opening time of the circuit-breaker prevents accurate control of contact separation, the requirement for minimum arcing times to be on the same phase can be ignored.

6.111.9.1.5 Single-phase capacitor bank (single or back-to-back) current switching tests

Test-duty 1 (BC1) shall comprise a total of 48 O tests. Test-duty 2 (BC2) shall comprise a total of 120 CO tests.

Test-duty 1 (BC1):

- 12 O, distributed on one polarity (step: 15°);
- 6 O at minimum arcing time on one polarity;
- 12 O, distributed on the other polarity(step: 15°);
- 6 O at minimum arcing time on the other polarity;
- additional tests to achieve 48 O, distributed (step: 15°).

Test-duty 2 (BC2):

– 12 CO, distributed on one polarity (step: 15°);
– 42 CO at minimum arcing time on one polarity;
– 12 CO, distributed on the other polarity (step: 15°);
– 42 CO at minimum arcing time on the other polarity;
– Additional tests to achieve 120 CO, distributed (step: 15°).

The C operations may be no-load operations. In this case a series of separate making tests according to 6.111.9.1.1 shall be performed.

6.111.9.2 Test conditions for class C1 circuit-breakers

6.111.9.2.1 Class C1 test-duties

The capacitive current switching tests for class C1 circuit-breakers shall consist of test-duties as specified in table 19 without preconditioning (6.111.9.1.1).

For the make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and opening operations may need to be adjusted but shall remain as close as possible to the close-open time as defined in 3.7.143.

No appreciable charge shall remain on the capacitive circuits before the making operations.

For all capacitor bank making operations, the making shall occur within ±15° of the peak value of applied voltage (on one phase for three-phase tests). When applicable, the making current shall be at least equal to the back-to-back capacitor bank inrush making current.

Where, due to limitations of the test plant, it is not possible to comply with the requirements during the CO operating cycles, then it is permitted to perform the requirements of test-duty 2 (LC2, CC2 and BC2) as a series of separate making tests followed by a series of CO tests.

Table 19 – Class C1 test-duties

Test-duty	Operating voltage of the releases	Pressure for operation and interruption	Test current as percentage of rated capacitive switching current %	Type of operation or operating sequence
1: LC1, CC1 and BC1	Maximum voltage	Rated pressure	10 to 40	O
2: LC2, CC2 and BC2	Maximum voltage	Rated pressure [a]	Not less than 100	CO

NOTE 1 The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control of the opening operation.

NOTE 2 For convenience of testing, CO operating cycles may be performed in test-duty 1 (LC1, CC1 and BC1).

[a] If applicable, pressure for operation and interruption shall be at the minimum functional pressure conditions for at least three CO operating cycles, one at the minimum arcing time and two at the maximum arcing time.

The separate making tests of this test series shall comprise:

– the same number of operations;
– when applicable, the making current shall be equal to the rated back-to-back capacitor bank inrush making current;
– the test voltage shall be the same as for test-duty 2;
– closing shall occur within 15° of the peak value (on the same phase for three-phase tests).

After the separate making operations, the CO operating cycles, following the same procedure for the separate making tests described previously, shall be performed with no-load conditions on the closing.

NOTE 1 When switching capacitive currents, the opening operation in a CO operating cycle is not influenced by the pre-arc of the preceding closing operation but may be impacted by the actual behaviour of the fluid for interruption caused by the closing operation (for example local differences in density, turbulence, fluid motion). Therefore, the closing and opening operations may be separated as mentioned above with regard to the electrical stress but not with regard to the motion conditions of the fluid for interruption. A no-load closing operation prior to the opening operation is necessary for these reasons.

The prospective damping factor for the inrush current during back-to-back switching, i.e. the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0,75 for circuit-breakers having a rated voltage less than 52 kV and equal to or greater than 0,85 for circuit-breakers having a rated voltage equal to or greater than 52 kV.

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by periods of approximately 6°. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE 2 In order to obtain more consistent opening and closing times of the circuit-breaker, by agreement of the manufacturer voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time, this is a valid test and shall be included in the count for the total requirement. In such an event the following will be necessary:

– advance the setting of the control of the tripping impulse by 6° and repeat the test. The new setting shall be kept for other tests at minimum arcing time;
– make one less opening operation to retain the overall total count of tests.

The number of operations and operating cycles at minimum arcing time as stated in 6.111.9.2.2 shall be achieved, even if the specified total number of operations is exceeded.

A re-ignition followed by interruption at a later current zero shall be treated as a breaking operation with a long arcing time.

Within each test-duty, the order of the operations as written in 6.111.9.2.2 is suggested but not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty 1 (LC1, CC1 and BC1) and test-duty 2 (LC2, CC2 and BC2).

Where the capacitive current switching tests are performed for a certain rating or type of application (e.g. line-charging current switching test), the test is valid also for a different rating or another type of application (e.g. cable-charging current switching test) without additional testing, if the specified values are covered by these tests taking the stated tolerances into account.

6.111.9.2.2 Single-phase and three-phase capacitive current switching tests

Test-duty 1 (LC1, CC1 and BC1) shall comprise a total of 24 O tests. Test-duty 2 (LC2, CC2 and BC2) shall comprise a total of 24 CO tests.

Test-duty 1 (LC1, CC1 and BC1):

- 6 O, distributed on one polarity (step: 30°);
- 3 O at minimum arcing time on one polarity;
- 3 O at minimum arcing time on other polarity;
- 6 O at maximum arcing time on the other polarity;
- additional tests to achieve 24 O, distributed (step: 30°).

Test-duty 2 (LC2, CC2 and BC2):

- 6 CO, distributed on one polarity (step: 30°);
- 3 CO at minimum arcing time on one polarity;
- 3 CO at minimum arcing time on the other polarity;
- 6 CO at maximum arcing time on the other polarity;
- additional tests to achieve 24 CO, distributed (step: 30°).

The C operations may be no-load operations. In this case a series of separate making tests according to 6.111.9.2.1 shall be performed.

The preferred order for the tests is the following:

- capacitive current switching, test-duty 1 (LC1 or CC1 or BC1);
- capacitive current switching, test-duty 2 (LC2 or CC2 or BC2).

6.111.9.3 Test conditions corresponding to breaking in the presence of earth faults

a) Lines and cables

   Where tests corresponding to switching of line and cable charging currents in the presence of earth faults are required, the following shall apply:

   Single-phase laboratory tests shall be made with a test voltage as given in 6.111.7 and a capacitive current equal to

   - 1,25 times the rated capacitive breaking current in earthed neutral systems;
   - 1,7 times the rated capacitive breaking current in systems other than earthed neutral systems.

Test procedures are as given in 6.111.9.1 and 6.111.9.2, except that the total number of tests required is divided by two for each relevant test-duty.

NOTE If the tests corresponding to breaking in the presence of earth faults are carried out using the number of operations stated in 6.111.9.1 or 6.111.9.2, respectively, these tests cover the requirements given in 6.111.9.1 or 6.111.9.2 and the tests to 6.111.9.1 or 6.111.9.2 do not need to be performed.

b) Single capacitor banks

Tests are not necessary for capacitor banks in earthed neutral systems.

Switching earthed neutral capacitor banks on systems other than earthed neutral systems can result in higher stresses. As this is not a normal system condition, such test requirements are not considered in this standard.

c) Back-to-back capacitor banks

As this is not a normal system condition, such test requirements are not considered in this standard.

6.111.10 Tests with specified TRV

As an alternative to using the test circuits defined in 6.111.3, switching tests may be performed in circuits which fulfil the following requirements for the prospective recovery voltage:

– with the envelope of the prospective test recovery voltage defined as

$u'_c \geq u_c$

$t'_2 \leq t_2$

– in addition the initial part of the prospective recovery voltage shall remain below the line from the origin to the point defined by u_1 and t_1.

Specified values of u_1, t_1, u_c and t_2 are given in table 20.

Table 20 – Specified values of u_1, t_1, u_c and t_2

Test-duties	Recovery voltage values of figure 54 in relation to the peak value of the test voltage		Time values of figure 54	
	u_c p.u.	u_1 p.u.	t_1	t_2
1	≥ 1,98	≤ 0,02 x k_{af} *	≥ t_1 or t_3 in 4.102.3 for terminal fault	8,7 ms for 50 Hz
2	≥ 1,95	≤ 0,05 x k_{af} *		7,3 ms for 60 Hz
NOTE For single-phase synthetic tests the prospective recovery voltage is calculated based on the test voltage of the corresponding single-phase direct test.				
* k_{af} = amplitude factor = 1,4 (see tables 1a, 1b and 1c)				

6.111.11 Criteria to pass the test

6.111.11.1 General

The circuit-breakers shall have successfully passed the tests if the following conditions are fulfilled:

a) the behaviour of the circuit-breaker during making and breaking of the capacitive currents in all prescribed test-duties fulfils the conditions given in 6.102.8;

b) either no restrikes occurred during test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), or, if one restrike occurs during the complete test-duties 1 and 2, then both test-duties shall be repeated on the same apparatus without any maintenance. No restrike shall occur during the extended series of tests. External flashover and phase-to-ground flashover shall not occur. If NSDDs occur I.4 applies;

c) the condition of the circuit-breaker after the test series corresponds to the conditions given in 6.102.9.4. If no restrike occurred during test-duties 1 and 2, visual inspection is sufficient.

6.111.11.2 Criteria for reclassification of a circuit-breaker tested to the class C2 requirements as a class C1 circuit-breaker

A circuit-breaker tested in accordance with the class C2 test program can be qualified as a class C1 circuit-breaker if the requirements of items a) and c) above are fulfilled and if at least one of the following conditions is met:

a) the criteria for class C2 to pass the test are fulfilled;

b) the total number of restrikes during line charging current switching tests (LC1 and LC2) or cable charging current switching tests (CC1 and CC2) is not greater than
   - two in the first series of operations, i.e. 96 in case of single-phase tests and 48 in case of three-phase tests, see 6.111.9.1.2 and 6.111.9.1.3 (no repetition series is carried out) or
   - one during the first test series of operations, i.e. 96 in case of single-phase tests and 48 in case of three-phase tests, see 6.111.9.1.2 and 6.111.9.1.3 regardless of the number of restrikes observed during the repetition of the test series;

c) the total number of restrikes during capacitor bank switching tests (BC1 and BC2) is not greater than:
   - five in the first series of operations, i.e. 168 in case of single-phase tests and 104 in case of three-phase tests, see 6.111.9.1.4 and 6.111.9.1.5 (no repetition series is carried out) or,
   - one during the first test series of operations, i.e. 168 in case of single-phase tests and 104 in case of three-phase tests, see 6.111.9.1.4 and 6.111.9.1.5 regardless of the number of restrikes observed during the repetition of the test series.

6.112 Special requirements for making and breaking tests on class E2 circuit-breakers

6.112.1 Class E2 circuit-breakers intended for use without auto-reclosing duty

The electrical endurance capability of circuit-breakers, which are intended to be used without auto-reclosing duty, for example in cable-connected networks, is demonstrated by performing the basic short-circuit test-duties of 6.106 without intermediate maintenance. Additional tests are not required.

6.112.2 Class E2 circuit-breakers intended for auto-reclosing duty

Circuit-breakers intended for auto-reclosing duty, as usual for overhead-line networks, shall perform an electrical endurance test in accordance with, and in the order specified in, table 21 in addition to the basic short-circuit test-duties of 6.106, which shall be carried out without intermediate maintenance.

The test shall be carried out on a circuit-breaker, which is in a clean and new condition and identical to that which has been submitted to the basic short-circuit tests, given in 6.106. No intermediate maintenance shall be carried out. The test parameters shall be in accordance with 6.106 except as follows:

a) in the case of gas-filled circuit-breakers, the test shall be made at the rated pressure for insulation and/or operation and at the rated supply voltage of closing and opening devices and of auxiliary and control circuits;
b) the values of *t* shall be chosen for convenience of testing;
c) the minimum time interval between operating sequences should be stated by the manufacturer.

Arcing times shall be at random for the 10 % and 30 % tests. Adjustment of the arcing times shall be made in accordance with 6.102.10 for the 60 % and 100 % tests.

The condition of the circuit-breaker after the test shall comply with 6.102.9.2 and 6.102.9.3.

Table 21 – Operating sequence for electrical endurance test on class E2 circuit-breakers intended for auto-reclosing duty according to 6.112.2

Testing current (percentage of rated short-circuit breaking current) %	Operating sequences	Number of operating sequences (list 1) [a]	Number of operating sequences (list 2) [a]
10	O	84	12
	O - 0,3 s - CO	14	6
	O - 0,3 s - CO - *t* - CO	6 [b]	4 [b]
30	O	84	12
	O - 0,3 s - CO	14	6
	O - 0,3 s - CO - *t* - CO	6 [b]	4 [b]
60	O	2	8
	O - 0,3 s - CO - *t* - CO	2 [b]	8 [b]
100 (symmetrical)	O - 0,3 s - CO - *t* - CO	2 [b]	4 [b]

[a] List 1 is preferred. List 2 may be used as an alternative for circuit-breakers used for solidly earthed systems.

[b] When no reconditioning is made on the sample after the basic short-circuit test sequences in 6.106, the test already carried out may be taken into account in determining the number of additional operating sequences required to satisfy the requirements of table 21. In practice, this means reducing these figures marked [b] by 1.

7 Routine tests

Clause 7 of IEC 60694 is applicable with the following addition:

7.1 Dielectric test on the main circuit

Subclause 7.1 of IEC 60694 is applicable with the following addition:

In the case of circuit-breakers constructed by assembling identical breaking and making units in series, the test voltage to be applied across each single unit, when open, shall be the higher fraction of the total withstand voltage resulting from actual power-frequency voltage distribution with the circuit-breaker fully open and one terminal earthed.

With reference to figure 2 of IEC 60694, which shows a diagram of a three-pole circuit-breaker, the test voltage shall be applied, according to table 22.

Table 22 – Application of voltage for dielectric test on the main circuit

Test condition No.	Circuit-breaker	Voltage applied to	Earth connected to
1	Closed	AaCc	BbF
2	Closed	Bb	AaCcF
3	Open	ABC	abcF
NOTE If the insulation between poles is air at atmospheric pressure, test conditions nos. 1 and 2 may be combined, the test voltage being applied between all parts of the main circuit connected together and the base.			

7.2 Dielectric test on auxiliary and control circuits

Subclause 7.2 of IEC 60694 is applicable.

7.3 Measurement of the resistance of the main circuit

Subclause 7.3 of IEC 60694 is applicable.

7.4 Tightness test

Subclause 7.4 of IEC 60694 is applicable.

7.5 Design and visual checks

Subclause 7.5 of IEC 60694 is applicable with the following addition:

The circuit-breaker shall be checked to verify its compliance with the order specification.

The following items shall be checked as applicable:

- the language and data on the nameplates;
- identification of any auxiliary equipment;
- the colour and quality of paint and corrosion protection of metallic surfaces;
- the values of the resistors and capacitors connected to the main circuit.

7.101 Mechanical operating tests

Mechanical operating tests shall include the following:

a) at maximum supply voltage of operating devices and of auxiliary and control circuits and maximum pressure for operation (if applicable):
   - five closing operations;
   - five opening operations.

b) at specified minimum supply voltage of operating devices and of auxiliary and control circuits and minimum functional pressure for operation (if applicable):
   - five closing operations;
   - five opening operations.

c) at rated supply voltage of operating devices and of auxiliary and control circuits and rated pressure for operation (if applicable):
   - five close-open operating cycles with the tripping mechanism energised by the closing of the main contacts;
   - moreover, for circuit-breakers intended for rapid auto-reclosing (see 4.104), five open-close operating cycles O - *t* - C where *t* shall be not more than the time interval specified for the rated operating sequence.

Mechanical operating tests should be made on the complete circuit-breaker. However, when circuit-breakers are assembled and shipped as separate units, routine tests may be performed on components according to 6.101.1.2. In such cases, the manufacturer shall produce a programme of commissioning tests for use at site to confirm the compatibility of such separate units and components when assembled as a circuit-breaker. A guide for commissioning tests is given in 10.2.101.

For all required operating sequences the following shall be performed and records made of the closing and opening operations:

- measurement of operating times;
- where applicable, measurement of fluid consumption during operations, for example pressure difference.

Proof shall be given that the mechanical behaviour conforms to that of the test specimen used for type testing. For example, a no-load operating cycle, as described in 6.101.1.1, can be performed to record the no-load travel curves at the end of the routine tests. Where this is done, the curve shall be within the prescribed envelope of the reference mechanical travel characteristic, as defined in 6.101.1.1, from the instant of contact separation to the end of the contact travel.

Where the mechanical routine tests are performed on sub-assemblies, the reference mechanical travel characteristics shall be confirmed to be correct, as above, at the end of the commissioning tests on site.

If the measurement is performed on site, the manufacturer shall state the preferred measuring procedure. If other procedures are used, the results may be different and the comparison of the instantaneous contact stroke may be impossible to achieve.

The mechanical travel characteristics can be recorded directly, using a travel transducer or similar device on the circuit-breaker contact system or at other convenient locations on the drive to the contact system where there is a direct connection, and a representative image of the contact stroke can be achieved. The mechanical travel characteristics shall be preferably a continuous curve as shown in figure 23 a). Where the measurements are taken on site, other methods may be applied which record points of travel during the operating period.

In these circumstances, the number of points recorded shall be sufficient to derive the time to, and contact speed at, contact touch and contact separation, together with the total travel time.

After completion of the required operating sequences, the following tests and inspections shall be performed (if applicable):

- connections shall be checked;
- the control and/or auxiliary switches shall correctly indicate the open and closed positions of the circuit-breaker;
- all auxiliary equipment shall operate correctly at the limits of supply voltage of operating devices and of auxiliary and control circuits and/or pressures for operation.

Furthermore the following tests and inspections shall be made (if applicable):

- measurement of the resistance of heaters (if fitted) and of the control coils;
- inspections of the wiring of the control, heater and auxiliary equipment circuits and checking of the number of auxiliary contacts, in accordance with the order specification;
- inspection of control cubicle (electrical, mechanical, pneumatic and hydraulic systems);
- recharging duration(s);
- functional performance of pressure relief valve;
- operation of electrical, mechanical, pneumatic or hydraulic interlocks and signalling devices;
- operation of anti-pumping device;
- general performance of equipment within the required tolerance of the supply voltage;
- inspection of earthing terminals of the circuit-breaker.

For self-tripping circuit-breakers, the releases or the relays shall be set at the minimum calibration mark on the scale of current settings.

It shall be shown that the over-current releases or relays correctly initiate the opening of the circuit-breaker with the current through the main circuit not exceeding 110 % of the minimum tripping current corresponding to the value set on the scale of current settings. A secondary injection test may be used as an alternative.

For these tests, the current through over-current releases, or through current transformers, may be supplied from a suitable low-voltage source.

For circuit-breakers fitted with under-voltage opening releases, it shall be shown that the circuit-breaker opens and can be closed when voltages within the specified limits are applied to the releases (see 5.8.4 of IEC 60694).

If adjustments are required during the mechanical operating tests, the complete test sequence shall be repeated following the adjustments.

8 Guide to the selection of circuit-breakers for service

8.101 General

A circuit-breaker suitable for a given duty in service is best selected by considering the individual rated values required by load conditions and fault conditions.

The complete list of rated characteristics is given in clause 4. The following individual ratings are dealt with in this clause.

Type of rating and characteristic	*Subclause*
Rated voltage	8.102.1
Rated insulation level	8.102.2
Rated frequency	8.102.3
Rated normal current	8.102.4
Rated short-circuit breaking current	8.103.1
Transient recovery voltage for terminal faults	8.103.2
Rated out-of-phase making and breaking current	8.103.3
Rated short-circuit making current	8.103.4
Rated operating sequence	8.103.5
Rated duration of short-circuit	8.103.6
Classification as for electrical endurance (class E1 or E2 (with/without auto-reclosing duty)), where applicable	8.104

For rated characteristics not dealt with in clause 8, reference should, if applicable, be made to clause 4 as follows:

Type of rating and characteristic	*Subclause*
Rated short-time withstand current	4.5
Rated peak withstand current	4.6
Rated supply voltage of closing and opening devices and of auxiliary and control circuits	4.8
Rated supply frequency of operating devices and auxiliary circuits	4.9
Rated pressures of compressed gas supply for insulation, operation and/or interruption	4.10
Characteristics for short-line faults	4.105
Restrike performance during capacitive current switching (class C1 or C2)	4.107
Characteristics as for capacitive switching conditions (for example earthing conditions, type of capacitive load, etc.)	4.107
Rated line-charging breaking current	4.107.1
Rated cable-charging breaking current	4.107.2
Rated single capacitor bank breaking current	4.107.3
Rated back-to-back capacitor bank breaking current	4.107.4
Rated single capacitor bank inrush making current	4.107.5
Rated back-to-back capacitor bank inrush making current	4.107.6
Number of mechanical operations (class M1 or M2)	4.110

Other parameters to be considered when selecting a circuit-breaker are, for example:

Local atmospheric and climatic conditions	8.102.5
Use at high altitudes	8.102.6
Opening time	8.103.1
Small inductive breaking current	4.108

The duty imposed by the fault conditions with which a circuit-breaker is required to deal should be determined by calculating the fault currents at the place where the circuit-breaker is to be located in the system, in accordance with some recognised method of calculation.

When selecting a circuit-breaker, due allowance should be made for the likely future development of the system as a whole, so that the circuit-breaker may be suitable not merely for immediate needs but also for the requirements of the future.

Circuit-breakers which have satisfactorily completed type tests for a combination of rated values (i.e. voltage, normal current, making and/or breaking current) are suitable for any lower rated values (with the exception of rated frequency) without further testing. Switching of inductive loads (magnetising currents of transformers, high-voltage motors and shunt reactors) are specified in IEC 61233.

NOTE Some fault conditions such as evolving faults and some service conditions such as switching of arc furnaces are not dealt with in this standard and should therefore be considered as special conditions for which agreement should be reached between manufacturer and user.

The same is applicable to circuit-breakers used for any operation leading to a power-frequency recovery voltage higher than that corresponding to the rated voltage of the circuit-breaker, which may be the case at certain points of the system and, in particular, at the end of long lines. In this particular case, the value of current to be interrupted at the highest voltage which may occur across the terminals of the circuit-breaker when opening should be subject to a similar agreement.

8.102 Selection of rated values for service conditions

8.102.1 Selection of rated voltage

The rated voltage of the circuit-breaker should be chosen so as to be at least equal to the highest voltage of the system at the point where the circuit-breaker is to be installed.

The rated voltage of a circuit-breaker should be selected from the standard values given in 4.1 of IEC 60694.

In selecting the rated voltage the corresponding insulation levels specified in 4.2 should also be taken into account (see also 8.102.2).

8.102.2 Insulation coordination

The rated insulation level of a circuit-breaker should be selected according to 4.2.

The values in the tables stated there apply to both indoor and outdoor circuit-breakers. It should be specified in the enquiry whether the circuit-breaker is to be of indoor or outdoor type.

The insulation coordination in an electrical system serves to minimise damage to the electrical equipment due to overvoltages and tends to confine flashovers (when these cannot be economically avoided) to points where they will cause no damage.

Precautions should be taken to limit the overvoltages on the terminals of the circuit-breaker to stated values below the insulation level (see IEC 60071-2).

Where a circuit-breaker is required for a position necessitating a higher insulation level, this should be specified in the enquiry (see 9.101).

For circuit-breakers intended for use in synchronising operation when a substantial switching surge may simultaneously occur, refer to 4.2 and 6.2.7.2.

When selecting circuit-breakers for service, it is also necessary to take into account their characteristics in respect of transient phenomena and overvoltages. Experience shows that the unfavourable effects of transient phenomena and the risk of overvoltages for certain critical cases of application can be minimised by

– appropriate selection of the type of circuit-breaker;
– changes in the system or the use of additional equipment for damping and limiting transient phenomena (RC circuits, overvoltage arresters, non-linear resistances, etc.).

These precautions shall be discussed with the manufacturer for individual cases. Special tests can be agreed for evaluating the selected solution.

8.102.3 Rated frequency

The manufacturer should be consulted if a circuit-breaker is to be used at any frequency other than its rated frequency (see 4.3 of IEC 60694).

When circuit-breakers rated 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the test results, taking into account all significant facts such as the type of circuit-breaker and the type of test performed.

8.102.4 Selection of rated normal current

The rated normal current of a circuit-breaker should be selected from the standard values given in 4.4.

It should be noted that circuit-breakers have no specified continuous over-current capability. When selecting a circuit-breaker therefore, the rated normal current should be such as to make it suitable for any load current that may occur in service. Where intermittent over-currents are expected to be frequent and severe, the manufacturer should be consulted.

8.102.5 Local atmospheric and climatic conditions

The normal atmospheric and climatic conditions for circuit-breakers are given in clause 2.

A distinction is made between classes "minus 5 indoor", "minus 15 indoor", "minus 25 indoor", "minus 10 outdoor", "minus 25 outdoor" and "minus 40 outdoor" circuit-breakers, these being suitable for differing minimum ambient air temperatures. The manufacturer should be consulted if a circuit-breaker is to be located where the ambient air temperature may fall below –25 °C for an indoor circuit-breaker, and below –40 °C for an outdoor circuit-breaker, or where the temperature may exceed 40 °C (or if the 24 h average value exceeds 35 °C).

For outdoor circuit-breakers, the atmospheric conditions in certain areas are unfavourable on account of smoke, chemical fumes, salt-laden spray and the like. Where such adverse conditions are known to exist, special consideration should be given to the design of those parts of the circuit-breaker, especially the insulators, normally exposed to the atmosphere.

The performance of an insulator in such atmospheres also depends on the frequency of washing or cleaning operations and on the frequency of natural washing by rain. Since the performance of an insulator under such conditions is dependent on so many factors, it is not possible to give precise definitions of normal and heavily polluted atmospheres. Experience in the area where the insulator is to be used is the best guide.

The manufacturer should be consulted when the circuit-breaker is to be located where the wind pressure exceeds 700 Pa.

Three different classes of circuit-breakers are specified with regard to ice-coating. These classes correspond to an ice-coating not exceeding 1 mm, 10 mm and 20 mm. If a circuit-breaker is to be located where an ice-coating exceeding 20 mm is expected, agreement should be reached between manufacturer and user as to the ability of the circuit-breaker to perform correctly under such conditions.

Where applicable, the seismic qualification levels referred to in 2.2.4 of IEC 60694 should be taken into account.

For indoor installations, the humidity conditions are given in 2.1.1e) of IEC 60694. When selecting the circuit-breaker for service, it is recommended to indicate the cases, where the high values of humidity are expected and condensation can occur. The responsibility and the amount of precaution to be taken against the occurrence of condensation mentioned in note 3 of 2.1.1e) of IEC 60694 should be agreed between the manufacturer and user.

For indoor circuit-breakers, the manufacturer should be consulted for any special service conditions, for example when chemical fumes, aggressive atmosphere, salt laden spray, etc., are present.

8.102.6 Use at high altitudes

The normal service conditions specified in clause 2 of IEC 60694 provide for circuit-breakers intended for use at altitudes not exceeding 1 000 m.

For installation at altitudes above 1 000 m, 2.2.1 of IEC 60694 is applicable.

8.103 Selection of rated values for fault conditions

8.103.1 Selection of rated short-circuit breaking current

As stated in 4.101, the rated short-circuit breaking current is expressed by two values:

a) the r.m.s. value of its a.c. component;

b) the percentage d.c. component (for explanations, see I.2).

The percentage d.c. component varies with time from the incidence of the short-circuit. When the circuit-breaker meets the standard requirements stated in 4.101.2, the percentage d.c. component that the circuit-breaker can deal with is defined by the values given in figure 9, at the end of the time interval corresponding to the shortest possible opening time of the circuit-breaker plus, for a circuit-breaker to be tripped solely by a form of auxiliary power, a minimum relay time of one half-cycle of rated frequency. The curves in figure 9 are based on a constant a.c. component and on the short-circuit power factors stated in table 23, corresponding to the standard time constant τ = 45 ms and the special case time constants 60 ms, 75 ms and 120 ms, respectively.

Tests with a higher d.c. component cover tests at lower d.c. component, provided that the a.c. component is the same or greater and the TRV conditions associated with the lower d.c. component are met.

Table 23 – Relationship between short-circuit power factor, time constant and power frequency

Time constant τ ms	Short-circuit power factor $\cos \varphi$ 50 Hz	 60 Hz
45	0,071	0,059
60	0,053	0,044
75	0,042	0,035
120	0,026	0,022

When the location of the installation is sufficiently remote electrically from rotating machines, the decrement of the a.c. component is negligible and it is only necessary to verify that in the case of 50 Hz the short-circuit power factor is not less than 0,071 for the standard time constant τ = 45 ms and the minimum relay time of the protective equipment is not less than one half-cycle of the rated frequency. In these conditions, it is sufficient that the selected circuit-breaker has a rated short-circuit breaking current not less than the r.m.s. value of the short-circuit current at the point where the circuit-breaker is to be installed.

The basic short-circuit test-duties (6.106), together with the critical current tests (6.107) and, where applicable, short-line fault tests (6.109), have been chosen to prove the circuit-breaker for all values of current up to the rated short-circuit breaking current. Therefore, for situations where the prospective short-circuit current is lower, it is not necessary to perform a short-circuit test series based on a lower rated short-circuit breaking current.

In some cases, the percentage d.c. component may be higher than the values given in figure 9. For instance, when circuit-breakers are close to centres of generation, the a.c. component may decrease more quickly than in the normal case. The short-circuit current may then not have a current zero for a number of cycles. In such circumstances the duty of the circuit-breaker can be eased, for example, by delaying its opening, or by connecting an additional damping device with another circuit-breaker and opening the circuit-breakers in sequence. If the standard values of percentage d.c. component cannot be adhered to, the required percentage should be specified in the enquiry and testing should be subject to agreement between manufacturer and user. Attention is drawn to item b) of 8.103.2.

NOTE The current zero can be advanced by the effects of the arc voltages of the circuit-breaker and/or the interruptions of the short-circuit currents in the other phases with earlier current zeros. For such circumstances, standard circuit-breakers are applicable, subject to careful investigation.

The rated short-circuit breaking current should be selected from the standard values given in 4.101.1.

8.103.2 Selection of transient recovery voltage (TRV) for terminal faults, first-pole-to-clear factor and characteristics for short-line faults

The prospective transient recovery voltage (TRV) of the system should not exceed the reference line representing the transient recovery voltage specified for the circuit-breaker; it should cross the specified delay line close to zero voltage but should not re-cross it later (see 4.102.2). Standard values are shown in 6.104.5.

NOTE 1 The transient recovery voltages which appear when breaking the highest short-circuit currents are not necessarily more severe than those which appear in other cases. For example, the rate-of-rise of transient recovery voltage may be higher when breaking smaller short-circuit currents.

The standard values given for rated voltages below 100 kV are applicable to a first-pole-to-clear factor 1,5. For rated voltages 100 kV to 170 kV, a choice between first-pole-to-clear factors 1,3 and 1,5 is provided. For rated voltages above 170 kV the standard values are applicable to a first-pole-to-clear factor 1,3 (see also the note in 6.104.5.4).

The first-pole-to-clear factor k_{pp} =1,3 is based on a system with earthed neutral where three-phase faults not involving earth are considered highly improbable. For applications in isolated neutral and resonant earthed systems, the first-pole-to-clear factor 1,5 should be used. For applications in systems with earthed neutral in cases where the probability of three-phase faults not involving earth cannot be disregarded, and for applications in systems other than earthed neutral systems, a first-pole-to-clear factor of 1,5 may be necessary.

Generally it will not be necessary to consider alternative transient recovery voltages as the standard values specified cover the majority of practical cases.

More severe conditions may occur in some cases, for instance:

a) one case is when a short-circuit occurs close to a transformer but on the opposite side to the circuit-breaker and where there is no appreciable additional capacitance between the transformer and the circuit-breaker. In this case, both the peak voltage and rate-of-rise of transient recovery voltage may exceed the values specified in this standard.

NOTE 2 Care should also be taken when selecting a circuit-breaker for the primary side of a transformer which may have to interrupt a short-circuit on the secondary side.

Circuit-breakers being used next to current-limiting reactors may fail to interrupt due to the high natural frequency of these reactors. In those cases, a special circuit-breaker shall be specified or the natural frequency shall be lowered by adding a parallel capacitor to the reactor;

b) in the case of a short-circuit on circuit-breakers close to generators, the rate-of-rise of transient recovery voltage may exceed the values specified in this standard.

In such cases it may be necessary for special TRV characteristics to be agreed between manufacturer and user.

When circuit-breakers are required for installations necessitating the assignment of characteristics for short-line faults, the line on which they are to be used should have a surge impedance and peak-factor not greater than, and a time delay not less than, the standard values of line characteristic given in table 4. However, if this should not be the case, it is still possible that a standard circuit-breaker is suitable, especially if the short-circuit current of the system is less than the rated short-circuit breaking current of the circuit-breaker. This can be established by calculating the prospective TRV for short-line faults from the rated characteristics by the method given in annex A and comparing this with the prospective TRV derived from the actual characteristics of the system.

If special characteristics for short-line faults are required, they should be agreed between manufacturer and user.

8.103.3 Selection of out-of-phase characteristics

The requirements of this standard cater for the great majority of applications of circuit-breakers intended for switching during out-of-phase conditions. Several circumstances would have to be combined to produce a severity in excess of those covered by the tests of the standard and, as switching during out-of-phase conditions is rare, it would be uneconomical to design circuit-breakers for the most extreme conditions.

The actual system conditions should be considered when frequent out-of-phase switching is expected or where excessive stresses are probable.

A special circuit-breaker, or one rated at a higher voltage, may sometimes be required. As an alternative solution, the severity of out-of-phase switching duty is reduced in several systems by using relays with coordinated impedance-sensitive elements to control the tripping instant, so that interruption will occur either substantially after or substantially before the instant the phase angle reaches 180°.

A higher rate of rise than specified in tables 1a, 1b and 1c may occur when one circuit-breaker terminal is transformer-connected. Circuit-breakers tested in accordance with this standard are considered to comply with this higher rate-of-rise requirement, provided they have satisfied test-duty T30 of the basic short-circuit test series.

8.103.4 Selection of rated short-circuit making current

As stated in 4.103, the rated short-circuit making current shall correspond to the rated voltage and is related to the rated frequency and the d.c. time constant of the system. For a rated frequency of 50 Hz and based on the standard time constant τ = 45 ms, it shall be 2,5 times (i.e. approximately 1,8$\sqrt{2}$ times) the a.c. component of the rated short-circuit breaking current of the circuit-breaker. For a rated frequency of 60 Hz and based on the standard time constant τ = 45 ms, it shall be 2,6 times the a.c. component of the rated short-circuit breaking current of the circuit-breaker.

If one of the special case d.c. time constants (60 ms, 75 ms or 120 ms) stated in 4.101.2 applies, taking the explanations given in I.2 into account, the rated short-circuit making current shall be 2,7 times the a.c. component of the rated short-circuit breaking current of the circuit-breaker, for both 50 Hz and 60 Hz whatever the rated frequency.

The selected circuit-breaker should have a rated short-circuit making current not less than the highest peak value of the short-circuit currents expected at the application point.

In some cases, for example when induction motors are electrically close, the maximum peak value of the fault current may be more than the a.c. component of the short-circuit current multiplied by the factors given above. In such cases, a special design should be avoided and a standard circuit-breaker having a suitable rated short-circuit making current should be selected.

8.103.5 Operating sequence in service

The rated operating sequence of a circuit-breaker should be one of the operating sequences given in 4.104. Unless otherwise specified, the values of the time intervals given in 4.104 apply and the rated operating sequences provided for are as follows:

a) O - 3 min - CO - 3 min - CO;

b) CO - 15 s - CO;

c) O - 0,3 s - CO - 3 min - CO (for circuit-breakers intended for rapid auto-reclosing).

NOTE Instead of 3 min, other time intervals, namely 15 s for rated voltages less than or equal to 52 kV and 1 min are also used for circuit-breakers intended for rapid auto-reclosing. The interval to be chosen depends in principle upon system requirements such as continuity of service.

If the short-circuit current, which the circuit-breaker is capable of breaking on auto-reclosing, is less than the rated short-circuit breaking current, this should be specified by the manufacturer.

When the operating sequence in service is more severe than is provided for in this standard, this should be specified by the user in his enquiry and/or order in such a way that the manufacturer may modify the rating of the circuit-breaker appropriately. Examples of circuit-breakers for special duty are those used for controlling arc furnaces, electrode boilers and, in certain cases, rectifiers. Single-pole operation of a multipole circuit-breaker, for example with a view to single-phase making and breaking, is also a special duty.

8.103.6 Selection of rated duration of short-circuit

The standard value of rated duration of short-circuit (4.7 of IEC 60694) is 1 s.

If, however, a lower or higher duration is necessary, the recommended values of 0,5 s, 2 s and 3 s should be selected as the rated value.

For short-circuit durations greater than the rated duration, the relation between current and time, unless otherwise stated by the manufacturer, is in accordance with the formula:

$$I^2 \times t = \text{constant}$$

For self-tripping circuit-breakers, a rated duration of short-circuit shall be assigned only if the maximum time-lag is greater than the prospective one. In such a case, it shall be defined as above.

8.104 Selection for electrical endurance in networks of rated voltage above 1 kV and up to and including 52 kV

A circuit-breaker class E2 is defined in 3.4.113. Its electrical endurance capability for such service is demonstrated by performing the short-circuit test-duties of 6.106 without intermediate maintenance. This electrical endurance is considered to be sufficient for circuit-breakers used on cable-connected networks where auto-reclosing is not required.

For the more severe conditions of use on an overhead-line connected network, including auto-reclosing duty, a low-maintenance circuit-breaker capable of meeting the electrical endurance requirements specified in 6.112 is recommended.

8.105 Selection for capacitive current switching

Caution is required where capacitor banks are to be installed at substations where cables are already installed, and vice versa, as this can inflict back-to-back switching duties on the controlling circuit-breakers for these circuits. The back-to-back duty may be similar to that detailed in subclause 4.107.4.

9 Information to be given with enquiries, tenders and orders

9.101 Information to be given with enquiries and orders

When enquiring for or ordering a circuit-breaker, the following particulars should be supplied by the enquirer:

a) particulars of systems, i.e. nominal and highest voltages, frequency, number of phases and details of neutral earthing;

b) service conditions including minimum and maximum ambient air temperatures, altitude if over 1 000 m and any special conditions likely to exist or arise, for example unusual exposure to water vapour, moisture, fumes, explosive gases, excessive dust or salt air (see 8.102.5 and 8.102.6);

c) characteristics of circuit-breaker

The following information should be given:

	Type of information	Reference
1)	number of poles	
2)	class: indoor or outdoor	8.102.1
3)	rated voltage	8.102.2
4)	rated insulation level where a choice exists between different insulation levels corresponding to a given rated voltage, or, if other than standard, the desired insulation level	
5)	rated frequency	8.102.3
6)	rated normal current	8.102.4
7)	rated short-circuit breaking current	8.103.1
8)	first-pole-to-clear factor	8.103.2
9)	if other than standard, desired transient recovery voltage for terminal faults	8.103.2
10)	if other than standard, desired characteristics for short-line faults	8.103.2
11)	if other than standard, desired short-circuit making current	8.103.4
12)	rated operating sequence	8.103.5
13)	if other than standard, desired duration of short-circuit	8.103.6
14)	break-time	4.109
15)	if applicable, restrike performance during capacitive current switching (class C1 or C2)	4.107
16)	if applicable, characteristics for capacitive switching conditions (for example, earthing conditions, type of capacitive load, etc.)	4.107
17)	if applicable, rated line-charging breaking current	4.107.1
18)	if applicable, rated cable-charging breaking current	4.107.2
19)	if applicable, rated single capacitor bank breaking current	4.107.3
20)	if applicable, rated back-to-back capacitor bank breaking current	4.107.4
21)	if applicable, rated single capacitor bank inrush making current	4.107.5
22)	if applicable, rated back-to-back capacitor bank inrush making current	4.107.6
23)	if applicable, rated out-of-phase making and breaking current	4.106
24)	the type tests specified under special request (for example artificial pollution and radio interference, etc.)	6.2.8 and 6.3
25)	the frequency of mechanical operations (class M1 or M2)	4.110
26)	if applicable, characteristic for electrical endurance (class E1 or E2 (with/without auto-reclosing duty))	4.111
27)	if applicable, small inductive breaking current	4.108
28)	if applicable, any test exceeding the standardised type, routine and commissioning tests	

d) characteristics of the operating mechanism of circuit-breaker and associated equipment, in particular:
   1) method of operation, whether manual or power;
   2) number and type of spare auxiliary switches;
   3) rated supply voltage and rated supply frequency;
   4) number of releases for tripping, if more than one;
   5) number of releases for closing, if more than one.

e) requirements concerning the use of compressed gas and requirements for design and tests of pressure vessels.

NOTE The enquirer should give information of any special conditions not included above, that might influence the tender or order (see also the note in 8.101).

9.102 Information to be given with tenders

When the enquirer requests technical particulars of a circuit-breaker, the following information (those which are applicable) should be given by the manufacturer, with the descriptive matter and drawings:

a) rated values and characteristics:

	Type of information	**Reference**
1)	number of poles	
2)	class: indoor or outdoor, temperature, ice-coating	8.102.5
3)	rated voltage	8.102.1
4)	rated insulation level	8.102.2
5)	rated frequency	8.102.3
6)	rated normal current	8.102.4
7)	rated short-circuit breaking current	8.103.1
8)	first-pole-to-clear factor	8.103.2
9)	transient recovery voltage for terminal faults	8.103.2
10)	characteristics for short-line faults	8.103.2
11)	rated short-circuit making current	8.103.4
12)	rated operating sequence	8.103.5
13)	rated duration of short-circuit	8.103.6
14)	rated opening time, rated break-time and rated closing time	4.109
15)	restrike performance during capacitive current switching (Class C1 or C2)	4.107
16)	characteristics for capacitive current switching conditions	4.107
17)	rated line-charging breaking current	4.107.1
18)	rated cable-charging breaking current	4.107.2
19)	rated single capacitor bank breaking current	4.107.3
20)	rated back-to-back capacitor bank breaking current	4.107.4
21)	rated single capacitor bank inrush making current	4.107.5
22)	rated back-to-back capacitor bank inrush making current	4.107.6
23)	rated out-of-phase making and breaking current	4.106
24)	the type tests specified under special request (for example artificial pollution and radio interference, etc.)	6.2.8 and 6.3
25)	class M1 or class M2 for mechanical endurance	4.110
26)	class E1 or class E2 (with/without auto-reclose) for electrical endurance	4.111
27)	small inductive breaking current	4.108

b) type tests:

   certificate or report on request;

c) constructional features:

   The following details are required where they are applicable to the design:

   1) mass of complete circuit-breaker without fluids for insulation, interruption and operation;
   2) mass/volume of fluid for insulation, its quality and operating range, including the minimum functional value;
   3) mass/volume of fluid for interruption (where different fluid to items 2) and/or 4)), its quality and operating range, including the minimum functional value;
   4) mass/volume of fluid for operation (where different fluid to items 2) and/or 3)), its quality and operating range, including the minimum functional value;
   5) tightness qualification;
   6) mass/volume of fluids per pole to fill to a level sufficient to prevent deterioration of internal components during storage and transportation;
   7) number of units in series per pole;
   8) minimum clearances in air:
      – between poles;
      – to earth;
      – the safety boundaries during a breaking operation, for circuit-breakers with an external exhaust for ionised gasses or flame;
   9) any special arrangements (for example heating or cooling) to maintain the rated characteristics of the circuit-breaker at the required temperatures of the ambient air;

d) operating mechanism of circuit-breaker and associated equipment:

   1) type of operating mechanism;
   2) whether the circuit-breaker is suitable for trip-free or fixed trip operation and whether it is provided with a lock-out device preventing closing;
   3) rated supply voltage and/or pressure of closing mechanism, pressure limits where different to or expanding data required in c) 4) of 9.102;
   4) current required at rated supply voltage to close the circuit-breaker;
   5) energy expended to close the circuit-breaker, for example measured as a fall in pressure;
   6) rated supply voltage of shunt opening release;
   7) current required at rated supply voltage for shunt opening release;
   8) number and type of spare auxiliary switches;
   9) current required at rated supply voltage by other auxiliaries;
   10) setting of high and low pressure interlocking devices;
   11) number of releases for tripping, if more than one;
   12) number of releases for closing, if more than one;

e) overall dimensions and other information:

The manufacturer should give the necessary information as regards the overall dimensions of the circuit-breaker and details necessary for the design of the foundation.

General information regarding maintenance of the circuit-breaker and its connections should be given.

10 Rules for transport, storage, installation, operation and maintenance

Clause 10 of IEC 60694 is applicable, with the following additions:

10.1 Conditions during transport, storage and installation

Subclause 10.1 of IEC 60694 is applicable.

10.2 Installation

Subclauses 10.2.1 to 10.2.4 of IEC 60694 are applicable, with the following addition:

10.2.101 Guide for commissioning tests

After a circuit-breaker has been installed and all connections have been completed, commissioning tests are recommended to be performed. The purpose of these tests is to confirm that transportation and storage have not damaged the circuit-breaker. In addition, when a large part of the assembly and/or of the adjustment is performed on site, as identified in 7.101, the tests are required to confirm compatibility of the sub-components and the satisfactory nature of both the site work and the functional characteristics dependent upon it.

In addition to the requirements of 10.2.102, a minimum of 50 no-load operations shall be performed on site on the circuit-breaker where major sub-assemblies are combined at site without previous routine tests on the complete circuit-breaker. These operations shall be performed after assembly, all connections and checks having been made and the programme of commissioning tests having been completed. These operations may include deferred routine test operations forming part of the commissioning programme only where they are made after all site adjustments and tightness checks are complete. The purpose of these tests is to reduce occurrences of maloperation and failure early in the operational life of the circuit-breaker.

The manufacturer shall produce a programme of site commissioning checks and tests. Repetition of the full programme of routine tests, already performed in the factory, shall be avoided as the purpose of commissioning tests is for confirmation of

- absence of damage;
- compatibility of separate units;
- correct assembly;
- correct performance of the assembled circuit-breaker.

In general, this is achieved when the commissioning tests include, but are not limited to, the programme given in 10.2.102. The results of the tests shall be recorded in a test report.

10.2.102 Commissioning checks and test programme

10.2.102.1 Checks after installation

Subclause 10.2.101 requires the manufacturer to produce a programme of commissioning checks and tests. This should be based on, but is not limited to, the programme of checks and tests given here.

10.2.102.1.1 General checks

– assembly conforms to manufacturer's drawings and instructions;
– tightness of circuit-breaker, its fastenings, fluid systems and control devices;
– external insulation and, where applicable, internal insulation are undamaged and clean;
– paint and other corrosion protection are sound;
– operating devices, especially operating releases, are free from contamination;
– adequacy and integrity of the earth connection up to and including the interface with the substation earthing system;

and, where applicable:

– record the number on the operations counter(s) at delivery;
– record the number on the operations counter(s) at completion of all site testing;
– record the number on the operations counter(s) at first energisation.

10.2.102.1.2 Checks of electrical circuits

– conformity to the wiring diagram;
– correct operation of signalling (position, alarms, lockouts, etc.);
– correct operation of heating and lighting.

10.2.102.1.3 Checks of the insulation and/or extinguishing fluid(s)

Oil	Type, dielectric strength (IEC 60296), level
SF_6	Filling pressure/density, and quality checks, to confirm the acceptance levels of IEC 60376, IEC 60480 and IEC 61634. These quality checks are not required on sealed equipment and new gas used from sealed bottles. A dewpoint check and a check of the total impurities shall be carried out to confirm the manufacturer's acceptance levels
Gas mixtures	Quality to be confirmed prior to energisation
Compressed air	Quality (if applicable) and pressure

10.2.102.1.4 Checks on operating fluid(s), where filled or added to on site

Hydraulic oil	Level and, unless otherwise agreed, confirmation that the moisture content is sufficiently low to prevent internal corrosion or other damage to the hydraulic system
Nitrogen	Filling pressure and purity (for example oxygen free or 1 % tracer gas)

10.2.102.1.5 Site operations

Confirmation shall be given that the programme of commissioning checks and tests required by 7.101 has been completed and, where applicable, extended by the additional 50 operations required by 10.2.101.

10.2.102.2 Mechanical tests and measurements

10.2.102.2.1 Measurements of the characteristic insulating and/or interrupting fluid pressures (where applicable)

10.2.102.2.1.1 General

The following measurements shall be taken in order to compare them with the values both recorded during the routine tests and guaranteed by the manufacturer. These values serve as the reference for future maintenance and other checks and will enable any drift in operating characteristics to be detected.

These measurements involve a check of the operation of the alarm and lockout devices (pressure switches, relays, transducers, etc.) where applicable.

10.2.102.2.1.2 Measurements to be taken

a) Where applicable, on rising pressure:
   - the reset value of the opening/tripping lockout;
   - the reset value of the closing lockout;
   - the reset value of the auto-reclosing lockout;
   - disappearance of the low-pressure alarm.

b) Where applicable, on dropping pressure:
   - appearance of low-pressure alarm;
   - operating value of lockout of the auto-reclosing feature;
   - operating value of lockout of the closing;
   - operating value of lockout of the opening.

10.2.102.2.2 Measurements of characteristic operating fluid pressures (if applicable)

10.2.102.2.2.1 General

The following measurements (list to be adapted as necessary) should be taken, in order to compare them with the values both recorded during routine tests and guaranteed by the manufacturer. These values may serve as a reference during later checks (maintenance) and will enable any drift in operating characteristics to be detected.

The measurements involve a check of the operation of the lockout or alarm devices (pressure switches, relays, etc.).

10.2.102.2.2.2 Measurements to be taken

a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:
   - the reset value of the opening lockout;
   - the reset value of the closing lockout;
   - the reset value of the auto-reclosing lockout (if applicable);
   - disappearance of the low-pressure alarm;
   - cut-off of the pumping device;
   - opening of the safety valve (if applicable).

NOTE The measurements may be combined with the measurements of the recharging time of the operating mechanism (see 10.2.102.2.5.2).

b) On a drop in pressure with the pumping device switched off:
   - closing of the safety valve (if applicable);
   - starting of the pumping device;
   - appearance of the low-pressure alarm;
   - lockout of the auto-reclosing (if applicable);
   - lockout of the closing;
   - lockout of the opening.

In the case of a hydraulic control, the pre-inflation pressure of the accumulators should be indicated together with the ambient air temperature before the tests are performed.

10.2.102.2.3 Measurement of consumption during operations (if applicable)

With the pumping device switched off and the individual reservoir at the cut-in pressure of the pumping device, the consumption during each of the following operations or sequences should be evaluated:

- O three-pole;
- C three-pole;
- O - 0,3 s - CO three-pole (if applicable).

The steady-state pressure after each operation or operating sequence should be noted.

10.2.102.2.4 Verification of the rated operating sequence

The ability of the circuit-breaker to perform its specified rated operating sequence should be verified. The tests should be performed with the recharging device in service, with site supply voltage and, if applicable, starting with the cut-in pressure of the pumping device, as in 10.2.102.2.3.

Evidence should be given to demonstrate the coordination between the interlocking device intervention levels and the minimum pressures for operation measured during the rated operating sequence.

The site supply voltage is the on-load voltage available at the circuit-breaker from the normal site supply and should be compatible with the rated supply voltage of auxiliary and control circuits.

10.2.102.2.5 Measurement of time quantities

10.2.102.2.5.1 Characteristic time quantities of the circuit-breaker

a) Closing and opening times, time spread

The following measurements should be made at maximum pressure (cut-off of pumping device) and at the supply voltage, measured at the terminals of the equipment with full current flowing:

– closing time of each pole, time spread of the poles and when possible time spread of the breaking units or groups of units of each pole;
– opening time of each pole, time spread of the poles and when possible time spread of the breaking units or groups of units of each pole.

In the case of multiple trip coils, all should be tested and the times recorded for each.

The supply voltage before and during the operations should be recorded. Furthermore the instant at which the three-pole control relay, if any, is energised should also be recorded to enable calculation of the total time in three-pole operation (relay time plus closing or opening time).

When the circuit-breaker is provided with resistor closing or opening units, the resistor insertion times should be recorded.

b) Operation of control and auxiliary contacts

The timing of the operation of one of each kind (make and break) of control and auxiliary contacts should be determined in relation to the operation of the main contacts, on closing and on opening of the circuit-breaker.

10.2.102.2.5.2 Recharging time of the operating mechanism

a) Fluid-operated mechanism

The operation time of the pumping device (pump, compressor, control valve, etc.) should be measured:

– between minimum and maximum pressure (cut-in and cut-off of the pumping device);
– during the following operations or operating sequence, starting each time with minimum pressure (cut-in of the pumping device):
  – C three-pole;
  – O three-pole;
  – O - 0,3 s - CO three-pole (if applicable).

b) Spring-operated mechanism

The recharging time of the motor after a closing operation should be measured at the site supply voltage.

10.2.102.2.6 Record of mechanical travel characteristics

As required by 7.101, a record can be made of the mechanical travel characteristics where the circuit-breaker has been assembled as a complete circuit-breaker for the first time on site or where all or part of the routine tests are performed on site. The record shall confirm satisfactory performance by comparison with the reference mechanical travel characteristics obtained during the reference no-load tests detailed in 6.101.1.1.

10.2.102.2.7 Checks of certain specific operations

10.2.102.2.7.1 Auto-reclosing at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered to the lockout value for auto-reclosing and an auto-reclosing operating sequence be carried out (under site conditions it may be necessary to use a separate timing device to initiate reclosure). The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted and it should be ensured that there is sufficient safety margin to the minimum functional pressure for operation for opening, as a guard against pressure switch deviation and pressure transients.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the minimum functional pressure for operation for auto-reclosing (short-circuited contact). It should then be verified that an opening operation is still possible.

10.2.102.2.7.2 Closing at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for closing and a closing operation be carried out. The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted and a sufficient safety margin ensured to the minimum functional pressure for operation for opening.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the minimum functional pressure for operation for closing (short-circuited contact). It should then be verified that an opening operation is still possible.

10.2.102.2.7.3 Opening at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for opening and an opening operation be carried out. The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted.

10.2.102.2.7.4 Simulation of fault-making operation and check of anti-pumping device

Measurement should be taken of the time during which the circuit-breaker remains closed on a CO operating cycle with the trip circuit energised by the closing of the auxiliary contact.

The test also allows checking of the anti-pumping device operation and the absence of malfunction for any mechanical, hydraulic or pneumatic reasons, caused by the rapid application of the opening command.

The closing command should be maintained for 1 s to 2 s in order that the anti-pumping device can be checked for effective operation.

NOTE A simplified anti-pumping test may also be executed, using the local control. In this case, a closing command is applied and maintained, while a consecutive opening command is applied.

10.2.102.2.7.5 Behaviour of the circuit-breaker on a closing command while an opening command is already present

It should be verified that the circuit-breaker meets the technical specifications in the presence of a closing command when previously an opening command is applied and maintained.

10.2.102.2.7.6 Application of an opening command on both releases simultaneously (if applicable)

It may happen that both releases (normal and emergency) are energised simultaneously (or virtually simultaneously).

It should be ensured that the operations are not subject to any mechanical, hydraulic or pneumatic interference, particularly if the releases do not operate at the same level.

10.2.102.2.7.7 Protection against pole discrepancy (if applicable)

Protection against pole discrepancy should be checked by either of the following tests:

– with the circuit-breaker open, the closing release of one of the poles shall be energised and a check carried out to see that it closes and then opens;
– with the circuit-breaker closed, the opening release of one of the poles shall be energised and a check carried out to see that the other two poles open.

10.2.102.3 Electrical tests and measurements

10.2.102.3.1 Dielectric tests

Dielectric tests on auxiliary circuits shall be performed to confirm that transportation and storage of the circuit-breaker have not damaged these circuits. However, it is recognised that such circuits contain vulnerable sub-components and the application of the full testing voltage for the full duration can cause damage. In order to avoid this, and to avoid the temporary removal of proven connections, the supplier shall detail the test process that demonstrates that damage has not occurred as well as the method of recording the results from this test process.

For dielectric tests on the main circuit of metal-enclosed switchgear and controlgear, IEC 60298 [8] and IEC 60517 [9] are applicable.

10.2.102.3.2 Measurement of the resistance of the main circuit

Measurement of the resistance of the main circuit need only be made if interrupting units have been assembled on site. The measurement shall be made with a direct current in accordance with 7.3 of IEC 60694.

10.3 Operation

Subclause 10.3 of IEC 60694 is applicable.

10.4 Maintenance

Subclause 10.4 of IEC 60694 is applicable with the following addition:

In addition, the manufacturer should give information regarding the maintenance of circuit-breakers following

a) short-circuit operations;

b) operations in normal service.

This information should include the number of operations according to items a) and b) after which the circuit-breaker is to be overhauled.

Subclauses 10.4.1 to 10.4.3 of IEC 60694 are applicable. The checks required in 10.2.102.1.3 apply.

10.4.101 Resistors and capacitors

When checking resistors and capacitors, allowed variations of the values should be given.

11 Safety

Clause 11 of IEC 60694 is applicable with the following addition:

Any known chemical and environmental impact hazards should be identified in the circuit-breaker handbook/manual.

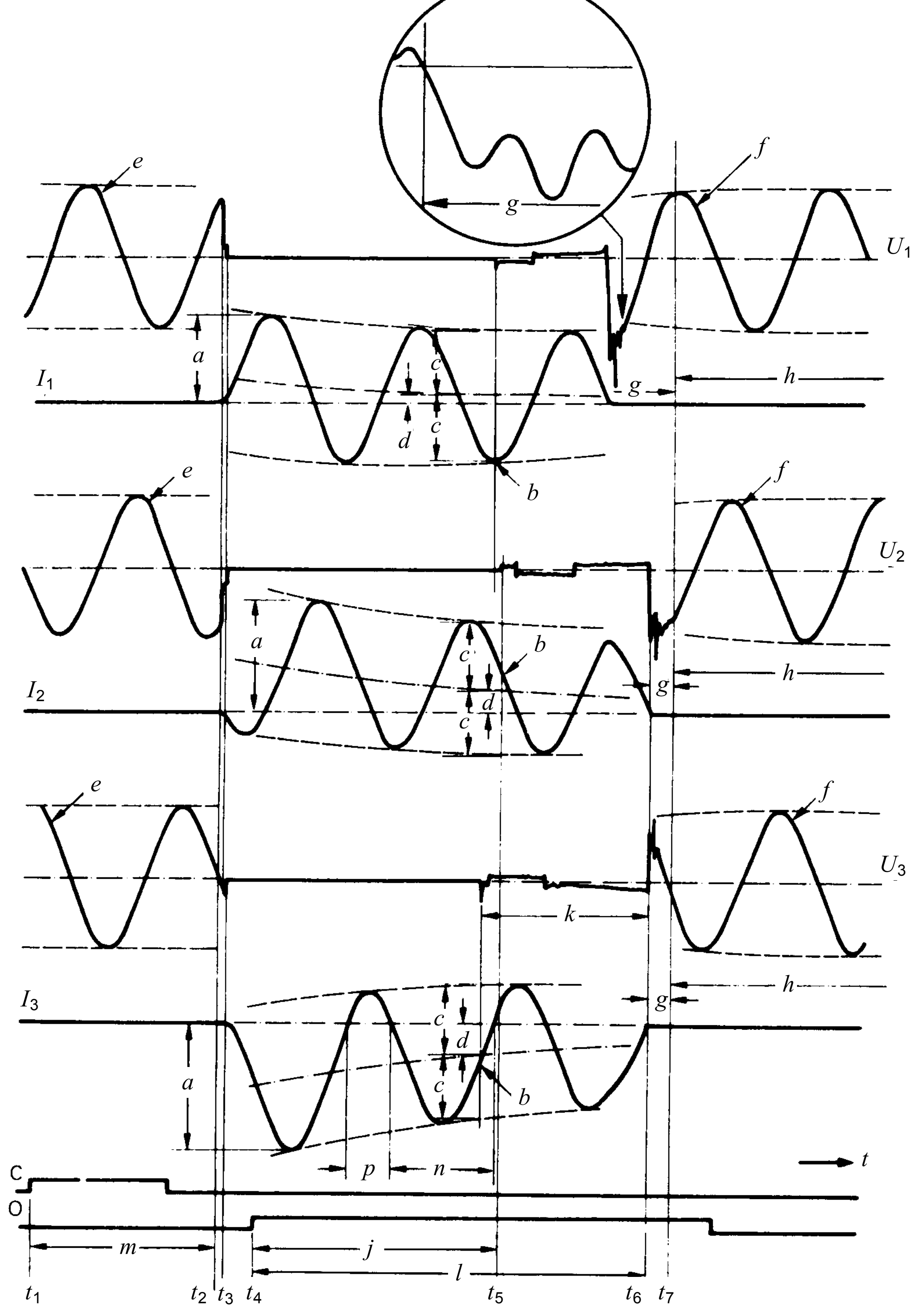


Figure 1 – Typical oscillogram of a three-phase short-circuit make-break cycle

Legend to figure 1:

U_1	voltage across the terminals of the first pole to clear
I_1	current in the first pole to clear
U_2, U_3	voltage across the terminals of the two other poles
I_2, I_3	current in the two other poles
C	closing command, e.g. voltage across the terminals of the closing circuit
O	opening command, e.g. voltage across the terminals of the opening release
t_1	the instant of initiation of the closing operation
t_2	the instant when the current begins to flow in the main circuit
t_3	the instant when the current is established in all poles
t_4	the instant of energizing the opening release
t_5	the instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles
t_6	the instant of final arc extinction in all poles
t_7	the instant when the transient voltage phenomena have subsided in the last pole to clear

a	(peak) making current
b	breaking current
c	peak value of the alternating component
d	direct current component
e	applied voltage
f	recovery voltage
g	transient recovery voltage
h	power frequency recovery voltage
j	opening time
k	arcing time
l	break time
m	make time
n	major loop
p	minor loop

Notes to the following figures 2 to 7:

NOTE 1 In practice, there will be a time spread between the travel of the contacts of the three poles. For clarity the travel of the contacts in the figures is indicated with a single line for all three poles.

NOTE 2 In practice, there will be a time spread between both the start and end of current flow in the three poles. For clarity, both the start and end of current flow in the figures is indicated with a single line for all three poles.

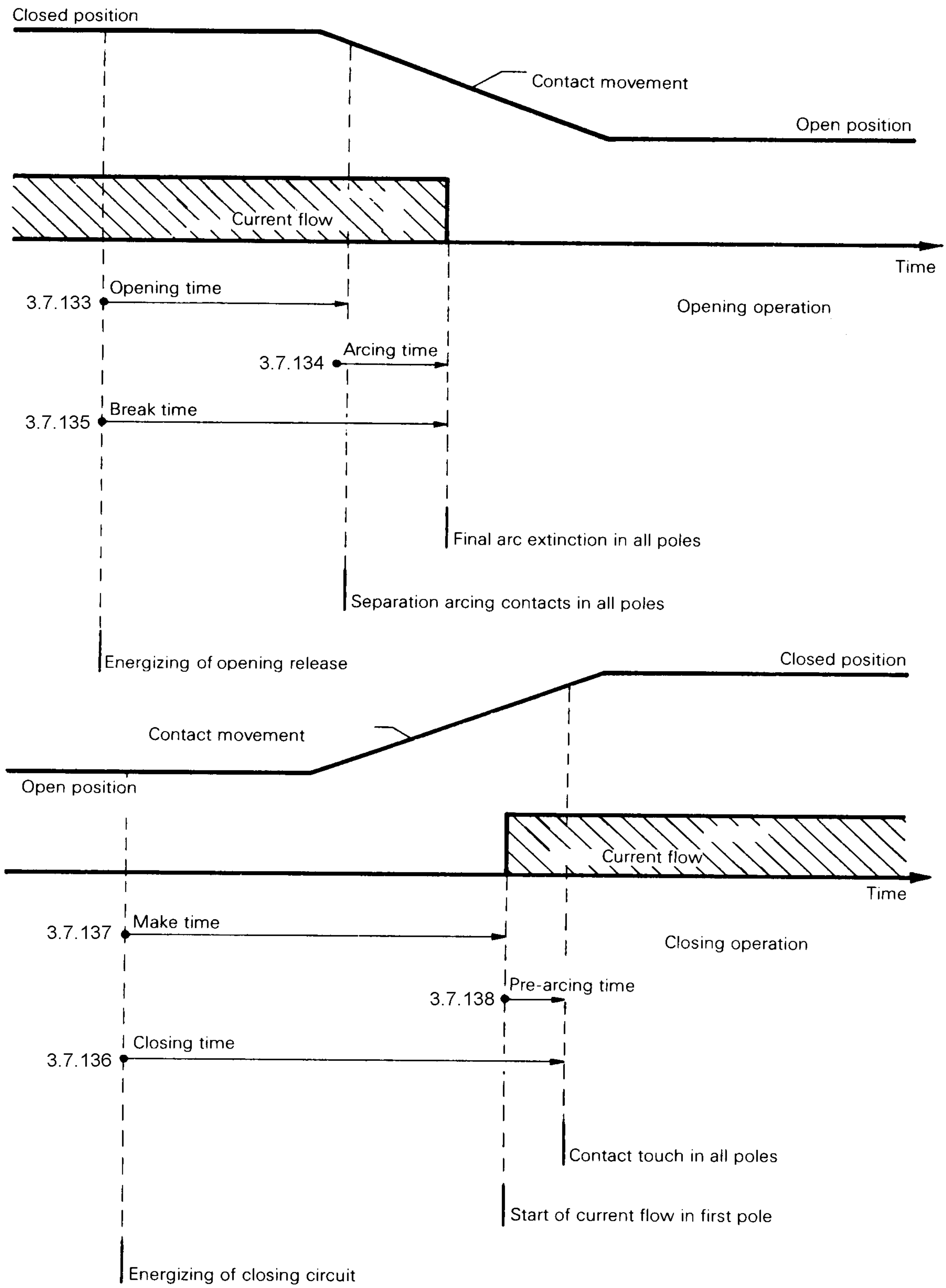


Figure 2 – Circuit-breaker without switching resistors. Opening and closing operations

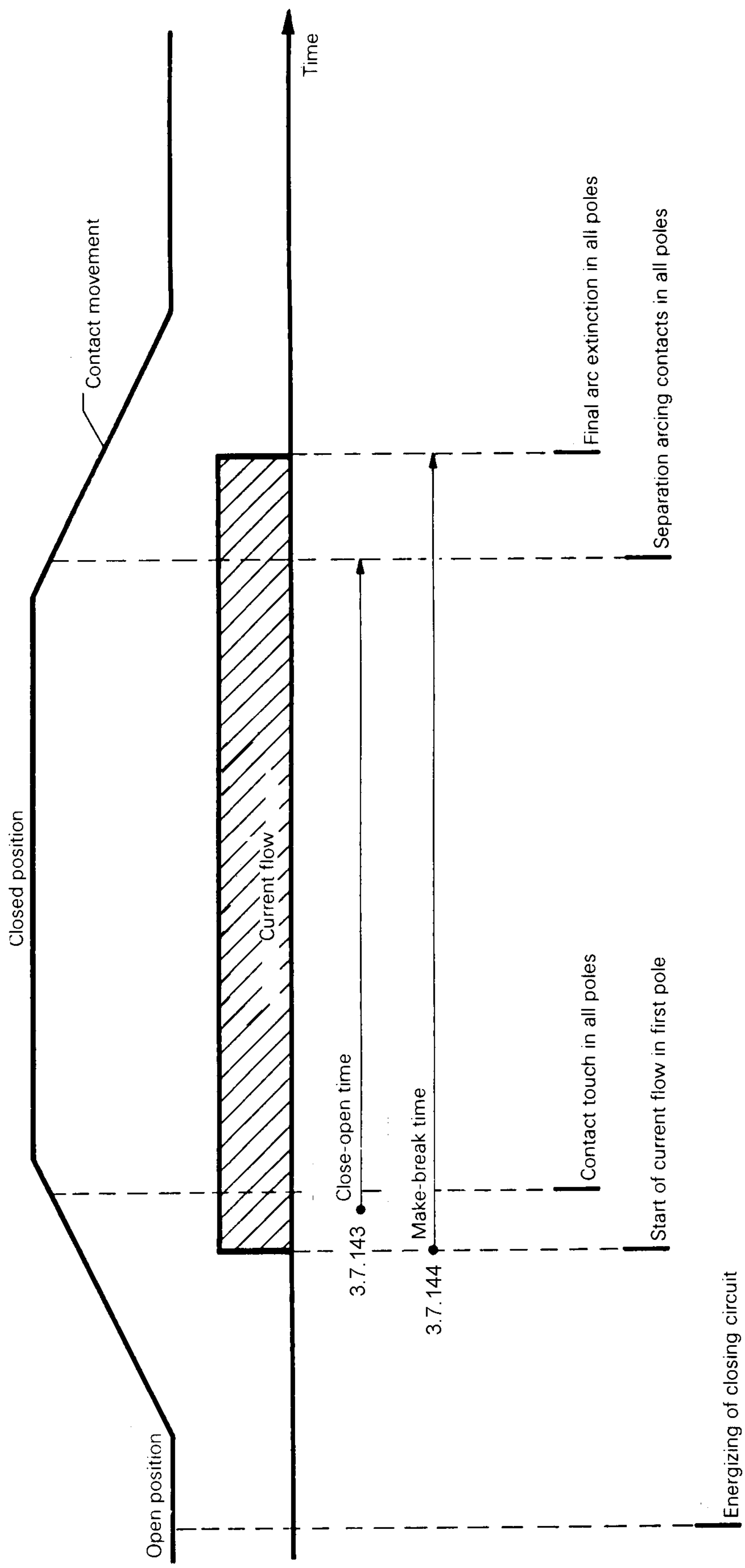


Figure 3 – Circuit breaker without switching resistors – Close-open cycle

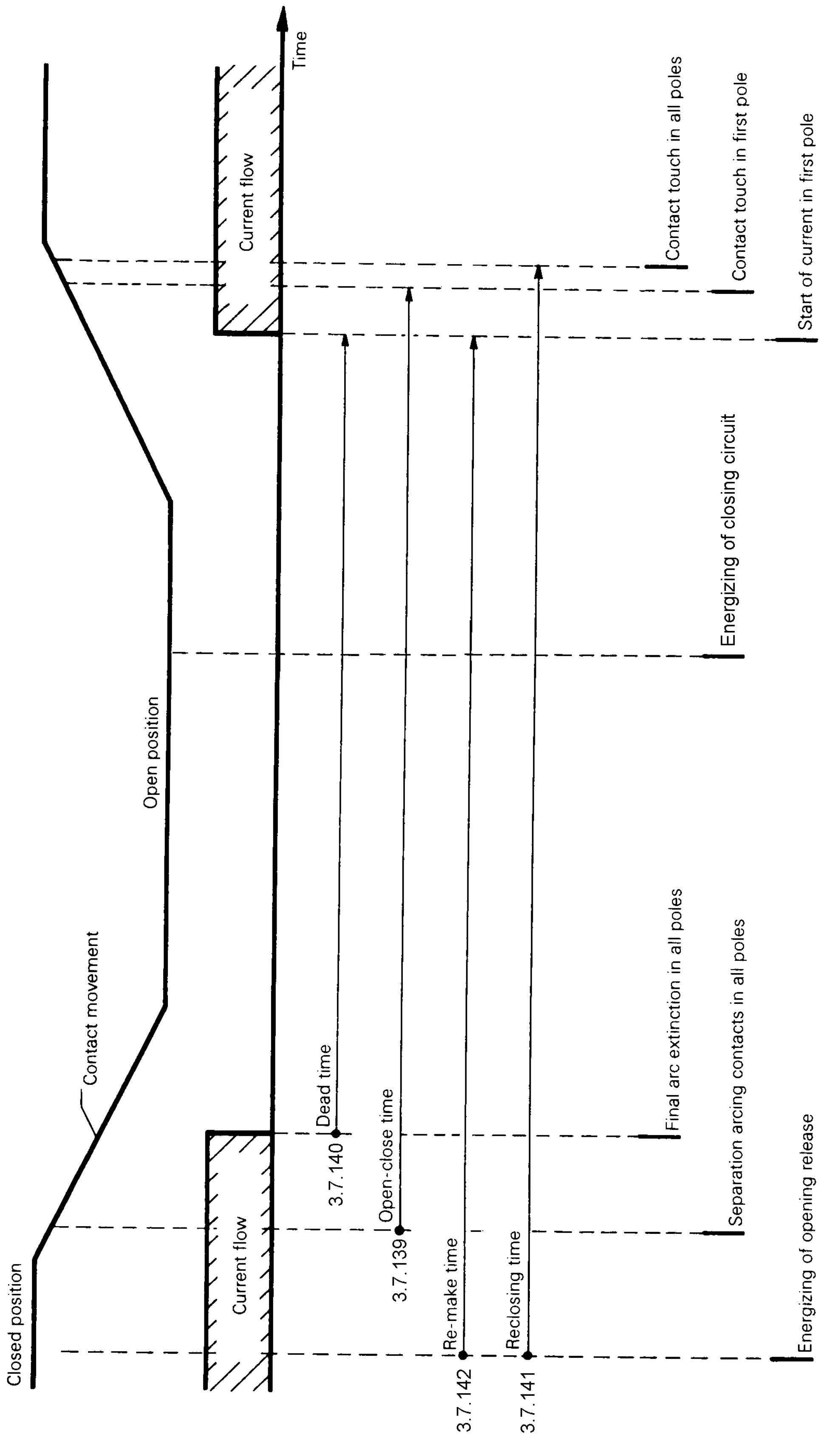


Figure 4 – Circuit-breaker without switching resistors – Reclosing (auto-reclosing)

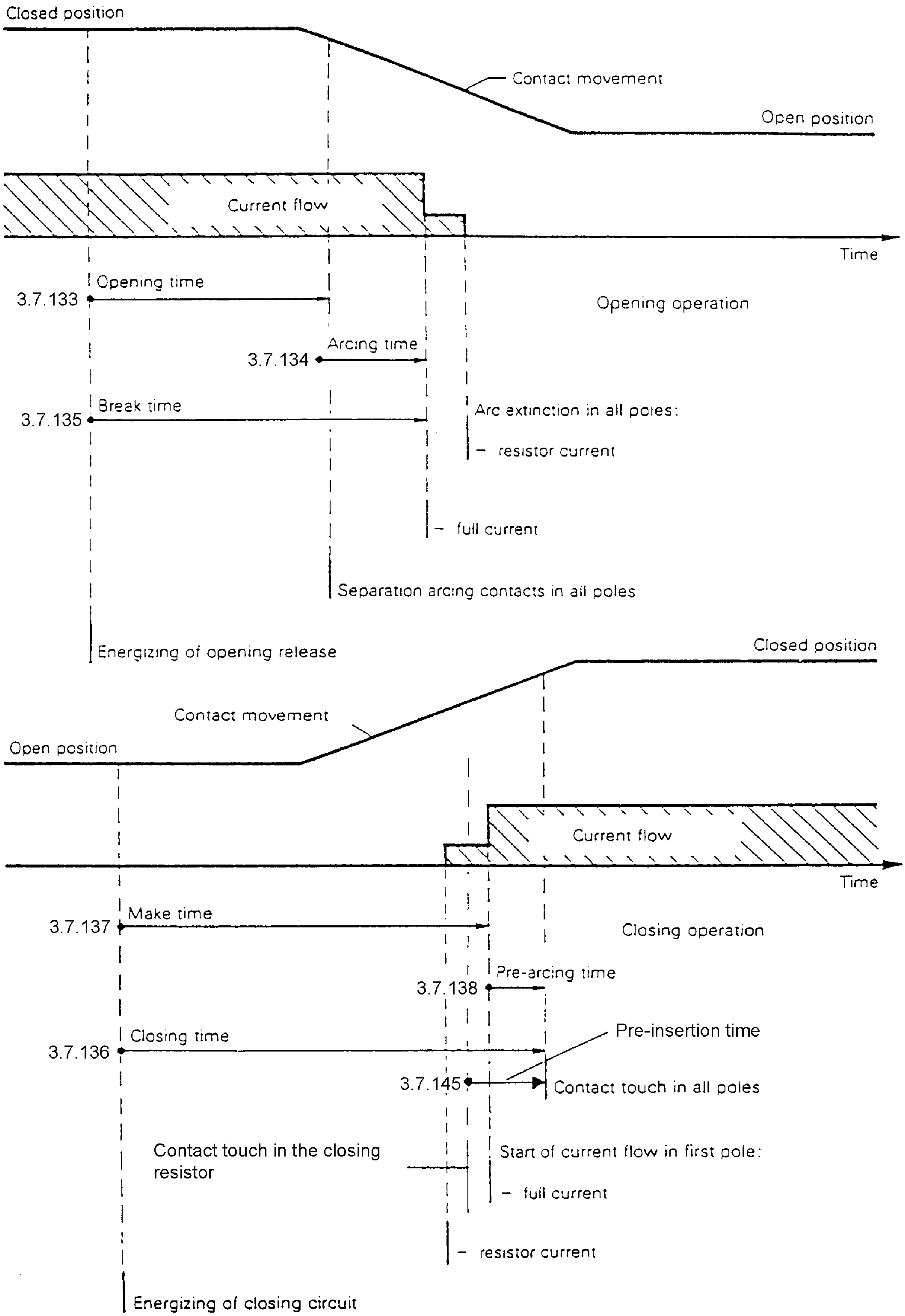


Figure 5 – Circuit-breaker with switching resistors. Opening and closing operations

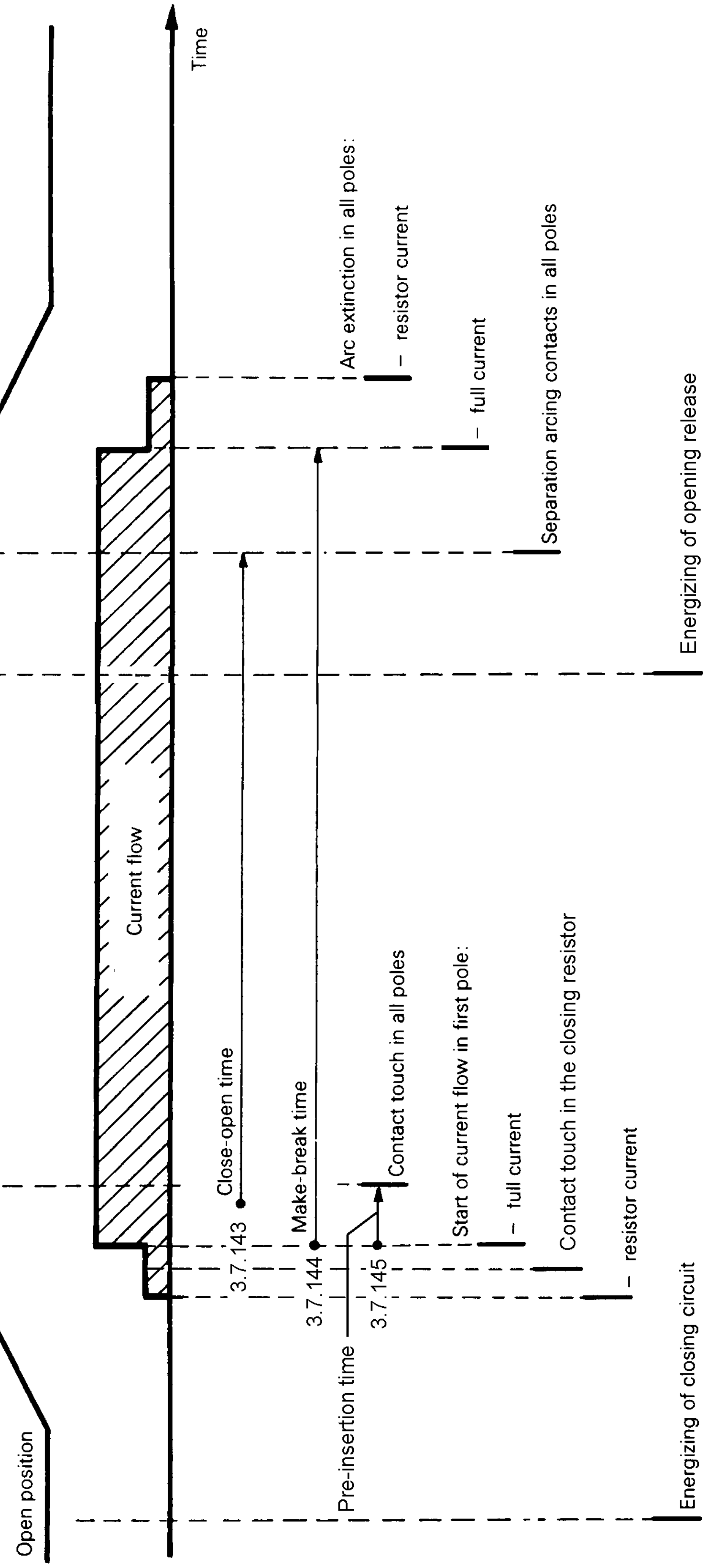


Figure 6 – Circuit-breaker with switching resistors – Close-open cycle

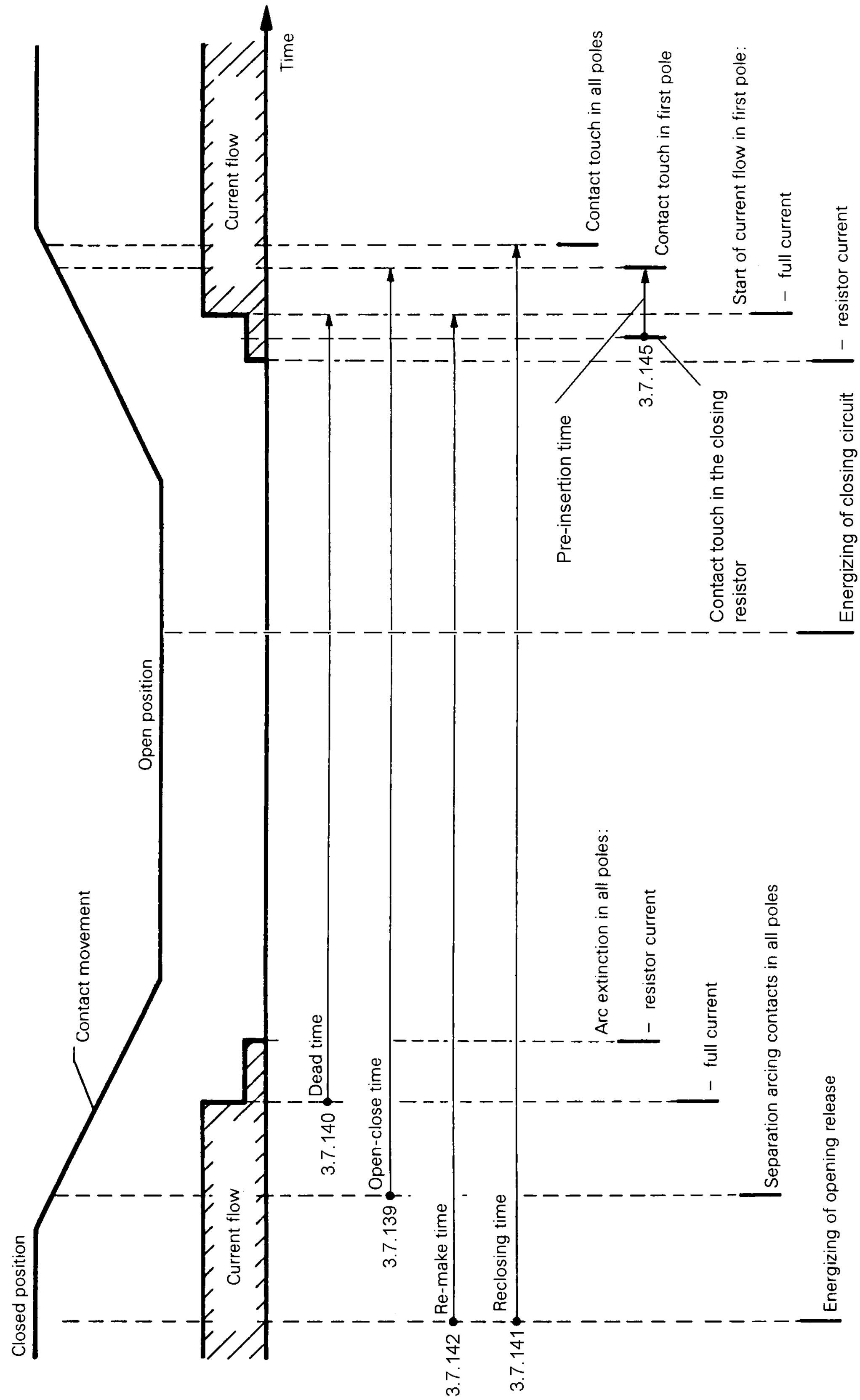
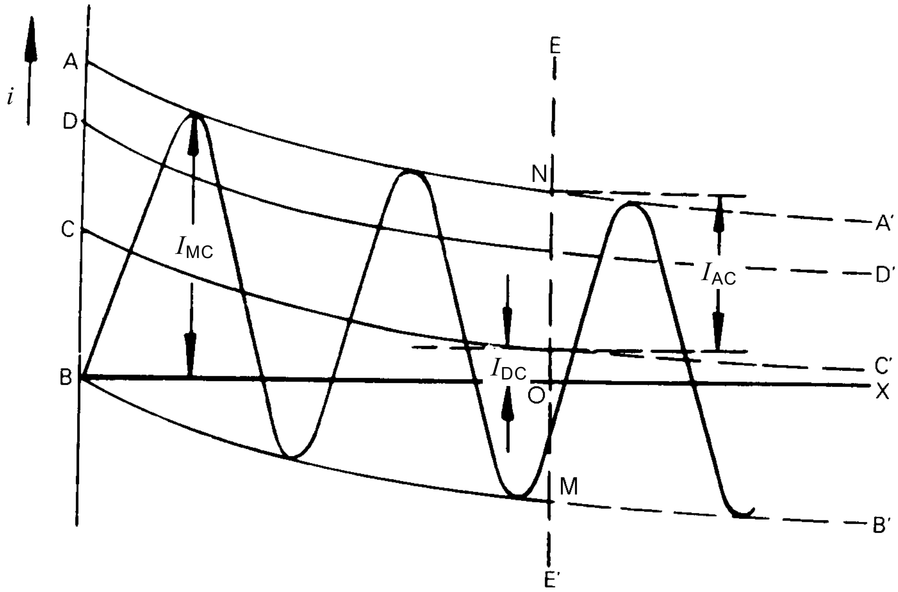


Figure 7 – Circuit-breaker with switching resistors – Reclosing (auto-reclosing)



AA' BB' }	envelope of current-wave
BX	normal zero line
CC'	displacement of current-wave zero-line at any instant
DD'	r.m.s. value of the a.c. component of current at any instant, measured from CC'
EE'	instant of contact separation (initiation of the arc)
I_{MC}	making current
I_{AC}	peak value of a.c. component of current at instant EE'
$\frac{I_{AC}}{\sqrt{2}}$	r.m.s. value of the a.c. component of current at instant EE'
I_{DC}	d.c. component of current at instant EE'

$$\frac{I_{DC}}{I_{AC}} \cdot 100 = \frac{\overline{ON} - \overline{OM}}{\overline{MN}} \cdot 100$$ percentage value of the d.c. component

Figure 8 – Determination of short-circuit making and breaking currents, and of percentage d.c. component

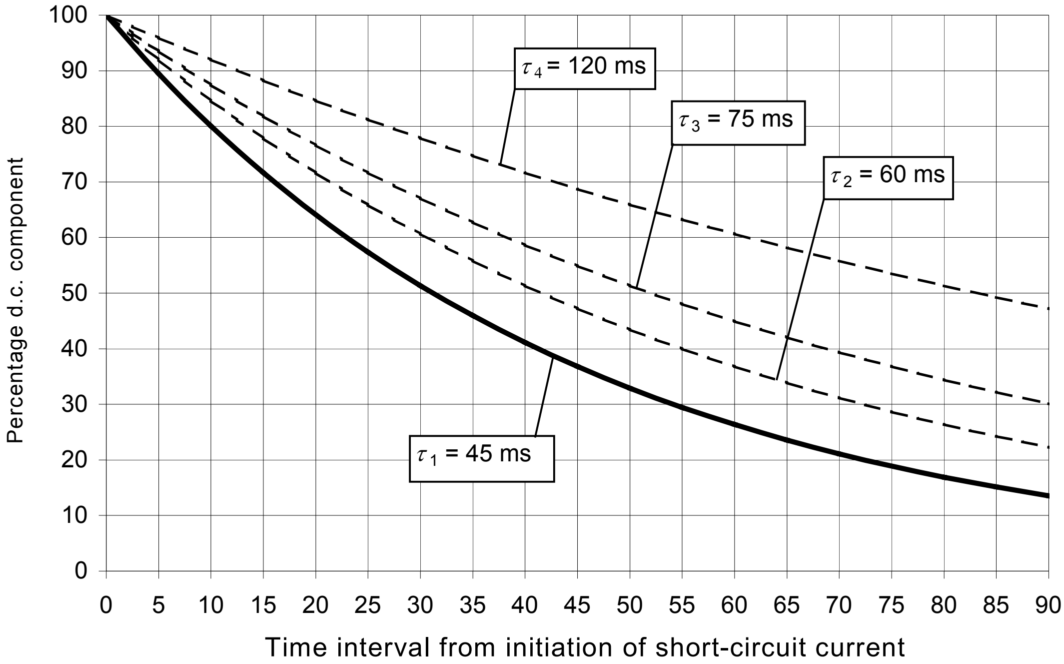


Figure 9 – Percentage d. c. component in relation to the time interval (T_{op} + T_r) for the standard time constant τ_1 and for the special case time constants τ_2, τ_3 and τ_4

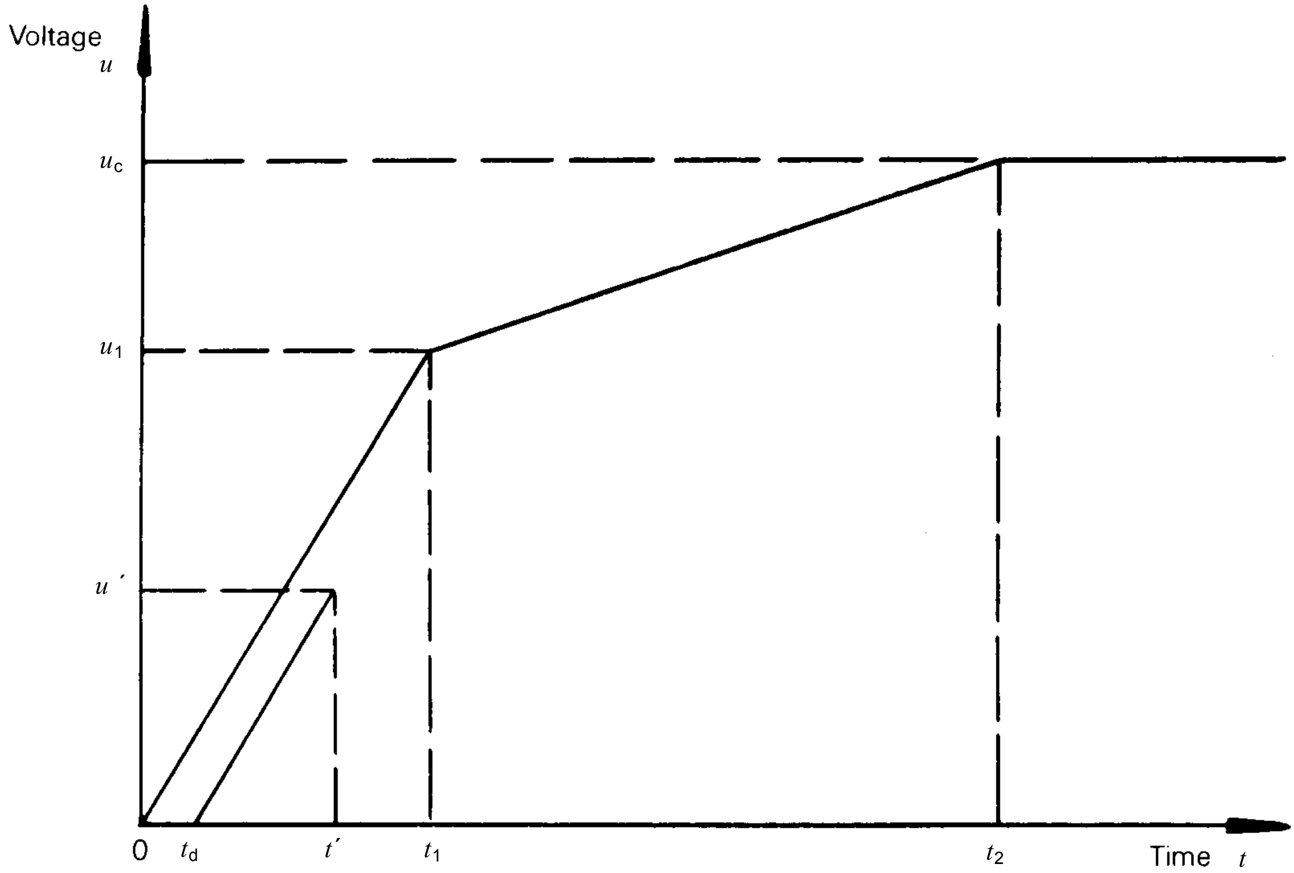


Figure 10 – Representation of a specified TRV by a four-parameter reference line and a delay line

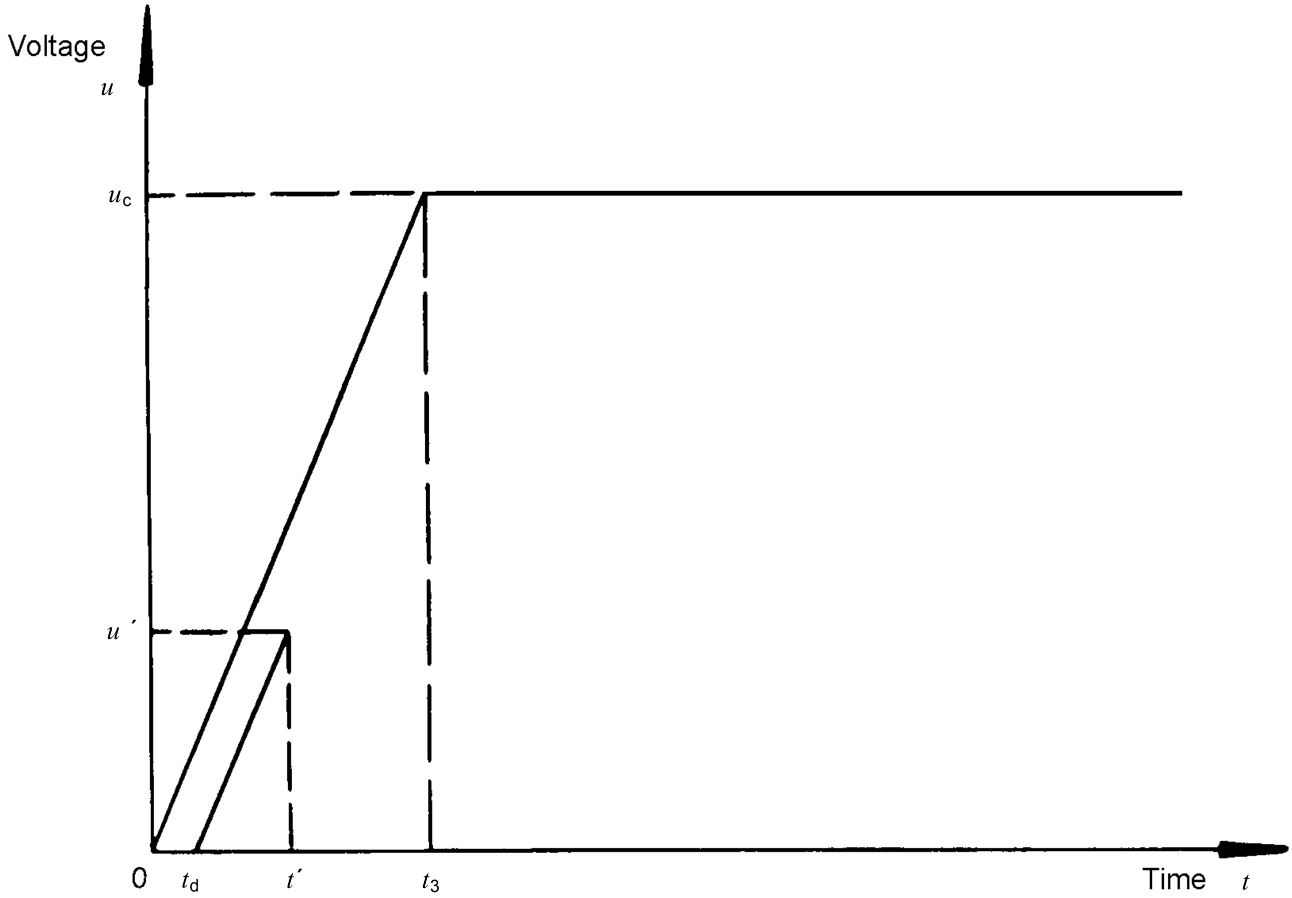
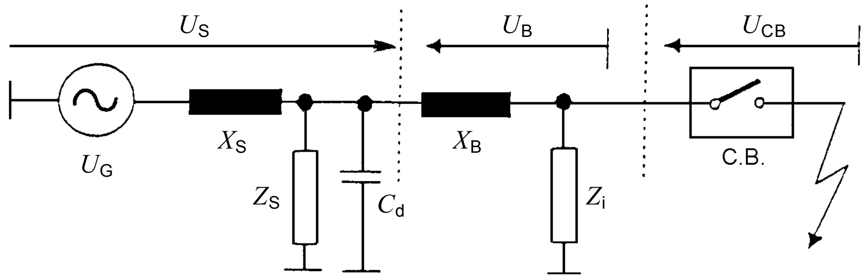


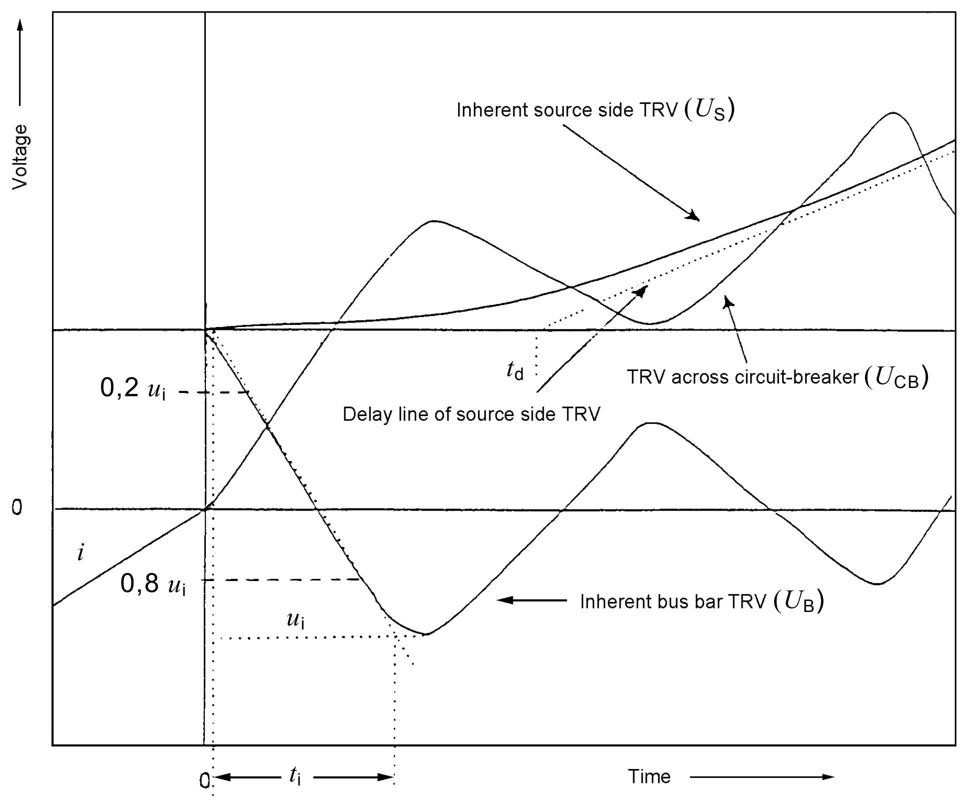
Figure 11 – Representation of a specified TRV by a two-parameter reference line and a delay line



C.B.	circuit-breaker	C_a	time delaying source side capacitance
U_G	supply side voltage	Z_s	source side TRV control components
U_B	bus voltage	Z_i	ITRV controlling components
U_{CB}	voltage across circuit-breaker	X_S	power frequency source side reactance
U_s	voltage across source side reactance	X_B	power frequency busbar reactance

NOTE If a lumped inductance is used as X_S, the ITRV controlling components may be connected in parallel to this inductance.

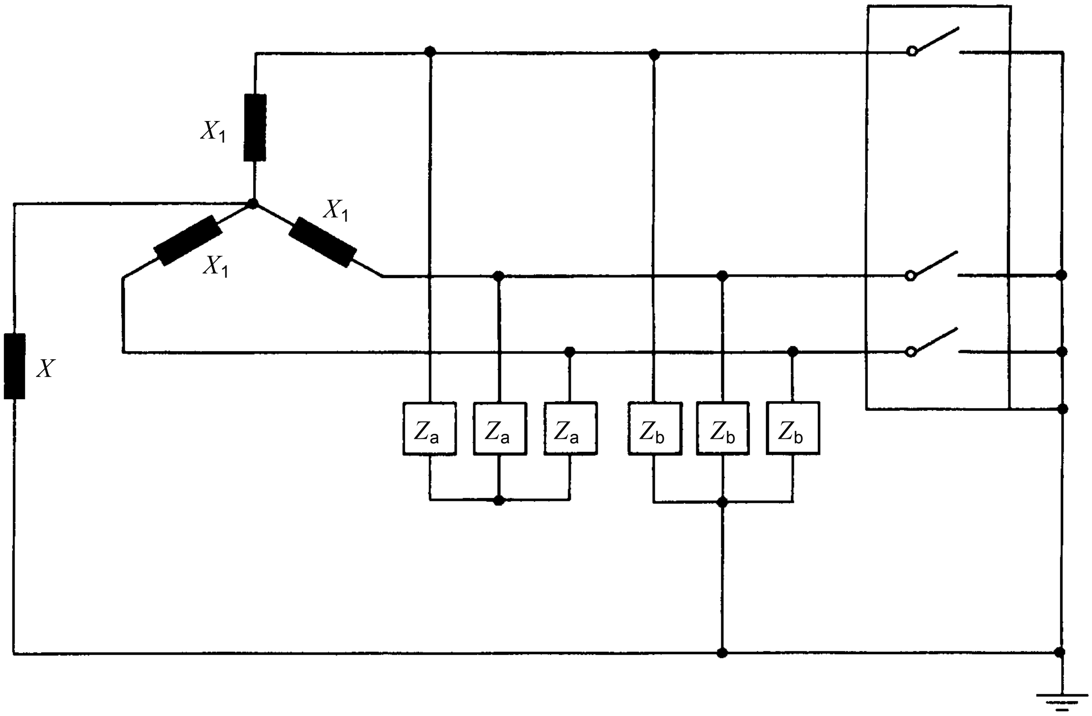
Figure 12a – Basic circuit for terminal fault with ITRV



u_i peak voltage of ITRV

t_i time co-ordinate of ITRV

Figure 12b – Representation of ITRV in relationship to TRV



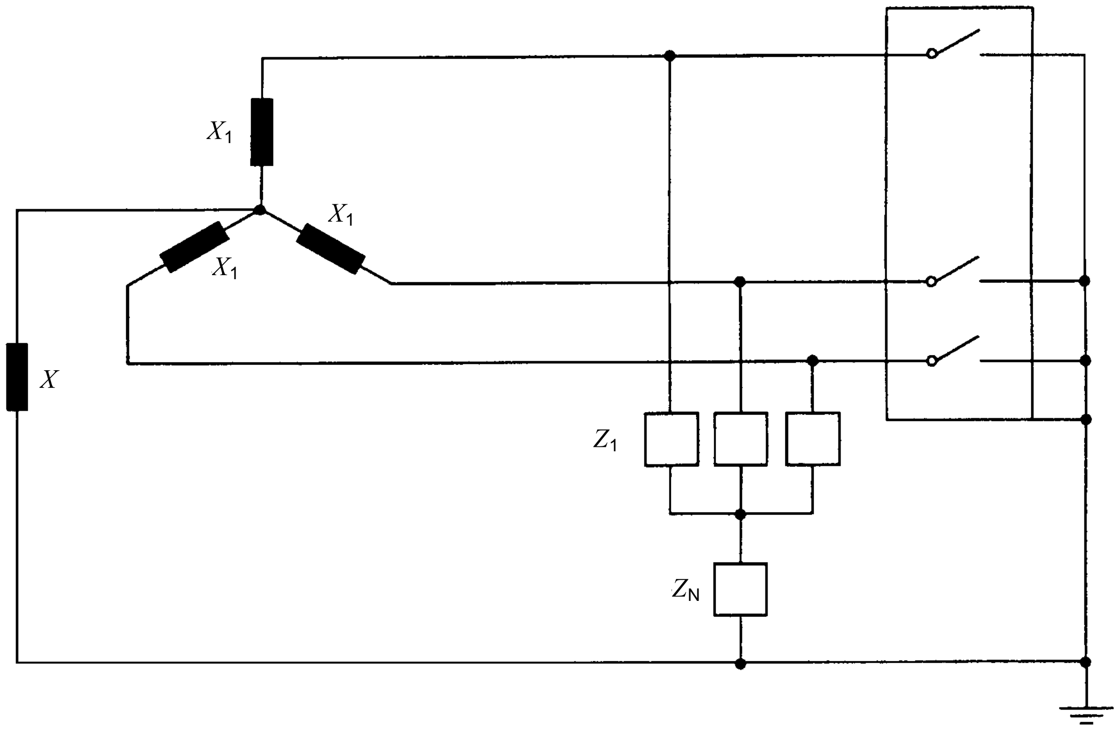
X_N : ∞ for first-pole-to-clear factor of 1,5

X_N : 0,75 X_1 for first-pole-to-clear factor of 1,3

for $Z_0/Z_1 \approx 2$:

$Z_a = Z_b = 2Z_1$

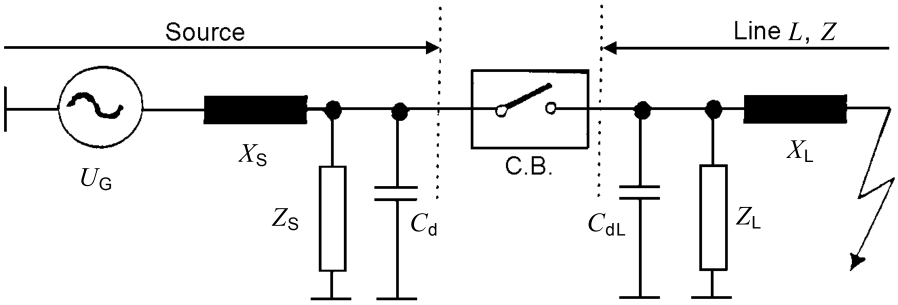
Figure 13 – Three-phase short-circuit representation



for $Z_0/Z_1 = 2$:

$Z_N = 1/3\ Z_1$

Figure 14 – Alternative representation of figure 13



U_G	supply voltage, phase to earth value	X_L	power frequency line side reactance
X_S	power frequency source side reactance	Z_L	line side TRV controlling components
Z_S	source side TRV controlling components	C_{dL}	time delaying line side capacitance
C_a	time delaying source side capacitance	Z	surge impedance of line
C.B.	circuit-breaker	L	length of line to fault

Figure 15 – Basic short-line fault circuit

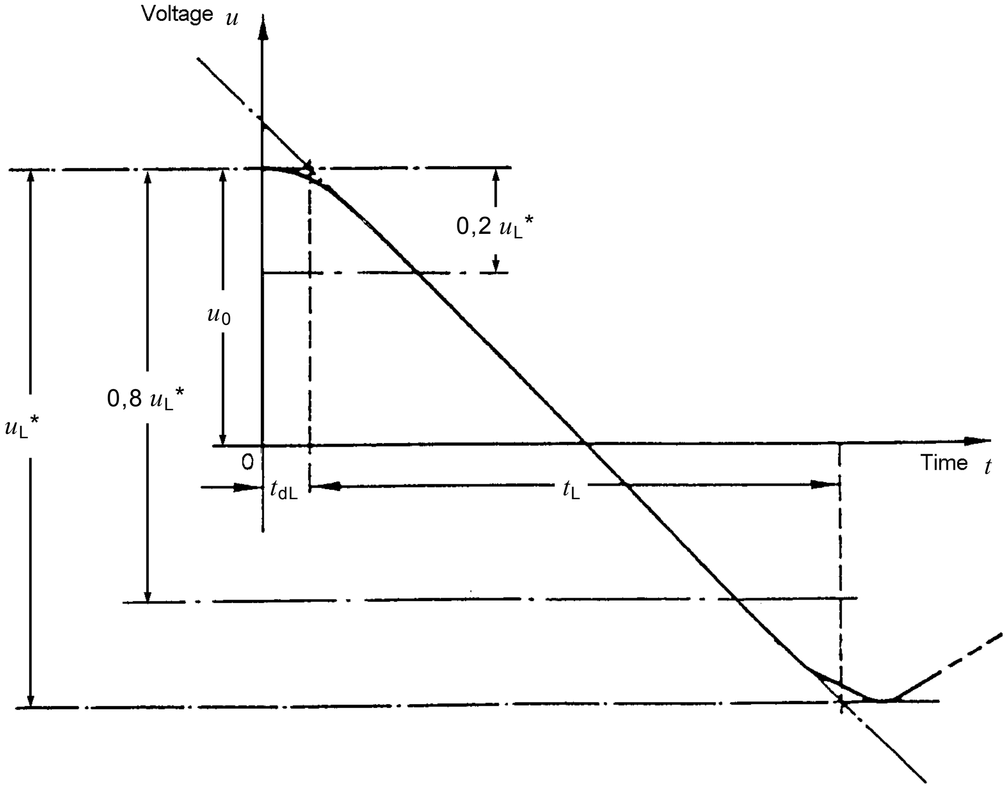
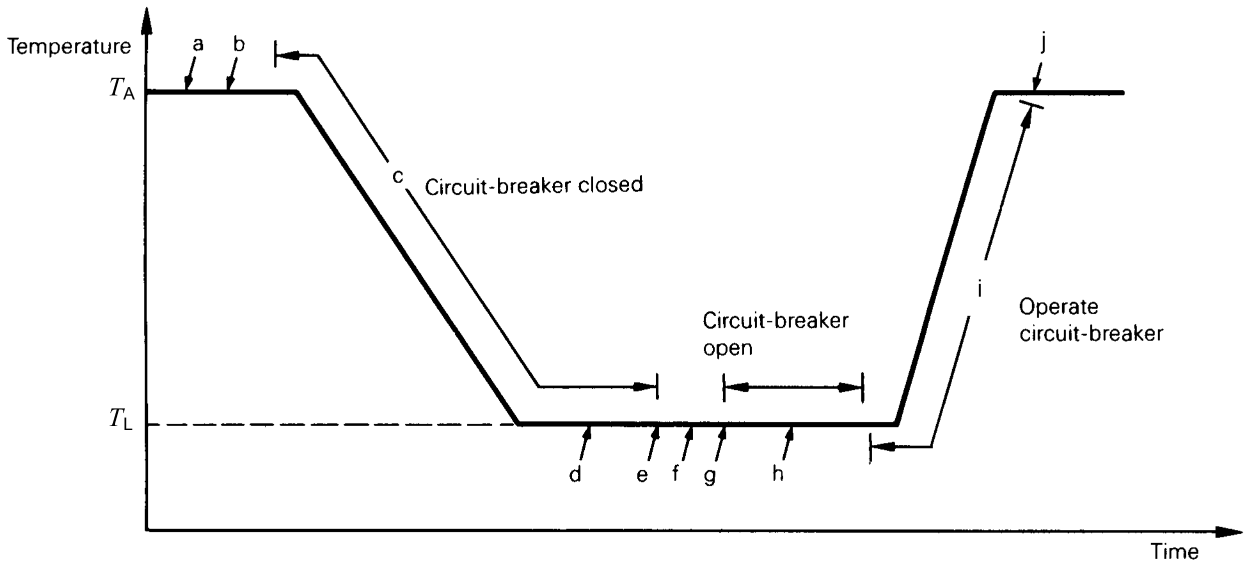
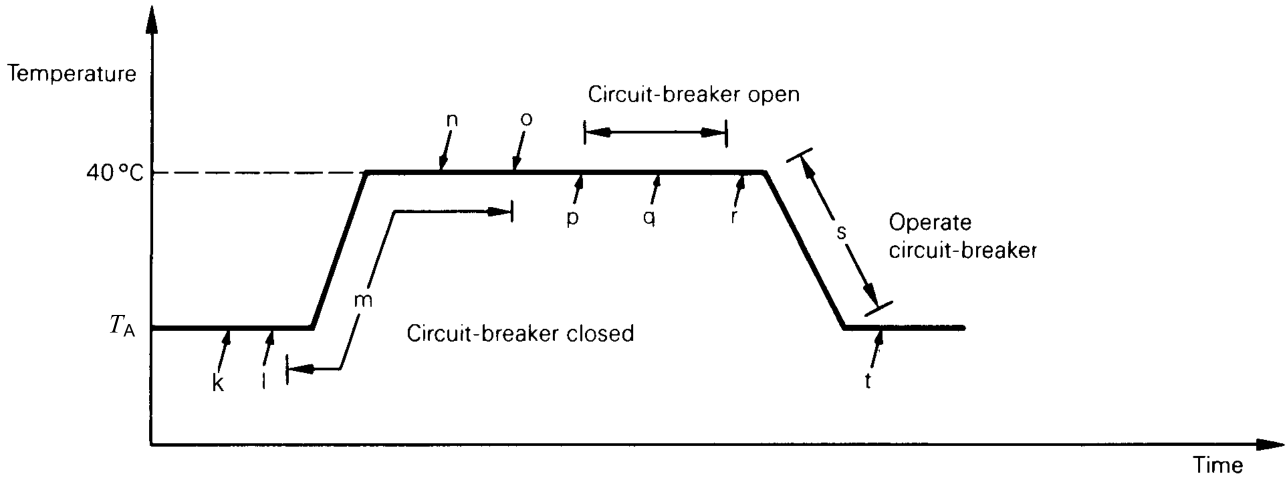


Figure 16 – Example of a line-side transient voltage with time delay and rounded crest showing construction to derive the values u^*_L, t_L and t_{dL}



a) Low temperature test



b) High temperature test

NOTE Letters a to t identify application points of tests specified in 6.101.3.3 and 6.101.3.4.

Figure 17 – Test sequences for low and high temperature tests

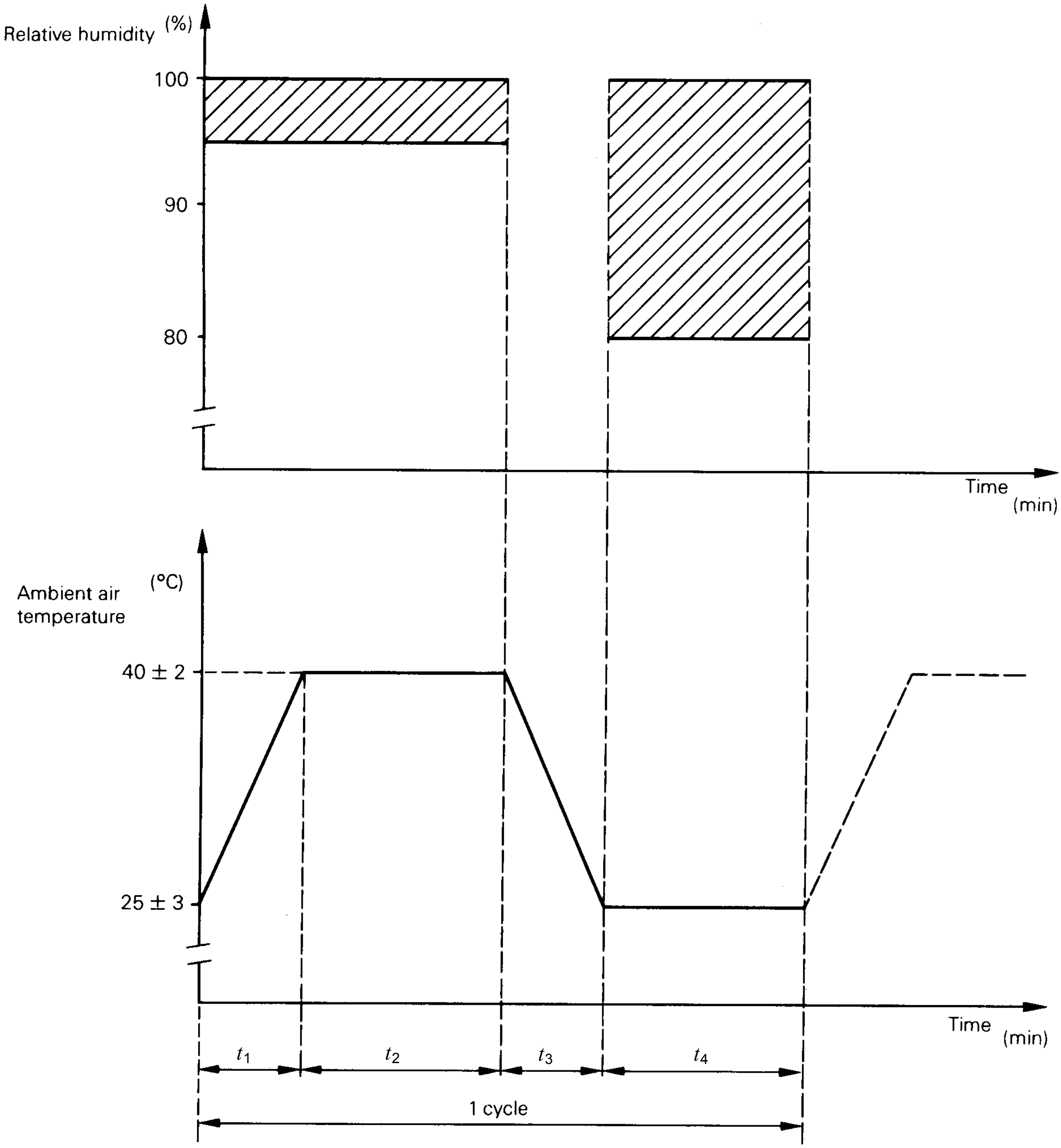
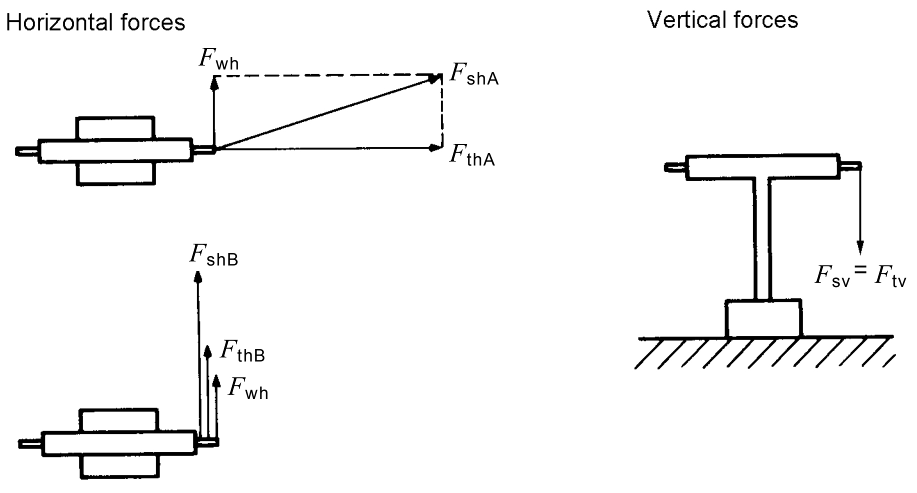


Figure 18 – Humidity test

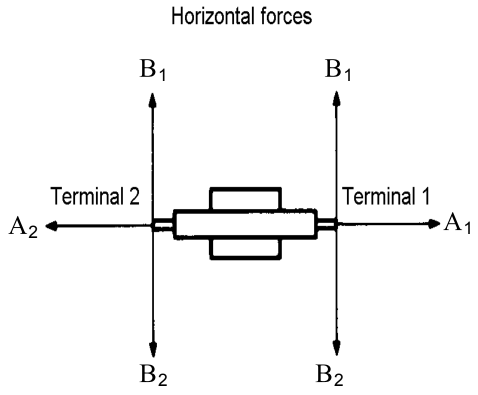


F_{thA}	tensile horizontal force due to connected conductors (direction A)
F_{thB}	tensile horizontal force due to connected conductors (direction B)
F_{tv}	tensile vertical force due to connected conductors (direction C)
F_{wh}	horizontal force on circuit-breaker due to wind pressure on ice-coated circuit-breaker
F_{shA}, F_{shB}, F_{sv}	rated static terminal load (resultant forces)

NOTE Refer to figure 20 for directions A, B and C.

Figure 19 – Static terminal load forces

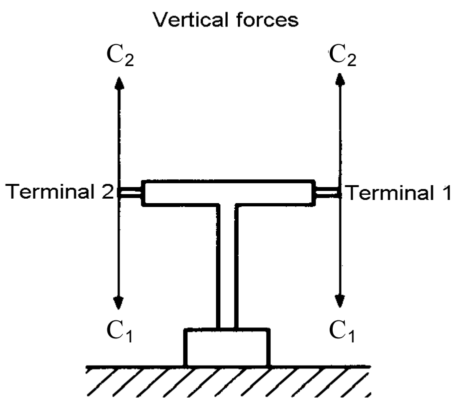
	Horizontal	Vertical	Remark
Forces due to dead weight, wind and ice on connected conductor	F_{thA}, F_{thB}	F_{tv}	According to table 9
Forces due to wind and ice on circuit-breaker*	F_{wh}	O	Calculated by manufacturer
Resultant force	F_{shA}, F_{shB}	F_{sv}	
* The horizontal force on the circuit-breaker, due to wind, may be moved from the centre of pressure to the terminal and reduced in magnitude in proportion to the longer lever arm. (The bending moment at the lowest part of the circuit-breaker should be the same.)			



Force directions: A_1, B_1, B_2 for Terminal 1

Force directions: A_2, B_1, B_2 for Terminal 2

Horizontal test forces: F_{shA} and F_{shB} (see figure 19)



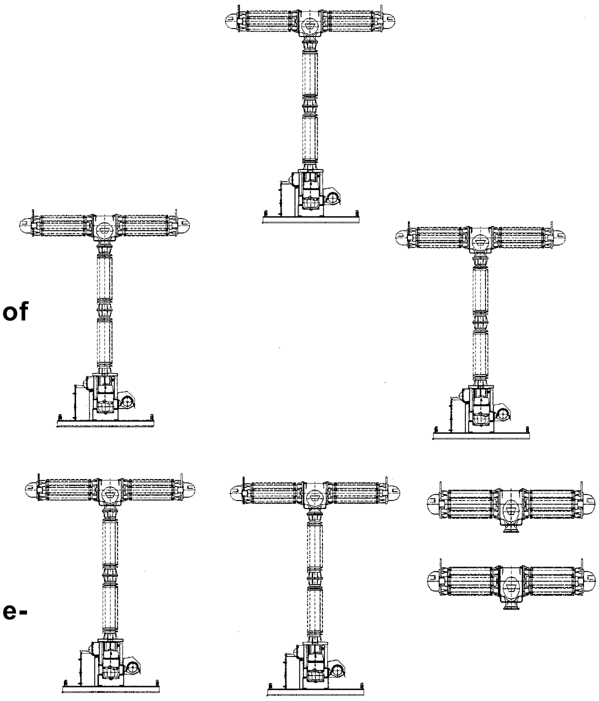
Force directions: C_1, C_2, for Terminal 1

Force directions: C_1, C_2, for Terminal 2

Vertical test forces (both directions): F_{sv} (see figure 19)

NOTE For circuit-breakers which are symmetrical about the pole unit vertical centreline, only one terminal needs to be tested.

Figure 20 – Directions for static terminal load tests



Recommended	1 specimen
Several test-duties during one occupation of the laboratory	2 specimens
Independent operating mechanism for each pole, tested single-phase	2 specimens + interrupting units of up to two poles

Figure 21 – Permitted number of samples for making, breaking and switching tests, illustrations of the statements in 6.102.2

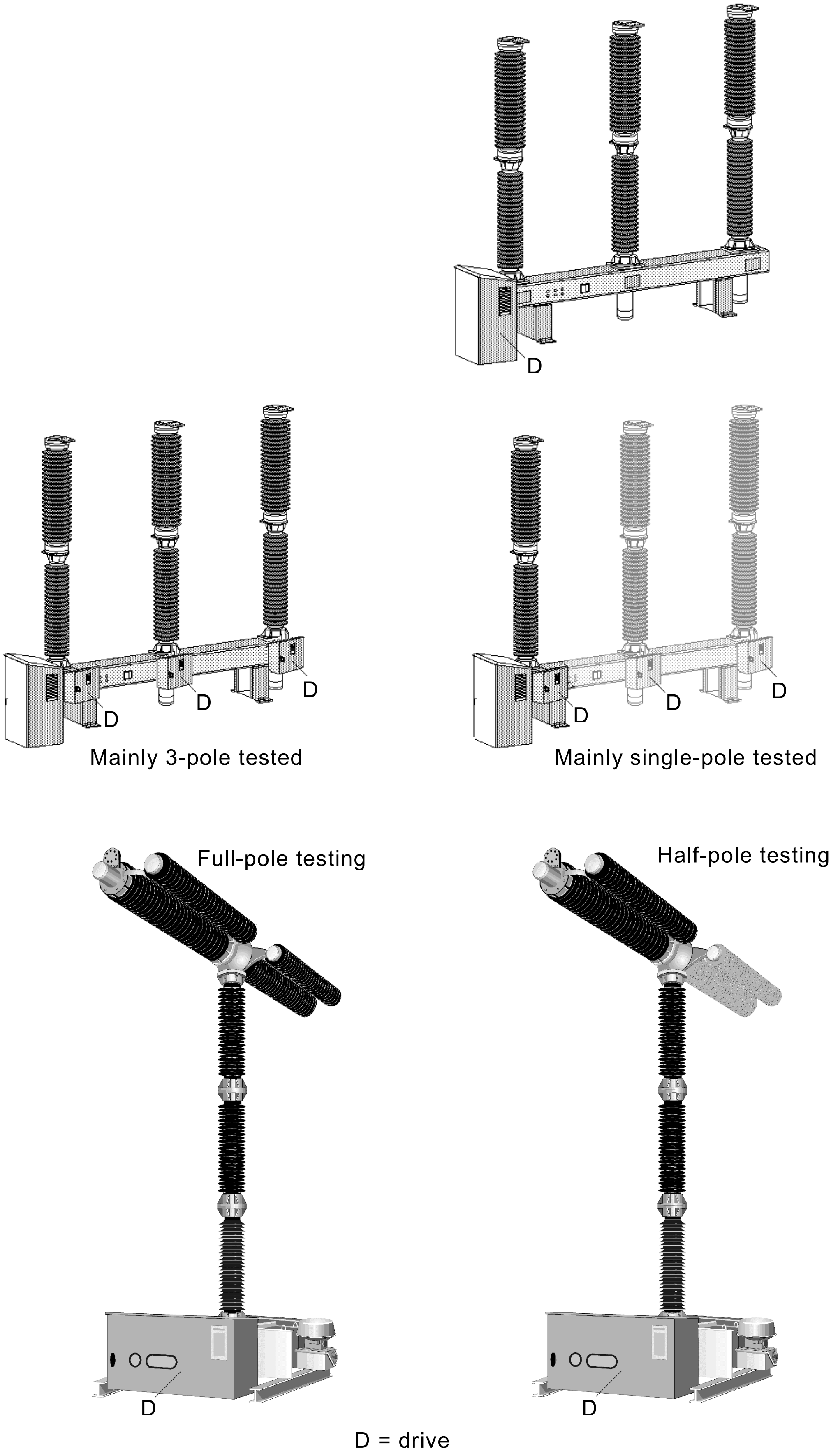


Figure 22 – Definition of a single test specimen in accordance with 3.2.2 of IEC 60694

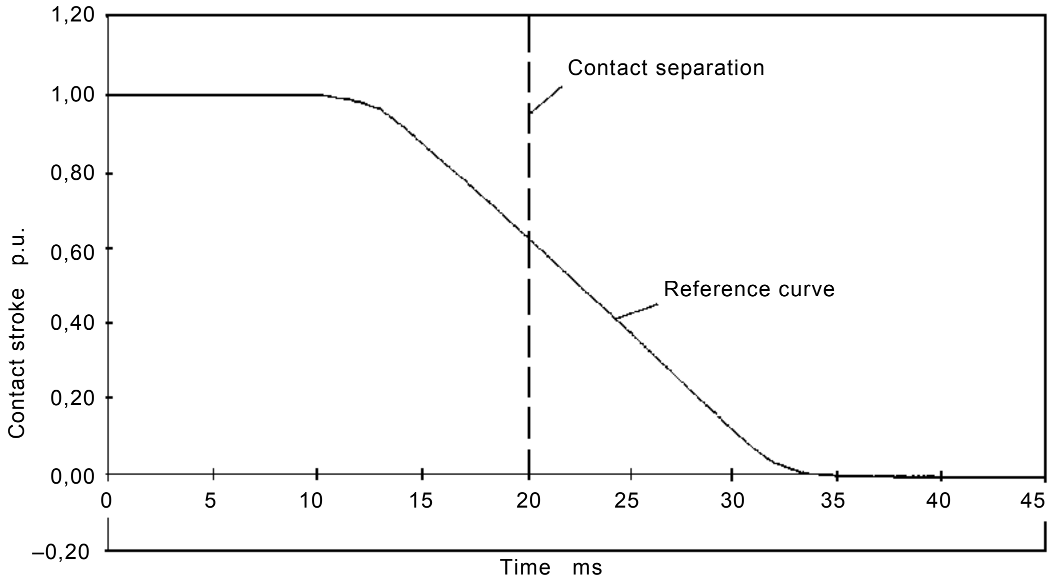


Figure 23a – Reference mechanical travel characteristics (idealised curve)

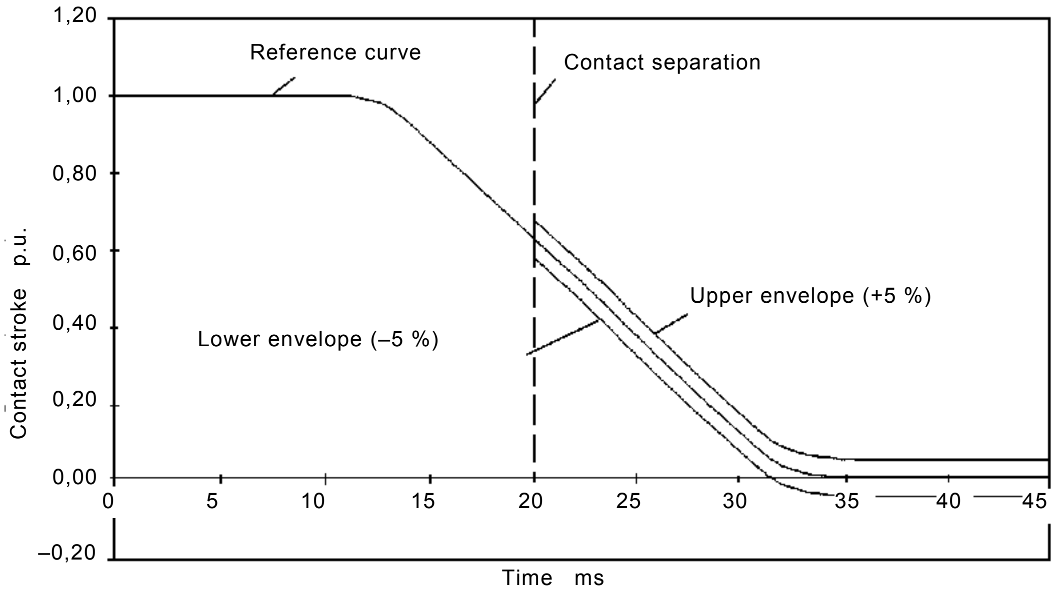


Figure 23b – Reference mechanical travel characteristics (idealised curve) with the prescribed envelopes centered over the reference curve (+5 %, –5 %), contact separation in this example at time *t* = 20 ms

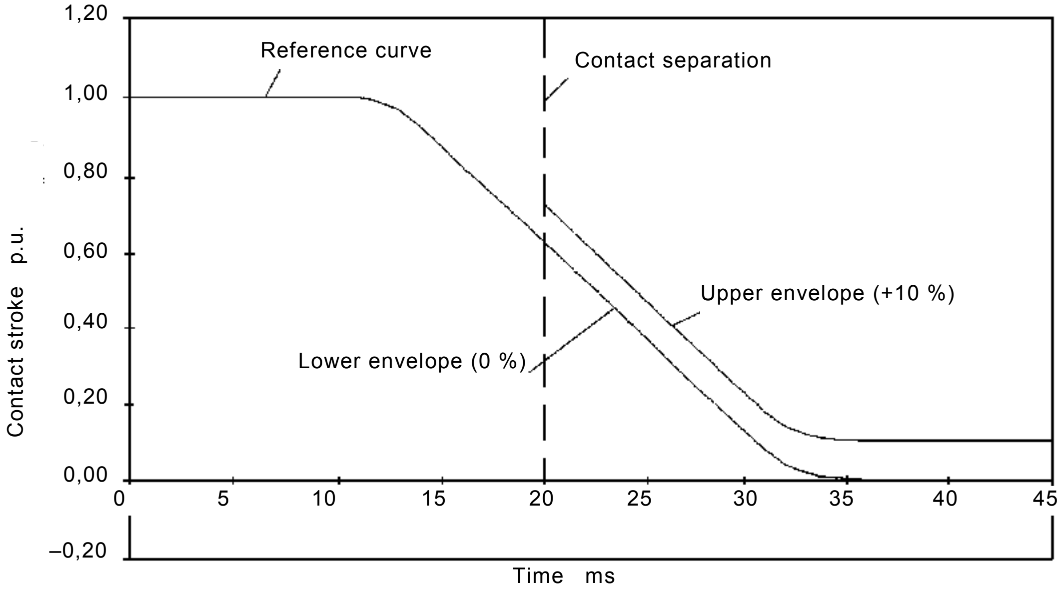


Figure 23c – Reference mechanical travel characteristics (idealised curve) with the prescribed envelopes fully displaced upward from the reference curve (+10 %, –0 %), contact separation in this example at time t = 20 ms

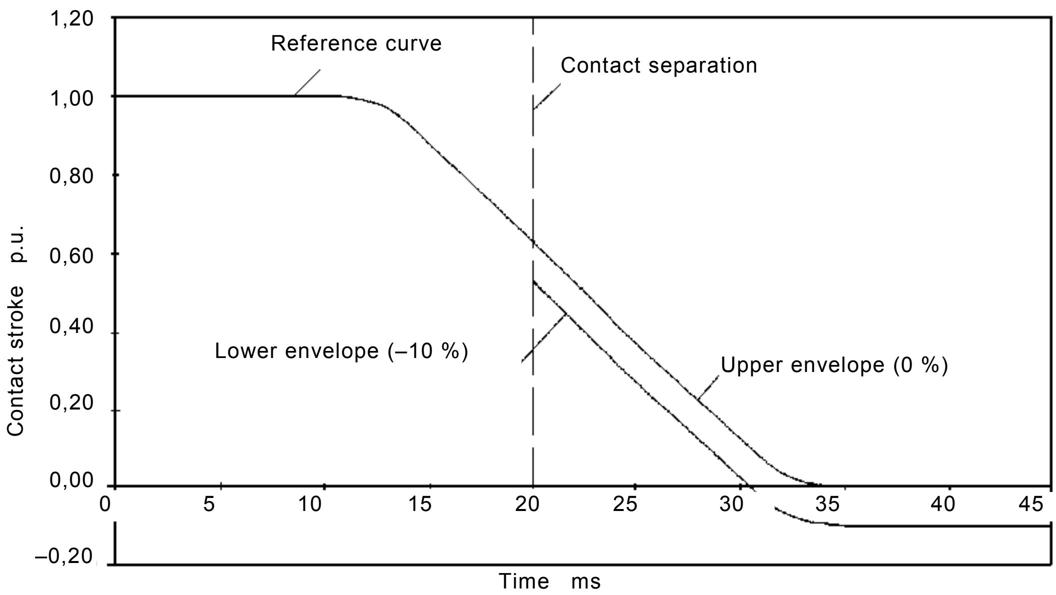


Figure 23d – Reference mechanical travel characteristics (idealised curve) with the prescribed envelopes fully displaced downward from the reference curve (+0 %, –10 %), contact separation in this example at time t = 20 ms

Pole of a circuit-breaker with two separate interrupter units in series.

Equivalent testing set-up for unit testing; second interrupter unit is substituted by a conductor of equivalent shape.

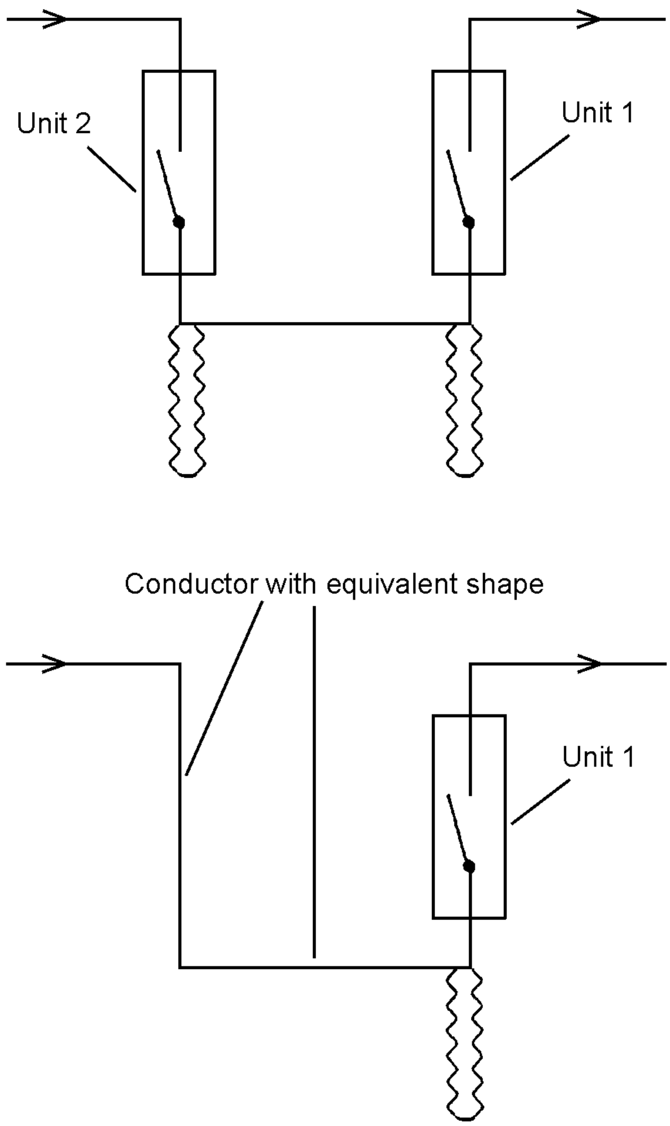
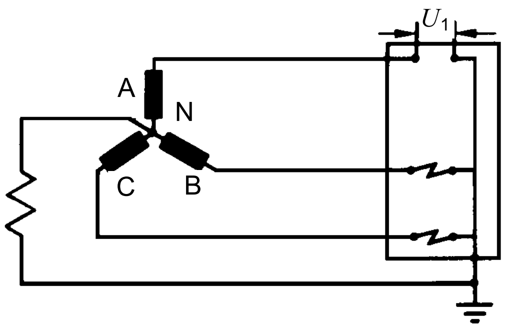


Figure 24 – Equivalent testing set-up for unit testing of circuit-breakers with more than one separate interrupter units



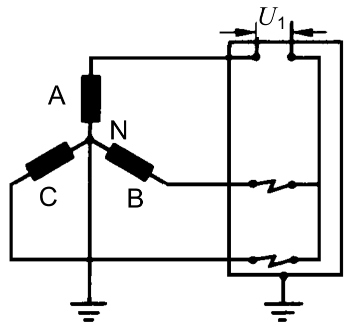
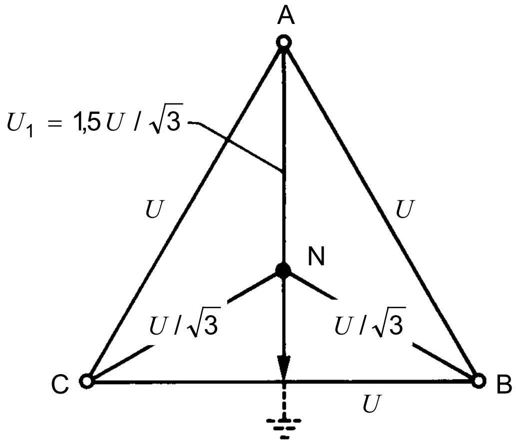


Figure 25a – Preferred circuit

Figure 25b – Alternative circuit



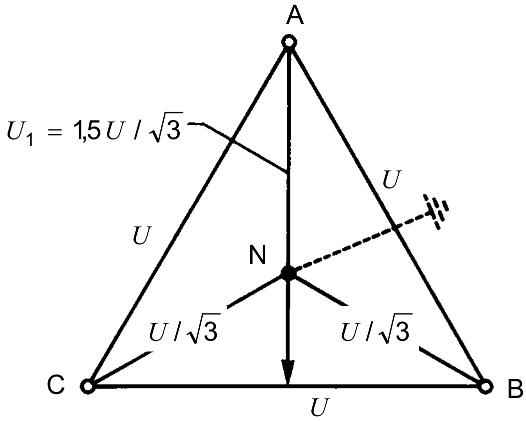


Figure 25 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,5

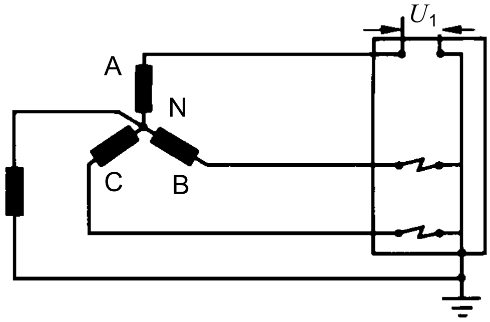


Figure 26a – Preferred circuit

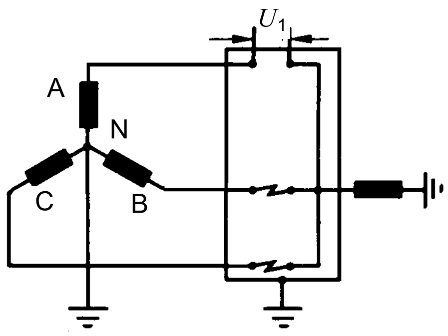
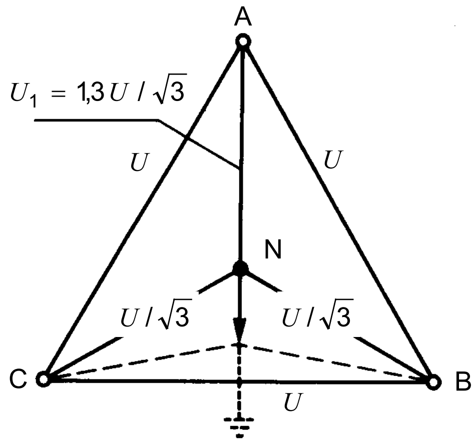


Figure 26b – Alternative circuit



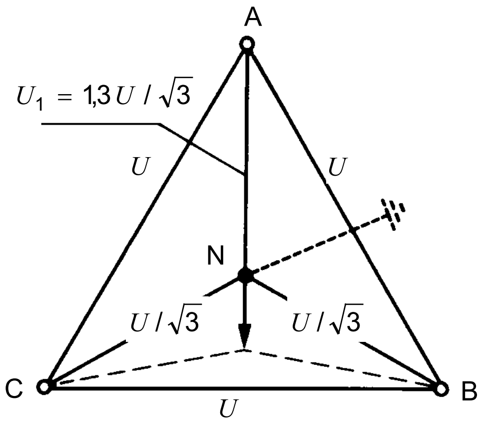


Figure 26 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,3

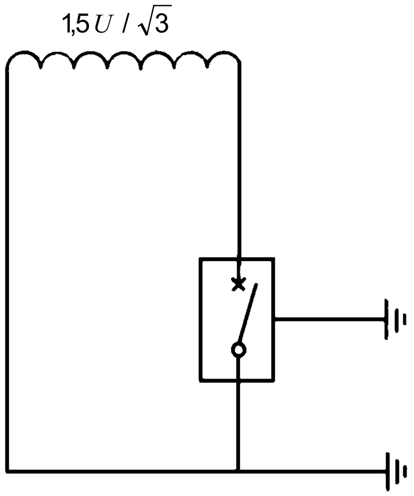


Figure 27a – Preferred circuit

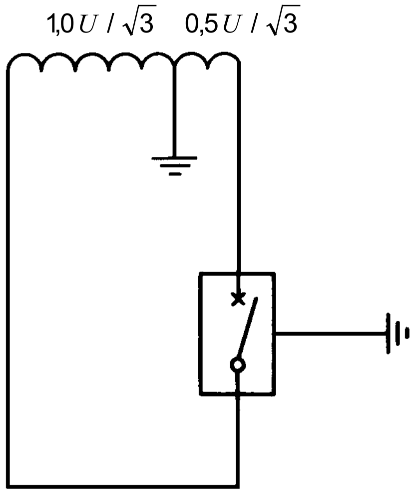


Figure 27b – Alternative circuit not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (e.g. GIS or dead tank circuit-breakers)

Figure 27 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,5

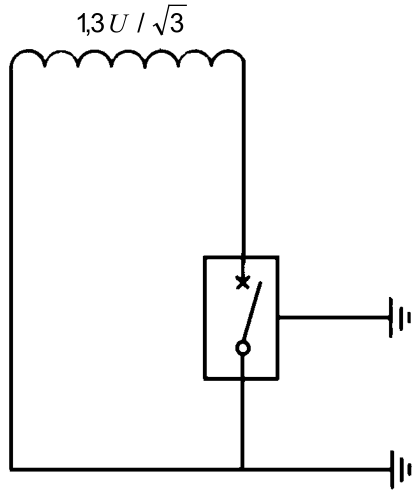


Figure 28a – Preferred circuit

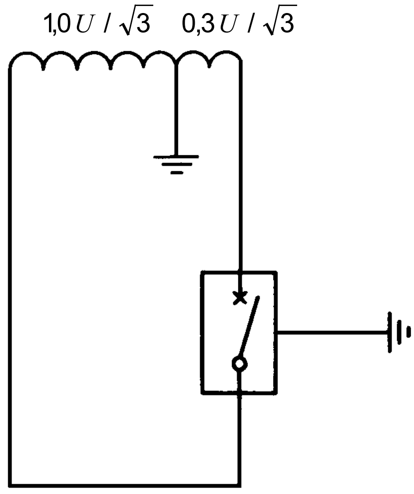


Figure 28b – Alternative circuit, not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (e.g. GIS or dead tank circuit-breakers)

Figure 28 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,3

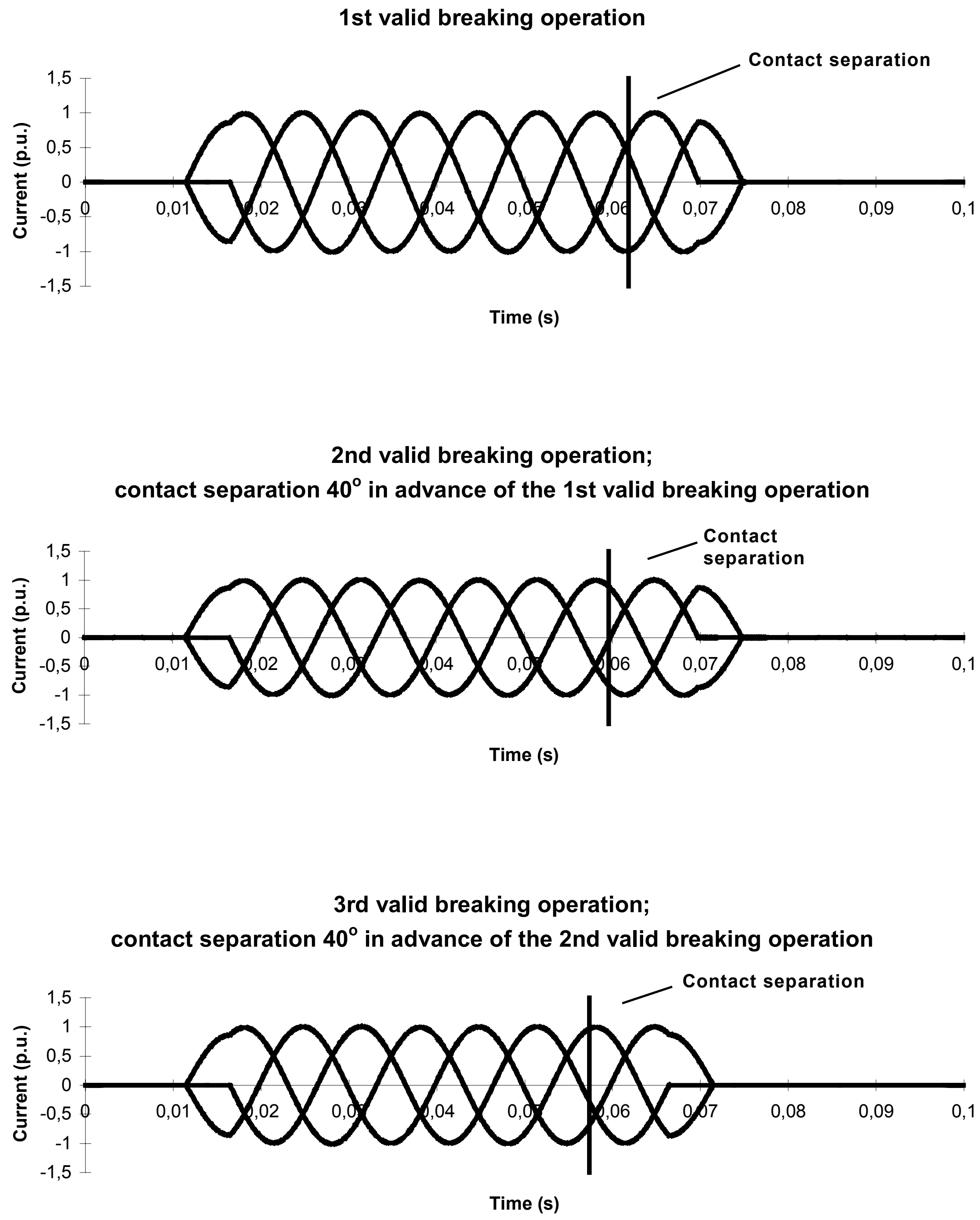
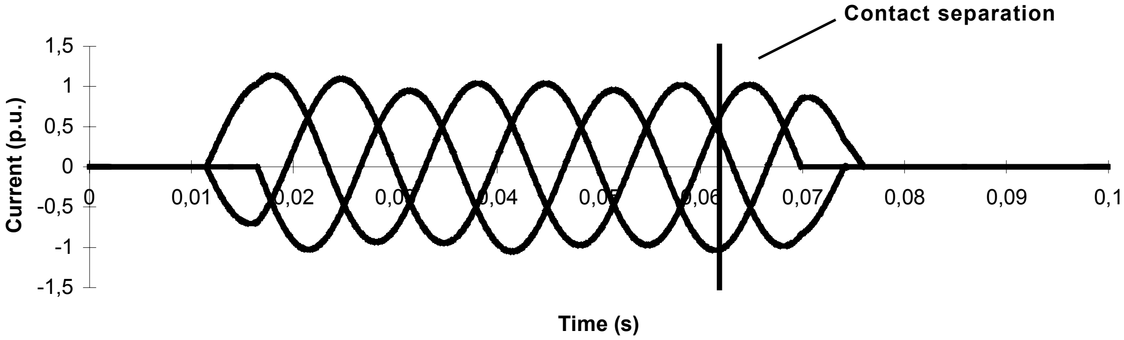
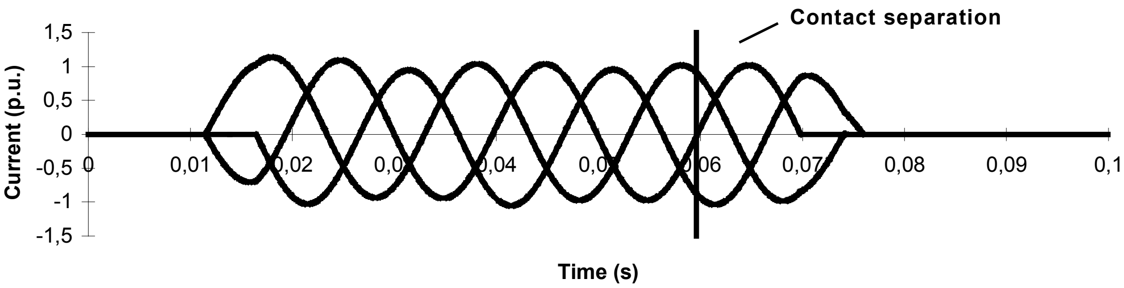


Figure 29 – Graphical representation of the three valid symmetrical breaking operations for three-phase tests in a non-solidly earthed neutral system (first-pole-to-clear factor 1,5)

1st valid breaking operation



2nd valid operation; contact separation 40° in advance of the 1st valid breaking operation



3rd valid breaking operation; contact separation 40° in advance of the 2nd valid breaking operation

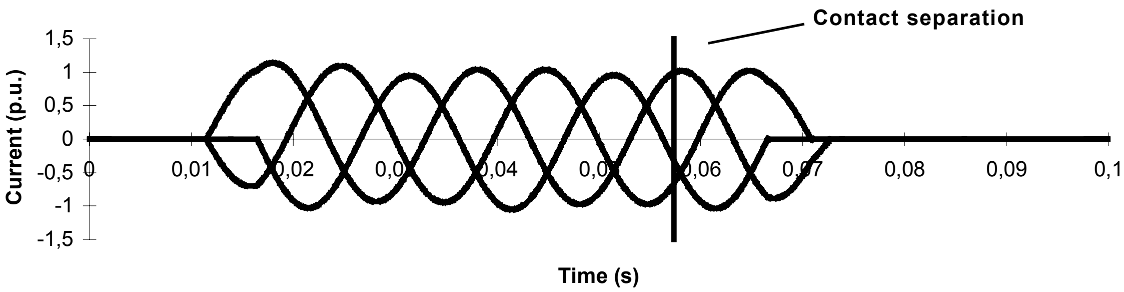
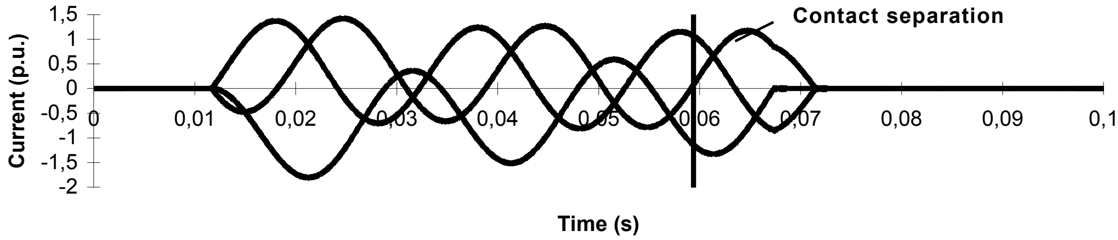
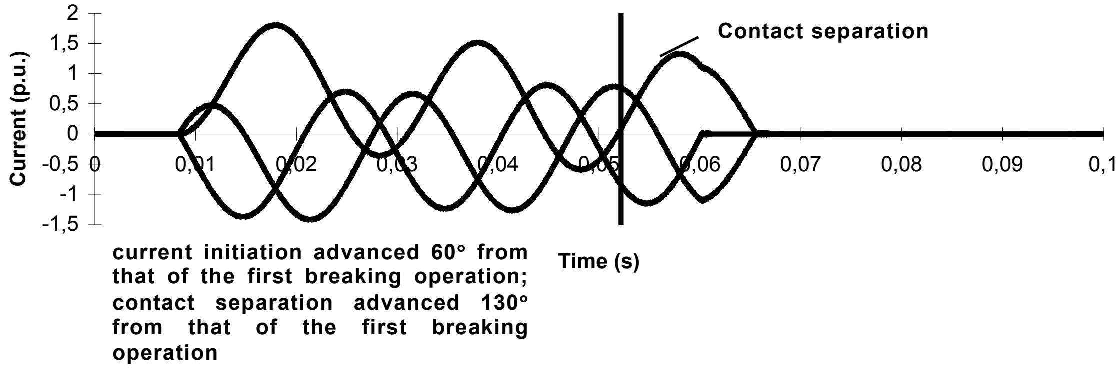


Figure 30 – Graphical representation of the three valid symmetrical breaking operations for three-phase tests in a solidly earthed neutral system (first-pole-to-clear factor 1,3)

1st valid breaking operation; first pole-to-clear on a major loop with the required d.c. level at contact separation



2nd valid breaking operation; one of the last pole-to-clear on an extended major loop with the required d.c. level at contact separation



3rd valid breaking operation; first pole-to-clear on a major loop with the required d.c. level at contact separation

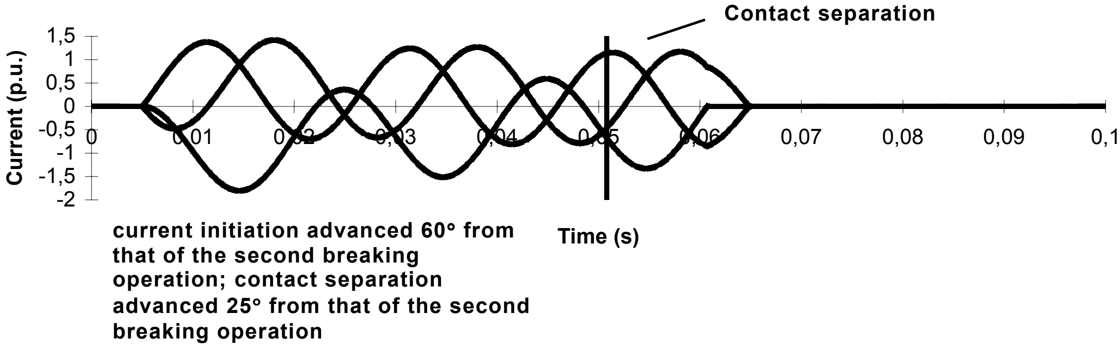
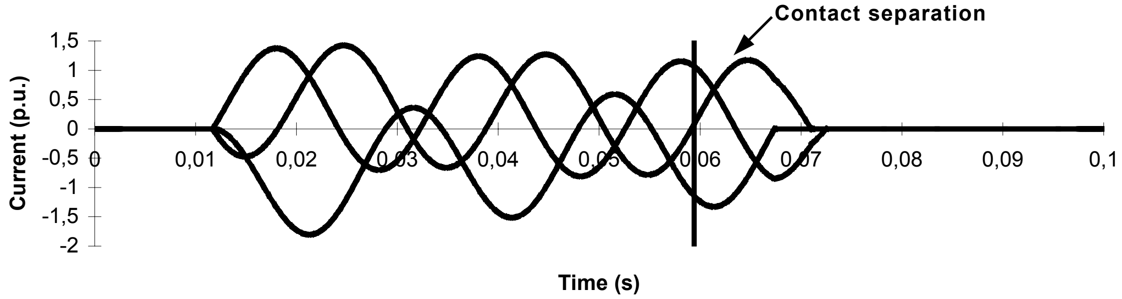
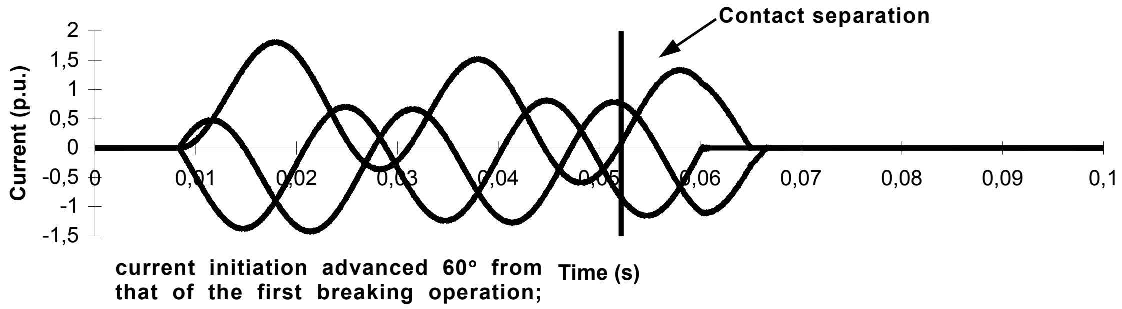


Figure 31 – Graphical representation of the three valid asymmetrical breaking operations for three-phase tests in a non-solidly earthed neutral system (first-pole-to-clear factor 1,5)

1st valid breaking operation; first pole-to-clear on a major loop with the required d.c. level at contact separation

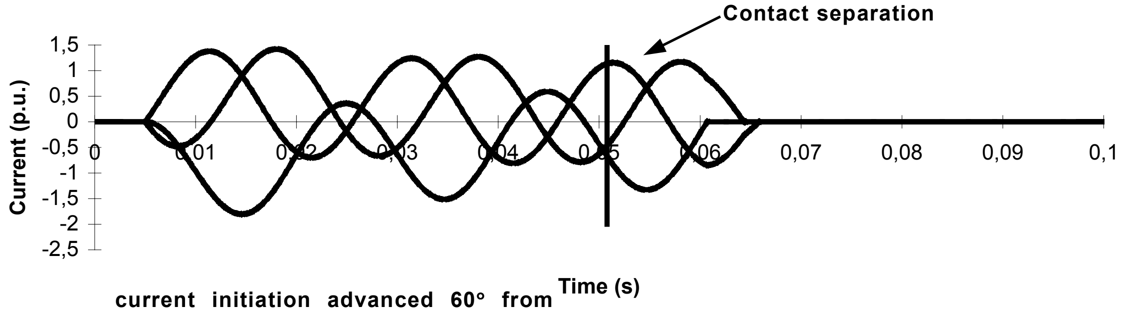


2nd valid breaking operation; second pole-to-clear after an extended major loop with the required d.c. level at contact separation



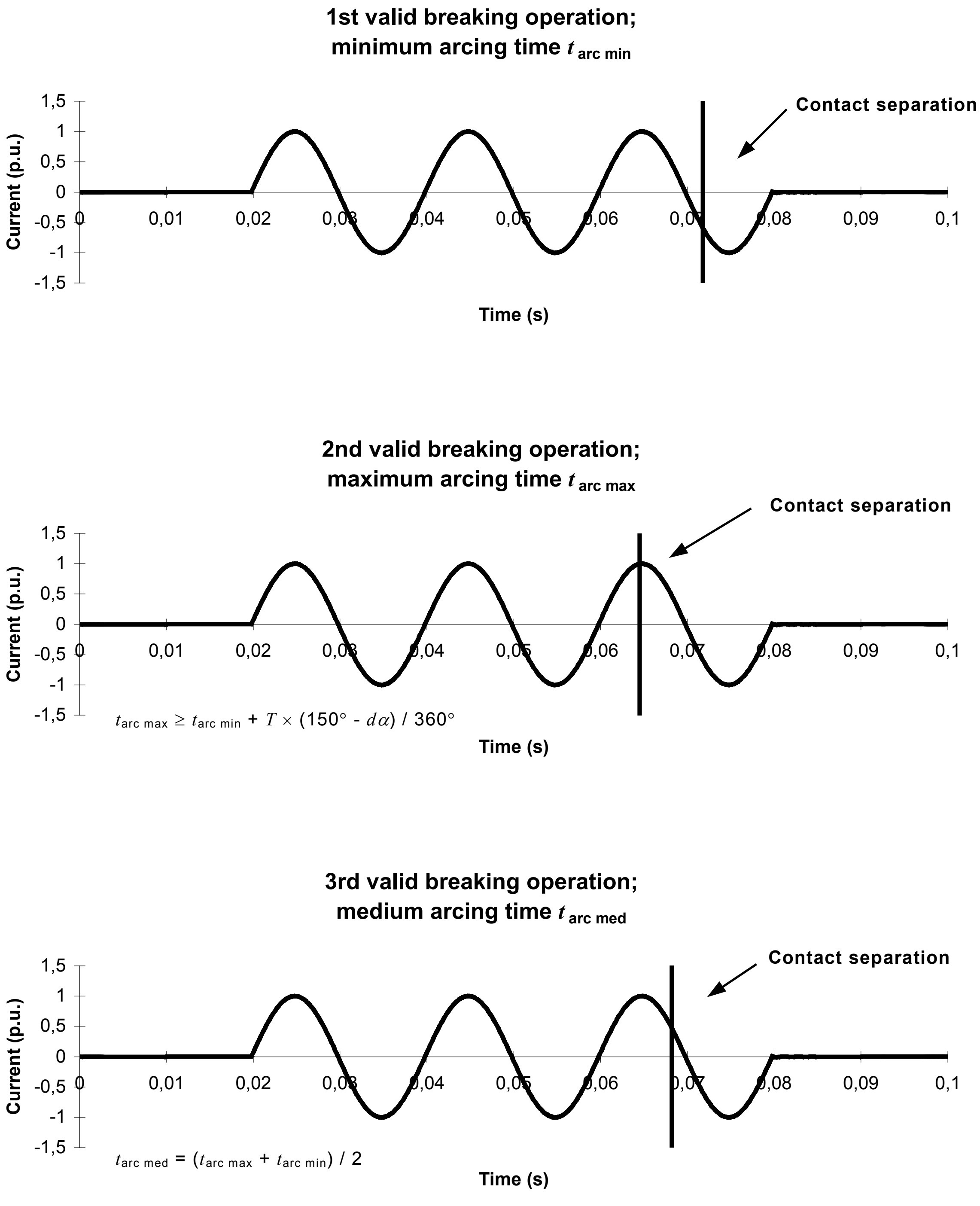
current initiation advanced 60° from that of the first breaking operation; contact separation advanced 130° from that of the first breaking operation

3rd valid breaking operation; first pole-to-clear after a major loop with the required d.c. level at contact separation



current initiation advanced 60° from that of the second breaking operation; contact separation advanced 25° from that of the second breaking operation

Figure 32 – Graphical representation of the three valid asymmetrical breaking operations for three-phase tests in a solidly earthed neutral system (first-pole-to-clear factor 1,3)

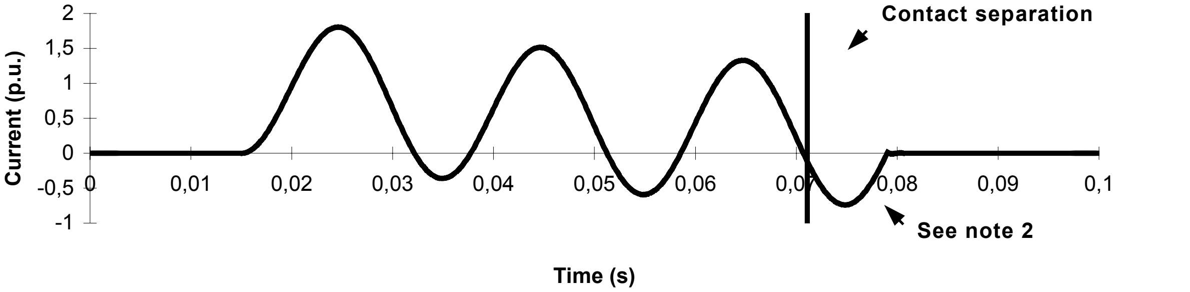


$d\alpha$ = 18°

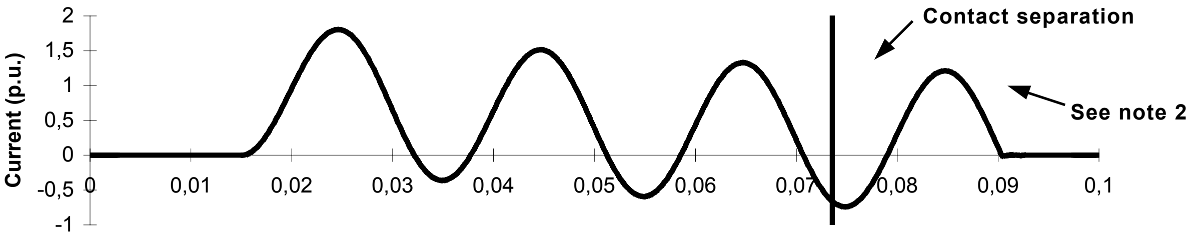
NOTE The polarity of the current may be reversed.

Figure 33 – Graphical representation of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions in a non-solidly earthed neutral system (first-pole-to-clear factor 1,5)

1st valid breaking operation; minimum arcing time $t_{\text{arc min}}$

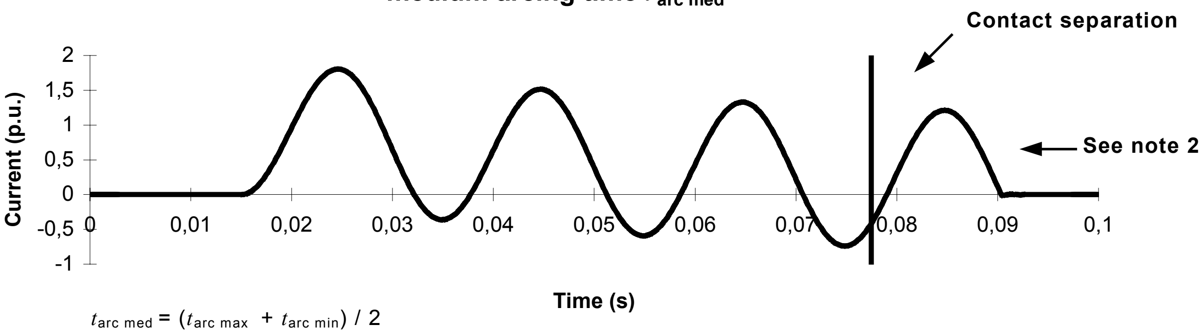


2nd valid breaking operation; maximum arcing time $t_{\text{arc max}}$



$t_{\text{arc max}} \geq t_{\text{arc min}} + \Delta t_1 - T \times (30° + d\alpha) / 360°$

3rd valid breaking operation; medium arcing time $t_{\text{arc med}}$



$t_{\text{arc med}} = (t_{\text{arc max}} + t_{\text{arc min}}) / 2$

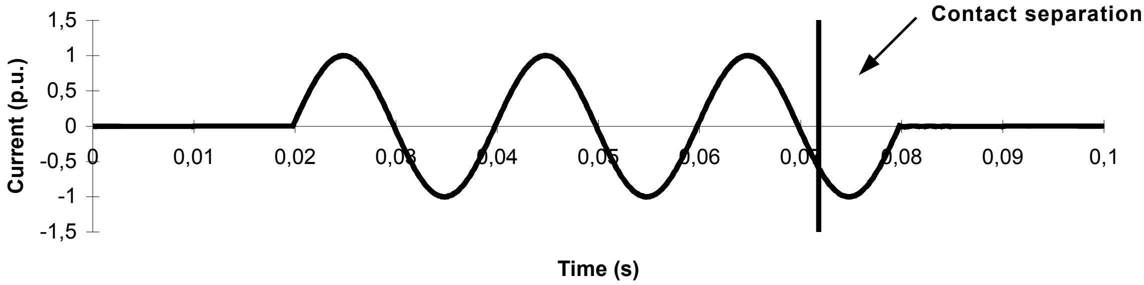
$d\alpha$ = 18°

NOTE 1 The polarity of the current may be reversed.

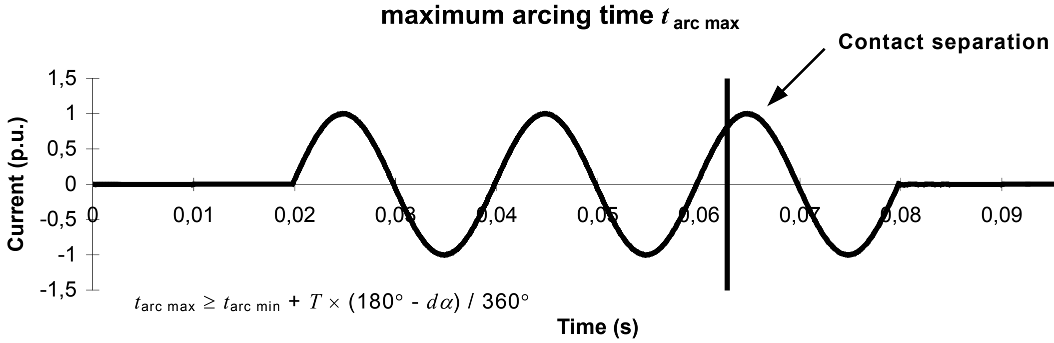
NOTE 2 The amplitude and the duration of the last current loop must meet the criteria stated in 6.102.10.

Figure 34 – Graphical representation of the three valid asymmetrical breaking operations for single-phase tests n substitution of three-phase conditions in a non-solidly earthed neutral system (first-pole-to-clear factor 1,5)

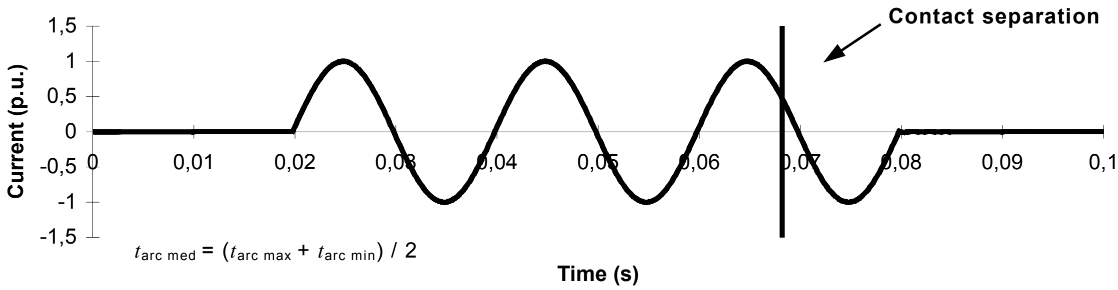
1st valid breaking operation;
minimum arcing time $t_{\text{arc min}}$



2nd valid breaking operation;
maximum arcing time $t_{\text{arc max}}$



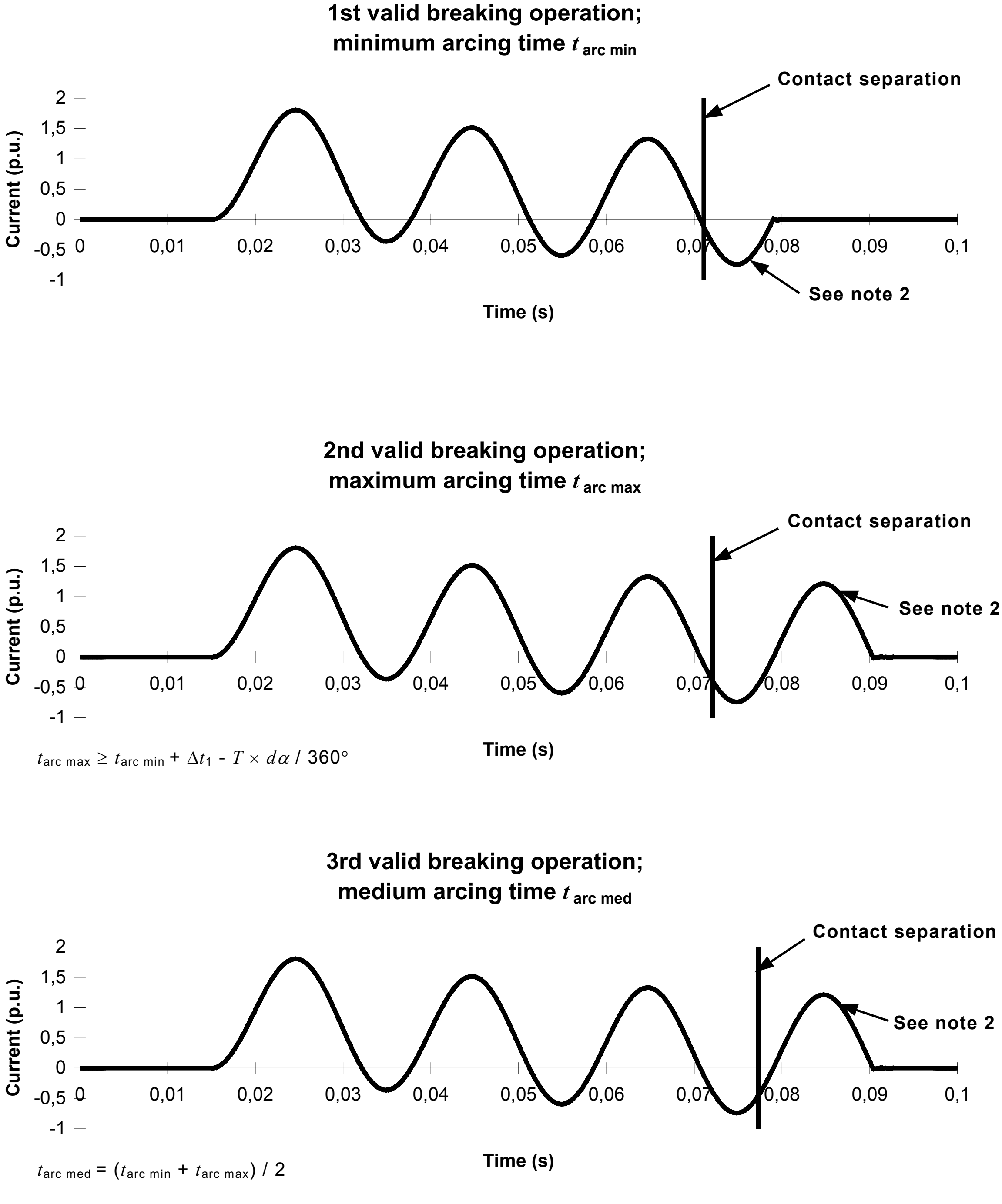
3rd valid breaking operation;
medium arcing time $t_{\text{arc med}}$



$d\alpha$ = 18°

NOTE The polarity of the current may be reversed.

Figure 35 – Graphical representation of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions in a solidly earthed neutral system (first-pole-to-clear factor 1,3)



$d\alpha$ = 18°

NOTE 1 The polarity of the current may be reversed.

NOTE 2 The amplitude and the duration of the last current loop must meet the criteria stated in 6.102.10.

Figure 36 – Graphical representation of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase conditions in a solidly earthed neutral system (first-pole-to-clear factor 1,3)

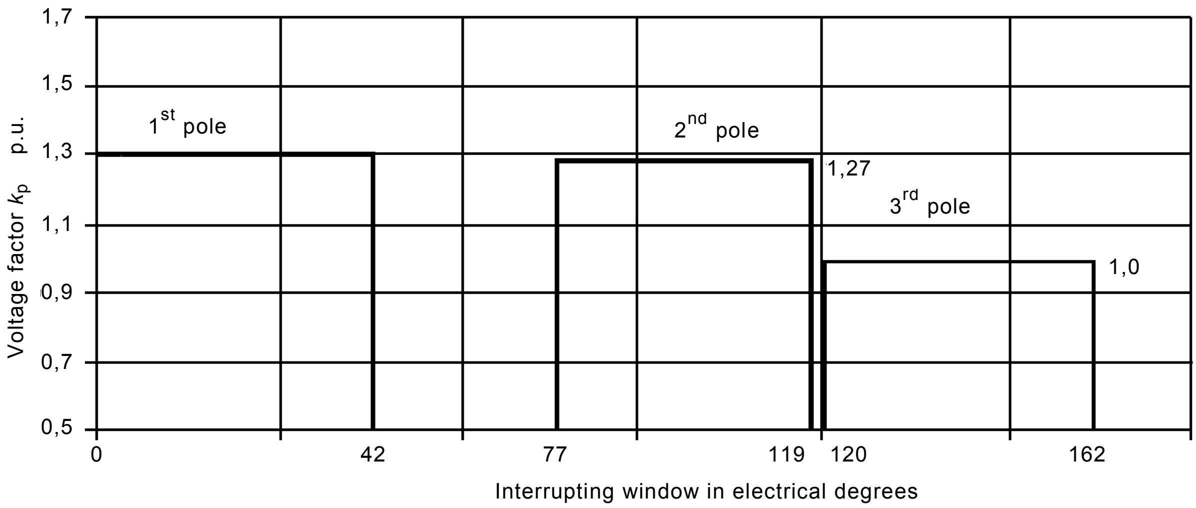


Figure 37 – Graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, for systems with a first-pole-to-clear factor of 1,3

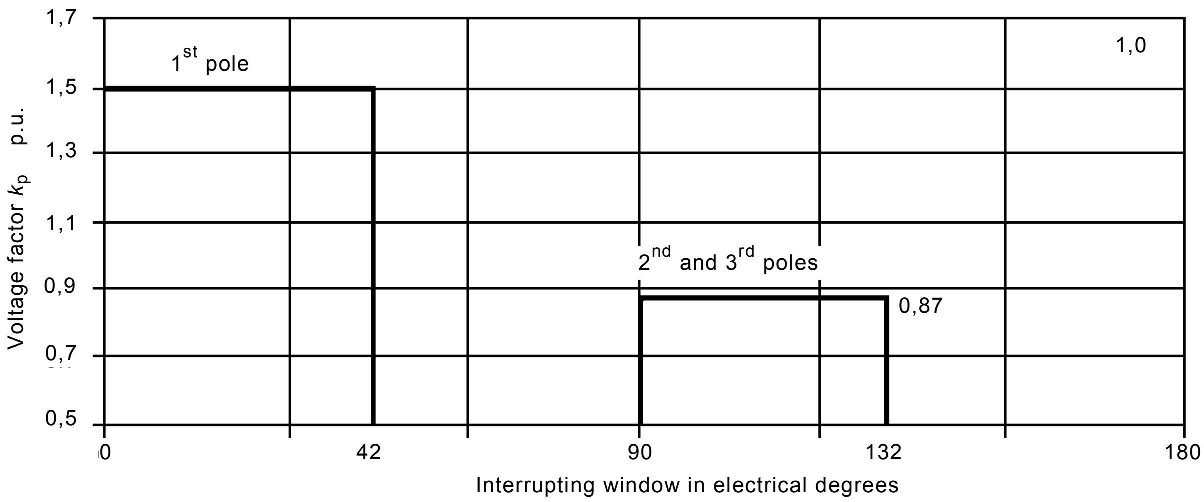


Figure 38 – Graphical representation of the interrupting window and the voltage factor k_p, determining the TRV of the individual pole, for systems with a first-pole-to-clear factor of 1,5

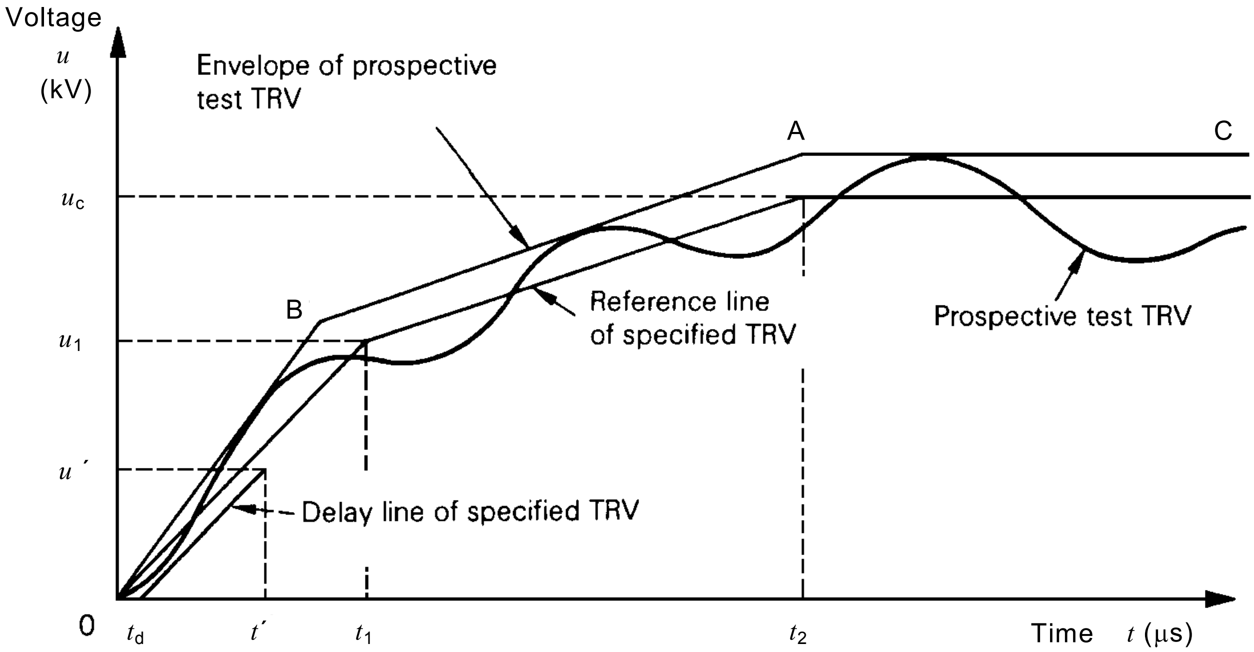


Figure 39 – Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with four-parameter reference line

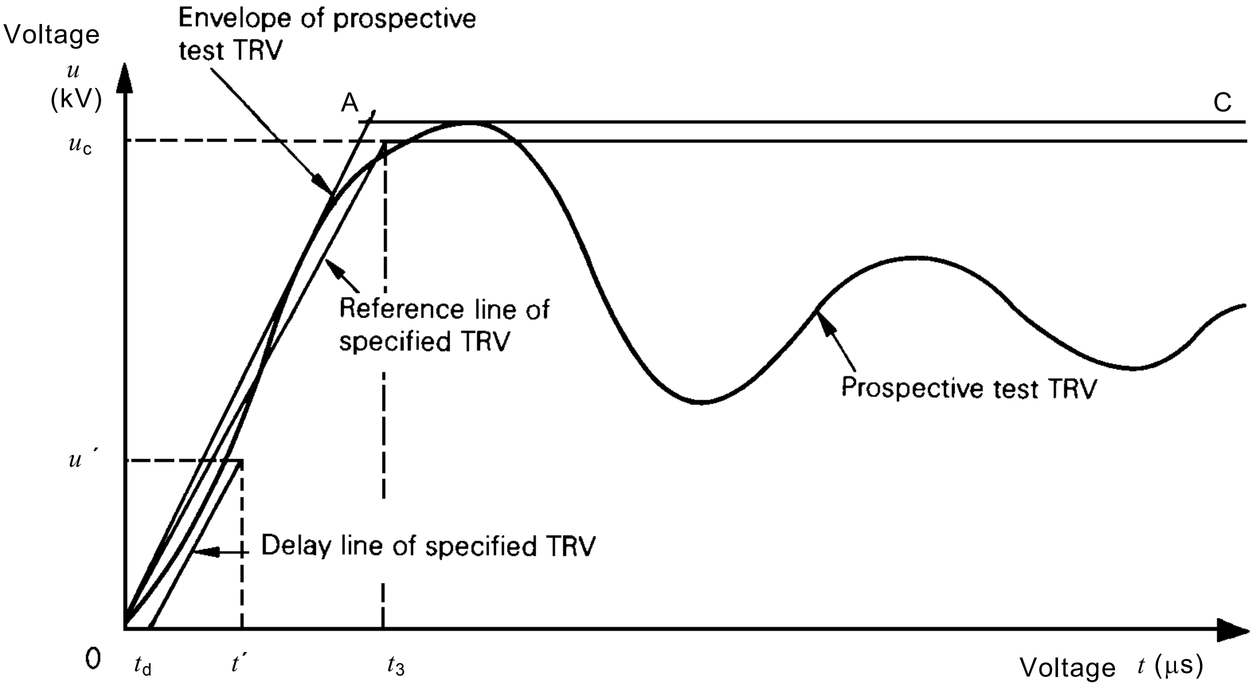


Figure 40 – Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line

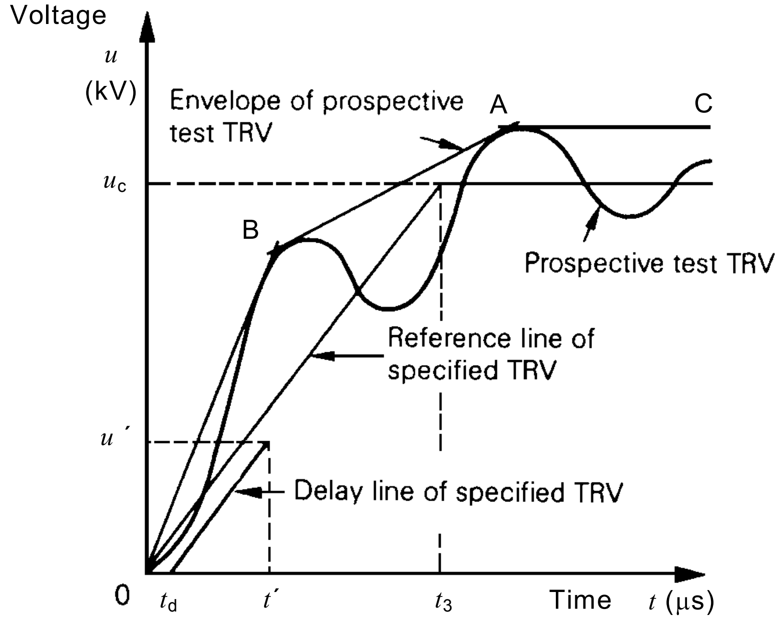


Figure 41 – Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line

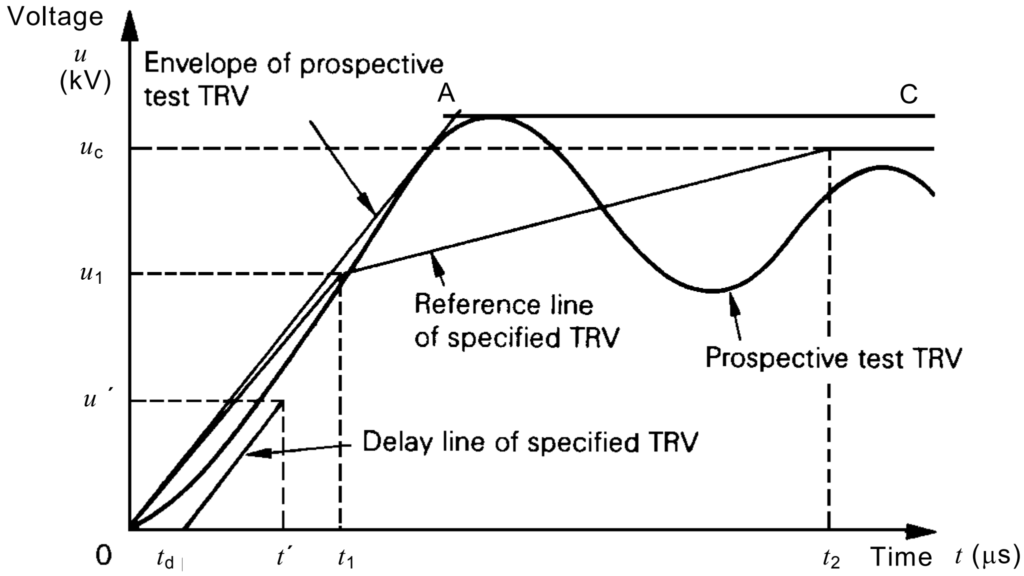


Figure 42 – Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with four-parameter reference line

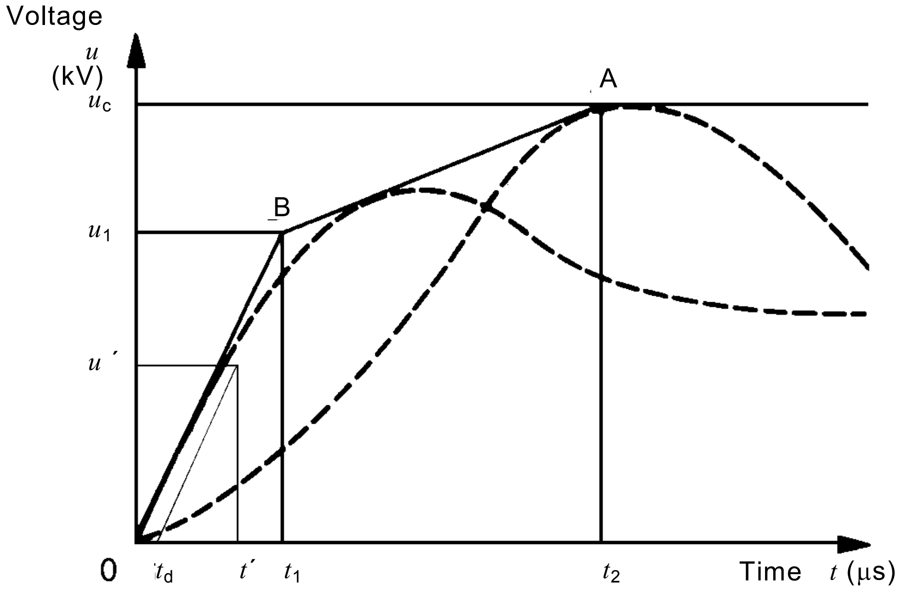
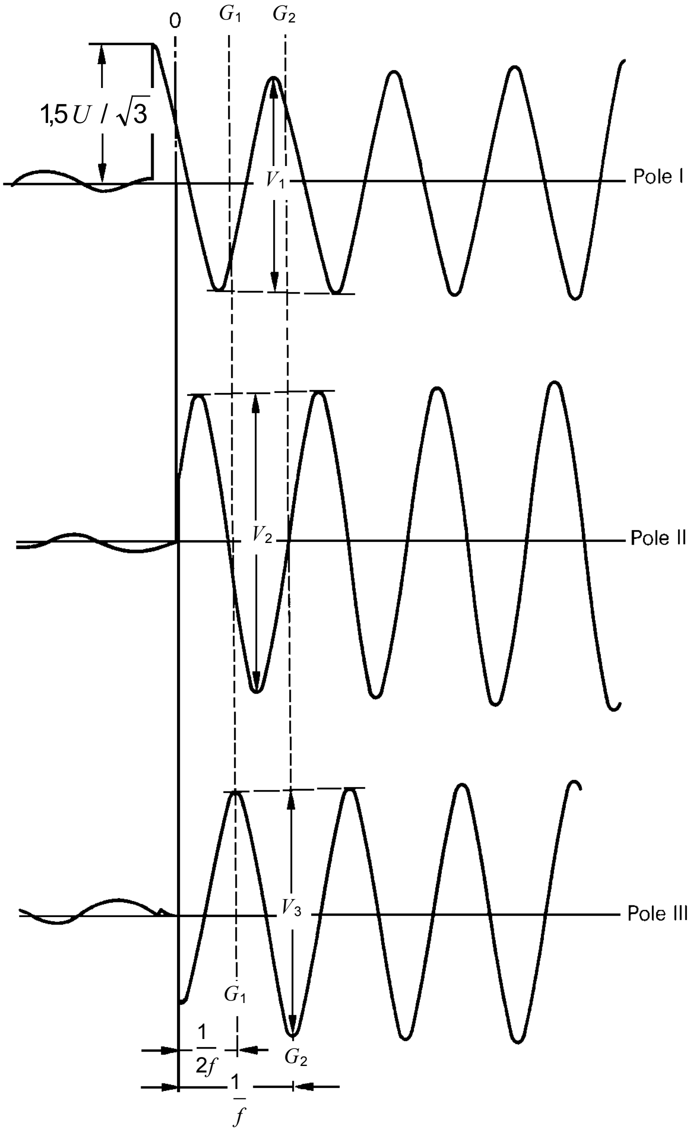


Figure 43 – Example of two prospective TRV-waves and their combined envelope in two-part test



Pole I	= first pole to clear
OO	= instant of final arc-extinction on all phases
G_1G_1	= instant $\frac{1}{2f}$ from OO
G_2G_2	= instant $\frac{1}{f}$ from OO
f	= test frequency
$\frac{V_1}{2\sqrt{2}}$	= value of power frequency recovery voltage of Pole I
$\frac{V_2}{2\sqrt{2}}$	= value of power frequency recovery voltage of Pole II
$\frac{V_3}{2\sqrt{2}}$	= value of power frequency recovery voltage of Pole III

In Pole III a voltage peak occurs exactly at instant G_1G_1. In such event measurement is made at later instant G_2G_2.

Average value of the power frequency recovery voltages of poles I, II and III

$$= \frac{\frac{V_1}{2\sqrt{2}} + \frac{V_2}{2\sqrt{2}} + \frac{V_3}{2\sqrt{2}}}{3}$$

The example illustrates three voltages obtained during a test upon a three-pole circuit breaker in a three-phase test circuit having one of it’s neutral points insulated, see figure 25a or 25b, thus producing momentarily in the first-pole-to-clear a 50 % increase in the recovery voltage, as shown in pole I.

Figure 44 – Determination of power frequency recovery voltage

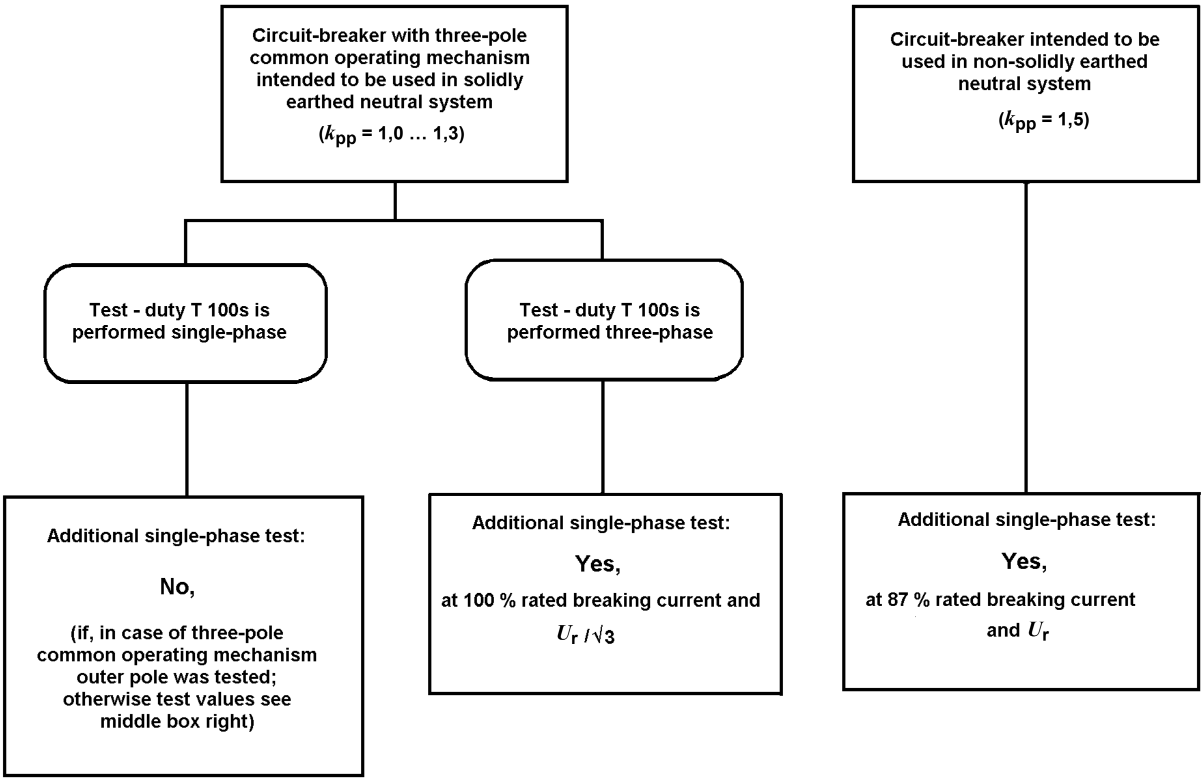
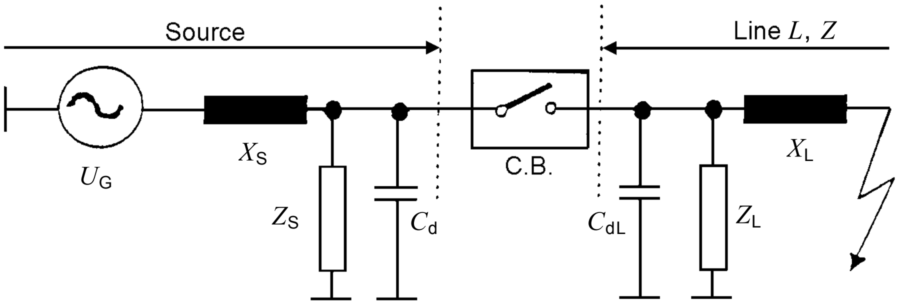
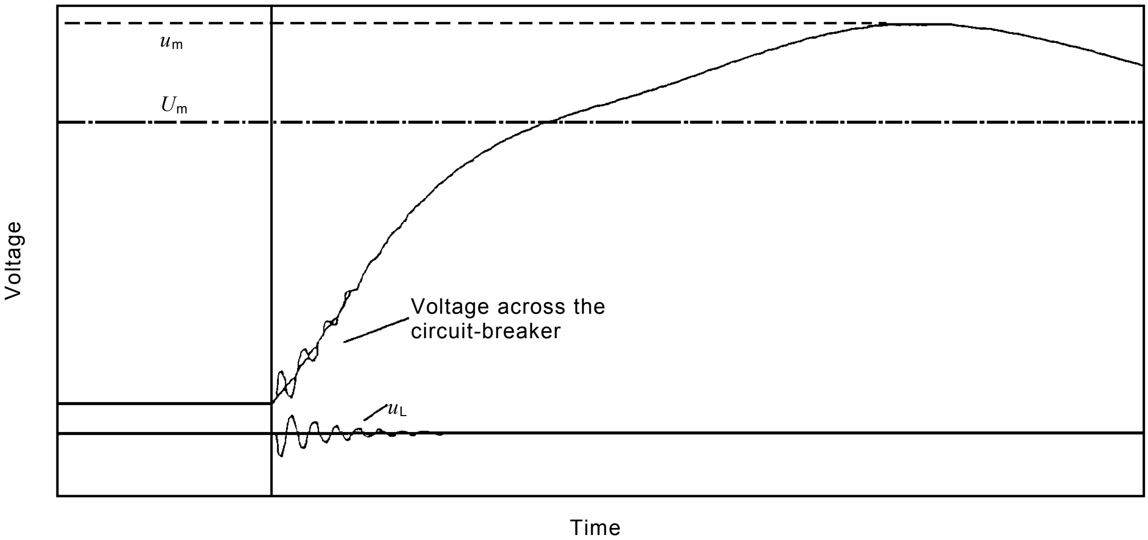


Figure 45 – Necessity of additional single-phase tests and requirements for testing



U_G	Supply voltage, phase to earth value	X_L	Power frequency line side reactance
X_S	Power frequency source side reactance	Z_L	Line side TRV controlling components
Z_S	Source side TRV controlling components	C_{dL}	Time delaying line side capacitance
C_d	Time delaying source side capacitance	Z	Surge impedance of line
C.B.	Circuit-Breaker	L	Length of line to fault



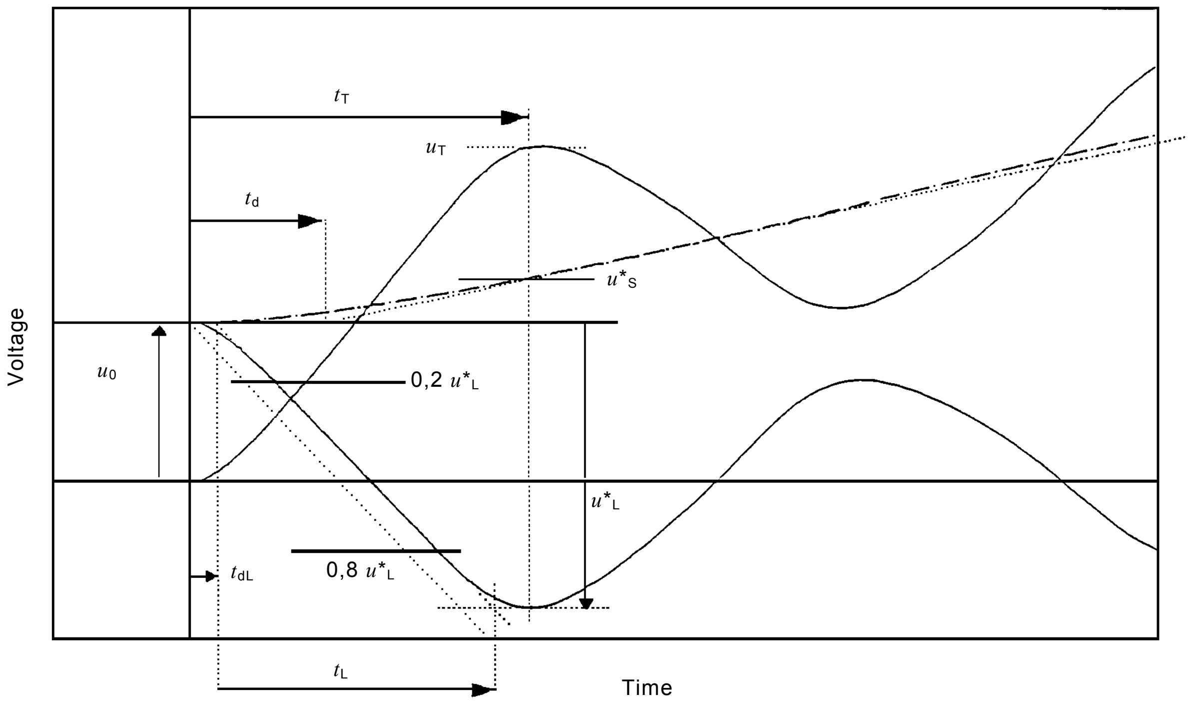
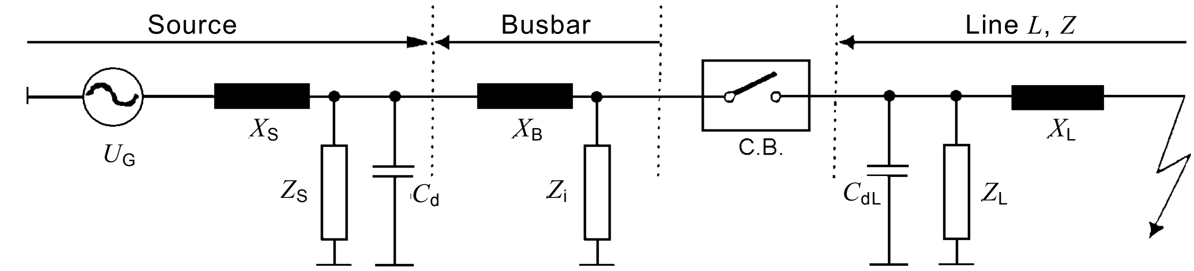


Figure 46 – Basic circuit arrangement for short-line fault testing and prospective TRV-circuit-type a) according to 6.109.3: Source side and line side with time delay



- U_G Supply voltage, phase to earth value
- X_S Power frequency source side reactance
- Z_S Source side TRV controlling components
- C_d Time delaying source side capacitance
- C.B. Circuit-Breaker
- X_B Power frequency busbar reactance
- Z_i ITRV controlling components
- X_L Power frequency line side reactance
- Z_L Line side TRV controlling components
- C_{dL} Time delaying line side capacitance
- Z Surge impedance of line
- L Length of line to fault

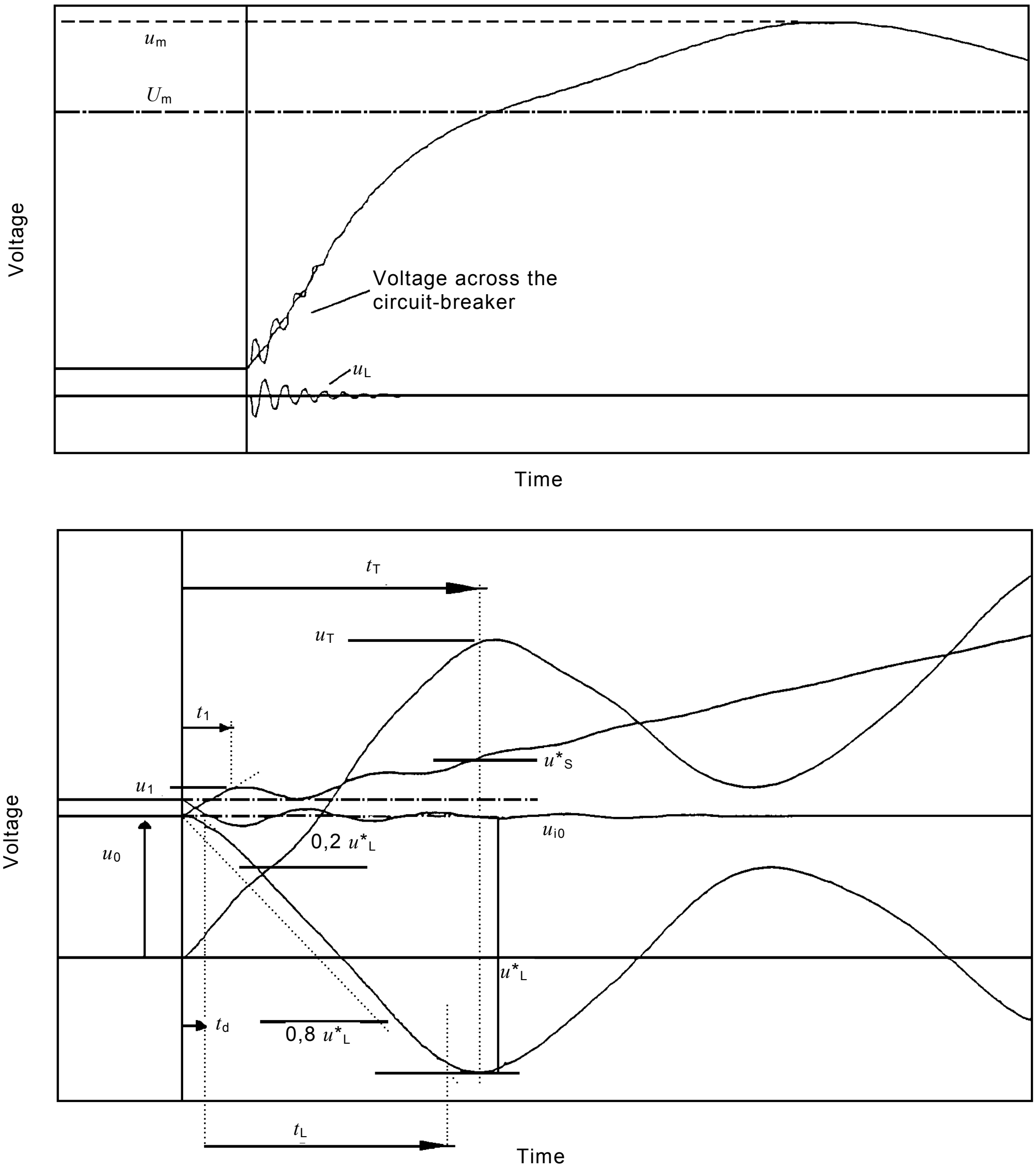
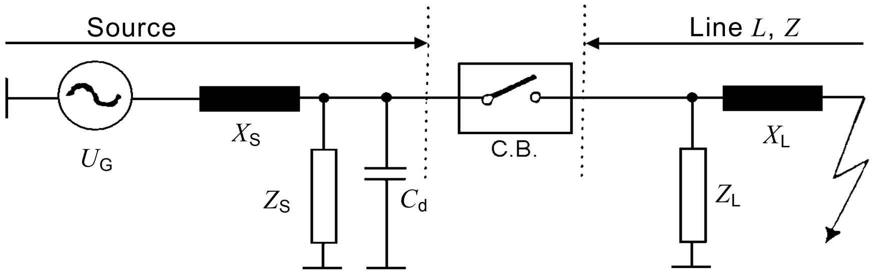
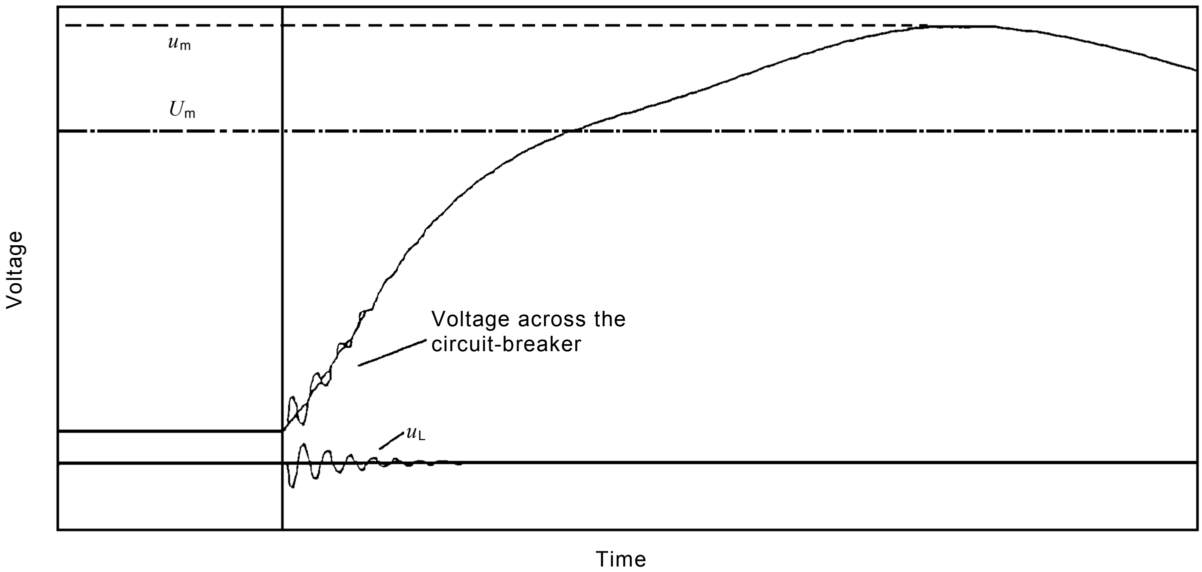


Figure 47 – Basic circuit arrangement for short-line fault testing – circuit type b1) according to 6.109.3: Source side with ITRV and line side with time delay



U_G	Supply voltage, phase to earth value	X_L	Power frequency line side reactance
X_S	Power frequency source side reactance	Z_L	Line side TRV controlling components
Z_S	Source side TRV controlling components	Z	Surge impedance of line
C_d	Time delaying source side capacitance	L	Length of line to fault
C.B.	Circuit-Breaker		



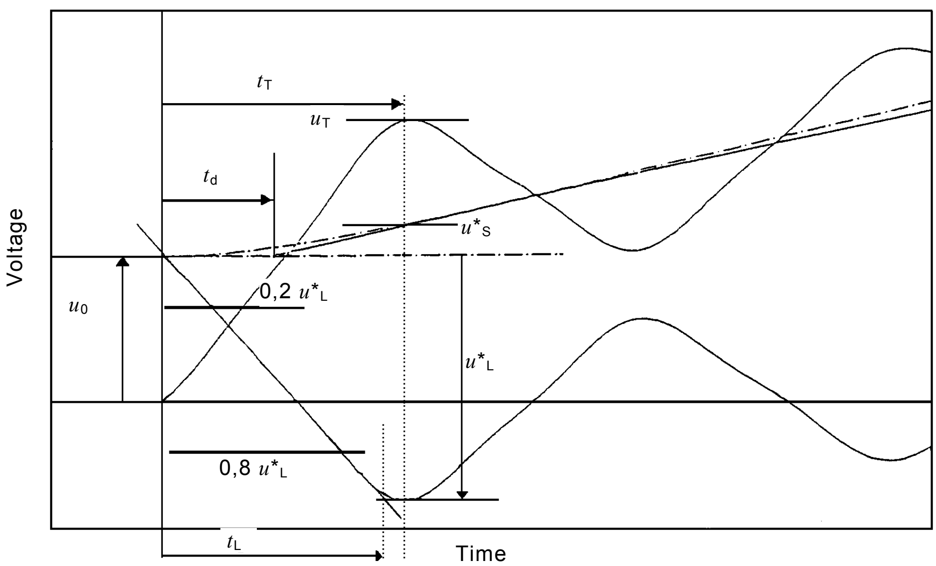


Figure 48 – Basic circuit arrangement for short-line fault testing – circuit type b2) according to 6.109.3: Source side with time delay and line side without time delay

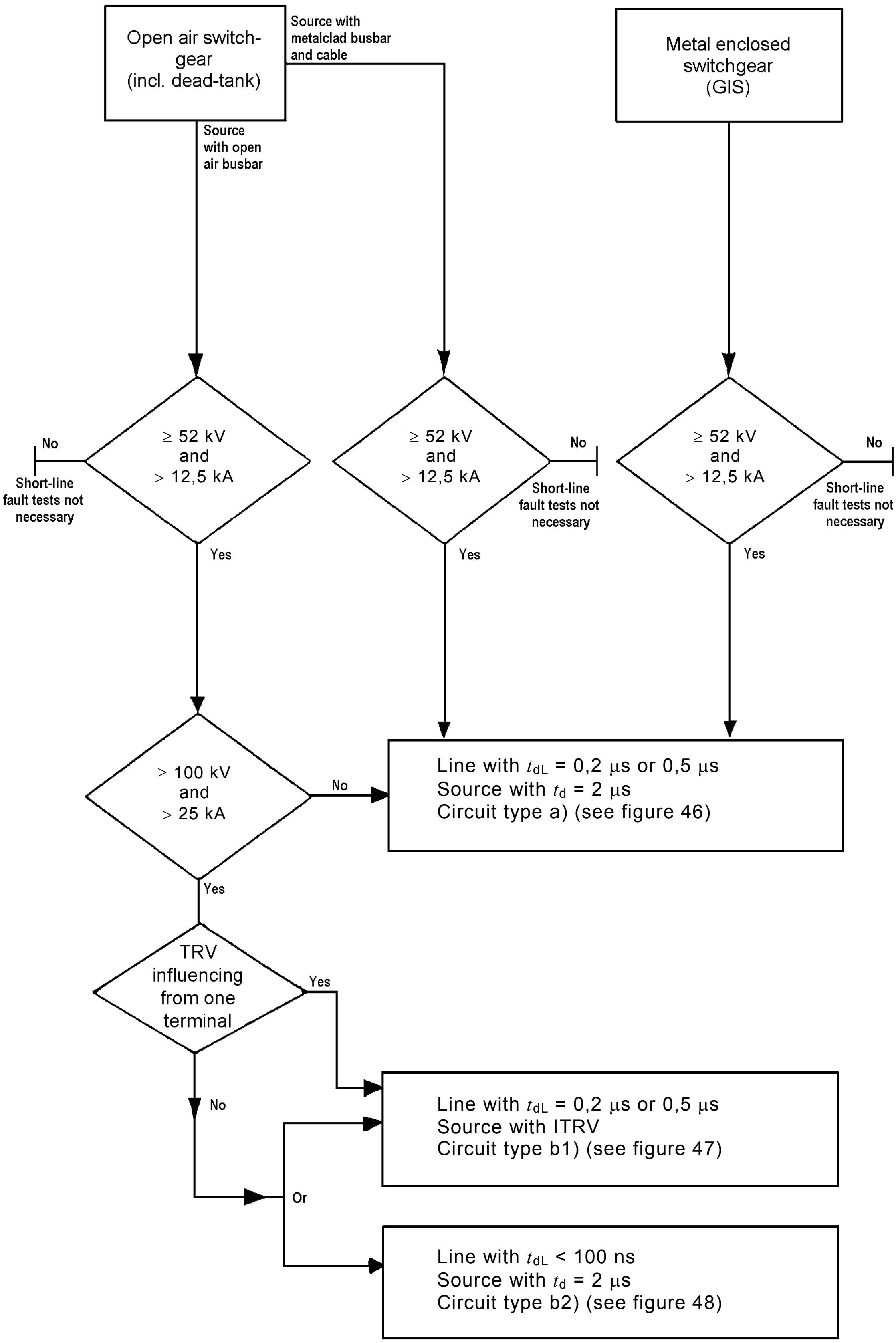


Figure 49 – Flow-chart for the choice of short-line fault test circuits

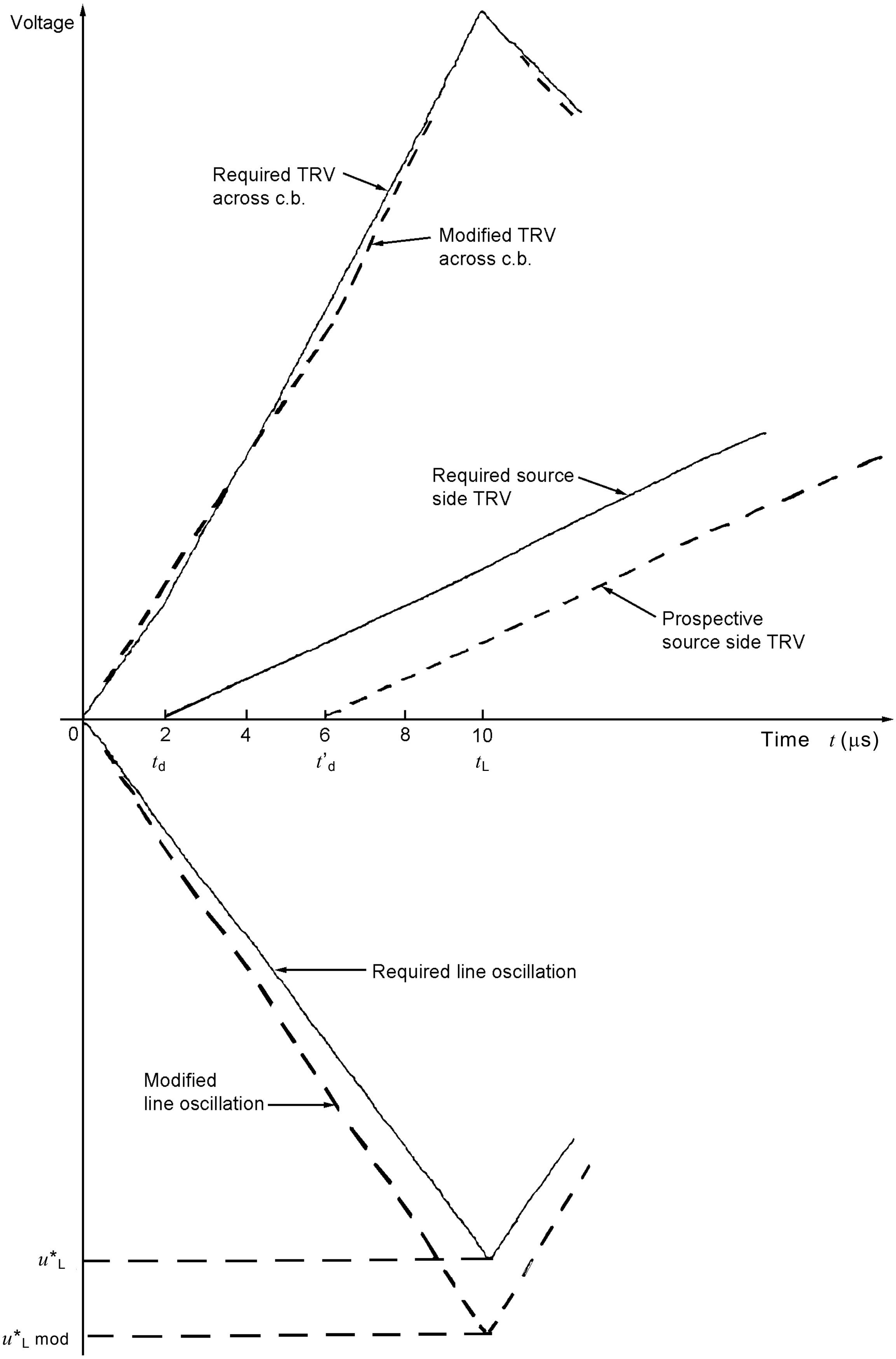
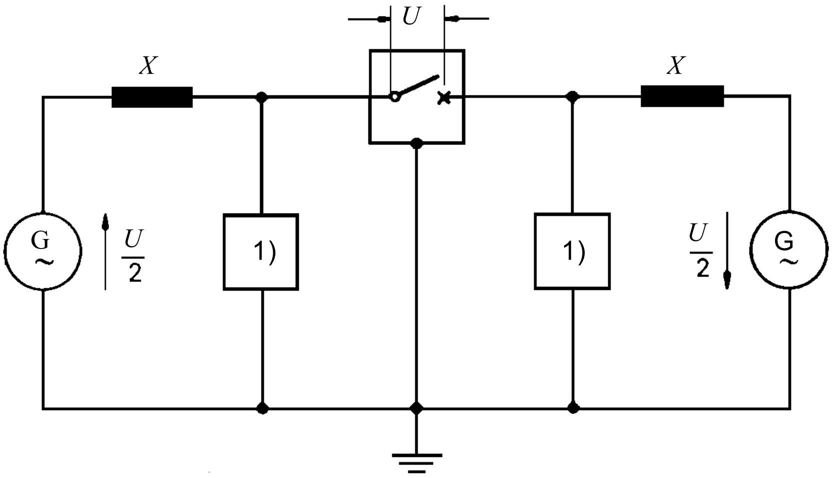
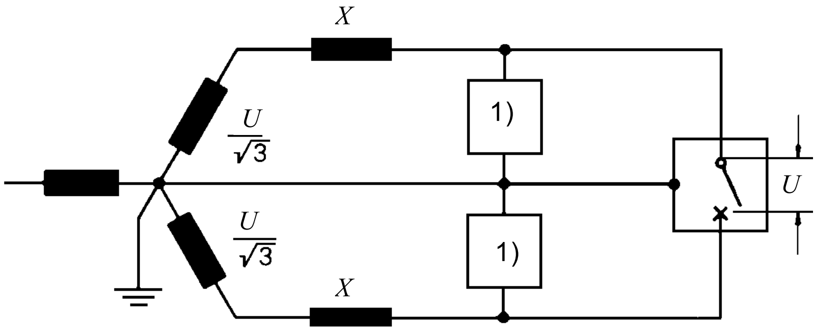


Figure 50 – Compensation of deficiency of the source side time delay by an increase of the excursion of the line side voltage



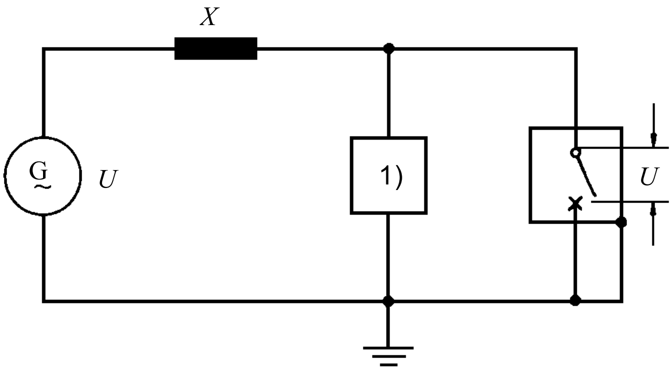
1) The squares represent combinations of capacitances and resistances.

Figure 51 – Test circuit for single-phase out-of-phase tests



1) The squares represent combinations of capacitances and resistances.

Figure 52 – Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees



1) The square represents combinations of capacitances and resistances.

Figure 53 – Test circuit for out-of-phase tests with one terminal of the circuit-breaker earthed (subject to agreement of the manufacturer)

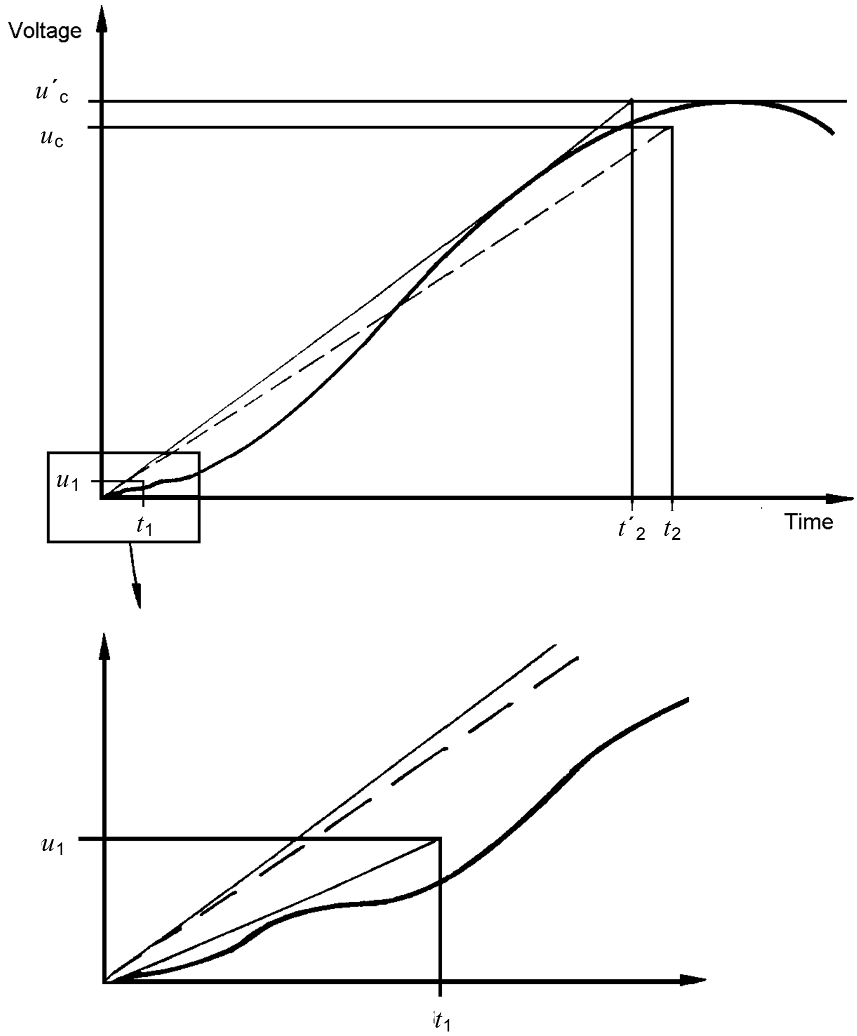


Figure 54 – Recovery voltage for capacitive current breaking tests

Annex A
(normative)

Calculation of transient recovery voltages for short-line faults from rated characteristics

A.1 Basic approach

For rating and testing purposes, it has been decided to consider only a short-line fault occurring from one phase to earth in a system having the neutral earthed and with a first-pole-to-clear factor of 1,0, the severity of this being sufficient to cover other cases, except in special circumstances where the system parameters may be more severe than the standard values.

The simplified single-phase circuit can be represented as shown in figures 46, 47 and 48.

During the short-circuit, the driving supply voltage U_G is

$$U_G = U_r / \sqrt{3} \quad \text{(A.1)}$$

where U_r is the rated voltage of the circuit-breaker.

This voltage U_G drives the current I_L through the circuit consisting of the reactances X_S, X_B (if any) and X_L in series.

The reactances are defined as follows:

– X_S source side reactance;

– X_B busbar reactance on source side;

– X_L line side reactance.

The corresponding inductances are

$$L_S = X_S/\omega \quad \text{(A.2a)}$$

$$L_B = X_B/\omega \quad \text{(A.2b)}$$

$$L_L = X_L/\omega \quad \text{(A.2c)}$$

The r.m.s. value of the voltage drop on the source side, not considering X_B because of its negligible contribution, is

$$U_S = I_L \times X_S = U_G \frac{I_L}{I_{SC}} \quad \text{(A.3)}$$

where

I_{sc} is the rated short-circuit breaking current;

I_L is the short-line fault breaking current.

The r.m.s. value of the voltage drop along the line is

$$U_L = I_L \times X_L = U_G \left(1 - \frac{I_L}{I_{sc}}\right) \tag{A.4}$$

At the instant when the current is interrupted, the induced voltage drop across the line inductance is:

$$u_0 = U_L \sqrt{2} = L_L \frac{\mathrm{d}i}{\mathrm{d}t} \tag{A.5a}$$

and for a symmetrical current:

$$u_0 = \omega \times L_L \times I_L \sqrt{2} \tag{A.5b}$$

This voltage drop returns to zero by a series of travelling waves reflected back and forth along the line between the circuit-breaker and the location of the fault, generating a transient voltage across the line in the form of a decaying saw-tooth oscillation[4)].

At the instant when the current is interrupted, the induced voltage drop across the source side inductance is:

$$u_x = U_x \sqrt{2} = L_S \frac{\mathrm{d}i}{\mathrm{d}t} \tag{A.6a}$$

and for a symmetrical current:

$$u_x = \omega \times L_S \times I_L \sqrt{2} \tag{A.6b}$$

This voltage drop returns to zero by a series of oscillations. It is superimposed to the driving source voltage, both forming the source side voltage u_S of the circuit-breaker.

The crest value U_m of the total induced voltage at the instant of current interruption is:

$$U_m = u_0 + u_x = (L_L + L_S) \frac{di}{dt} \tag{A.7a}$$

and for a symmetrical current:

$$U_m = \omega (L_L + L_S) I_L \sqrt{2} = U_G \sqrt{2} = U_r \sqrt{2} / \sqrt{3} \tag{A.7b}$$

The voltage at the source side terminals of the circuit-breaker is the difference between the driving supply voltage and the voltage drop across the reactance X_S. The resulting specified transient recovery voltage for short-line faults appearing across the circuit-breaker is the difference between the source side transient voltage u_S and the line side transient voltage u_L as shown in figure A.1.

The ratio between the voltage u_0 at the instant of breaking and the crest value U_m of the driving voltage is determined by the ratio of voltage drops across the line-side inductance and the source-side inductance, hence

$$u_0 / U_m = u_0 / (u_0 + u_x) = L_L / (L_L + L_S) = 1 - I_L / I_{SC} \tag{A.8}$$

This relation is shown in table A.1 for the standard ratios of short-line fault currents.

---

4) In practice the saw-tooth waveform is in some degree modified by a time delay, due to lumped capacitances present at the terminals of the circuit-breaker (capacitances of voltage transformers, current transformers, etc.); in addition, the top of the oscillation is slightly rounded.

Table A.1 – Ratios of voltage-drop and source-side TRV

I_L/I_{SC}	u_0/U_m	u_m/U_m
0,90	0,10	1,36
0,75	0,25	1,30
0,60	0,40	1,24

A.2 Transient voltage on line side

The peak value u_L* of the first peak of the transient voltage across the line is obtained by multiplying the value u_0 by the peak factor k.

$$u_L{}^* = ku_0 = kL_L \frac{di}{dt} \qquad \text{(A.9)}$$

The time t_L is obtained from the rate-of-rise du_L/dt of the transient voltage u_L across the line and the peak value u_L* of the transient voltage across the line:

$$\frac{du_L}{dt} = -sI_L = -Z\frac{di}{dt} \qquad \text{(A.10)}$$

then

$$t_L = \frac{u_L{}^*}{\frac{du_L}{dt}} = \frac{u_L{}^*}{sI_L} = k\frac{L_L}{Z} \qquad \text{(A.11)}$$

where

s is the RRRV factor (kV/μs/ kA);

Z is the surge impedance of the line;

f is the rated frequency.

The rated line characteristics Z, k and s are given in table 4 (see 4.105).

NOTE The approximate length of line corresponding to a given short-line fault can be obtained by the formula:

$$L = c\ t_L/2 \qquad \text{(A.12)}$$

where c is the speed of the travelling wave propagation assumed to be equal to: c = 0,3 km/μs (A.13)

A.3 Transient voltage on source side

The course of the source-side transient voltage from the initial value u_0 to the peak value u_m can be derived from tables 1a, 1b and 1c. The time coordinates t_1, t_2, t_3 and t_d given in these tables can be used directly. The voltage u_1 in tables 1a, 1b and 1c equalling the total induced voltage U_m at the instant of the current interruption is not affected, but the TRV peak value u_c results in a lower value u_m:

$$u_m = u_0 + k_{af}u_x \qquad \text{(A.14)}$$

then

$$u_m / U_m = (u_0 + k_{af}u_x)/U_m \qquad \text{(A.15a)}$$

and using equation (A.8)

$$u_m / U_m = 1 + (k_{af} - 1) I_L / I_{sc} \qquad \text{(A.15b)}$$

as given in table A.1.

The rate of rise of the source side TRV du/dt_{SLF} is lowered related to the standard value for terminal fault T100 du/dt_{TF}. For a four parameter wave shape it is

$$\left(\frac{du}{dt}\right)_{SLF} = \frac{U_m - u_0}{t_1} = \left(\frac{du}{dt}\right)_{TF} \times \frac{I_L}{I_{SC}} \qquad \text{(A.16)}$$

The peak value u_m of the source-side transient recovery voltage is also the peak value of the transient recovery voltage across the circuit-breaker provided that the voltage oscillation on the line has been damped to zero by the time t_2 (or t_3), as is generally the case.

The most important part of the resulting transient recovery voltage is up to the first peak value u_L* of the transient voltage across the line which is reached by the time t_T:

- line with time delay (see figures 46 and 47): $t_T = 2t_{dL} + t_L$ (A.17a)
- line without time delay (see figure 48): $t_T = t_{dL} + t_L$ (A.17b)

NOTE In contrast to the usual procedure for defining transient recovery voltages by their envelopes, for the evaluation of the total voltage across the circuit-breaker at the instant, when the line side voltage reaches its first peak u_L*, the actual waveshape is used. This modified procedure is applied because the envelope method would result in an intermediate voltage value in the rising slope of the TRV shortly before the peak, but not in the real crest value of the total voltage across the circuit-breaker, which is relevant for the assessment of the testing conditions. The envelope method is quite satisfactory, provided TRVs are not superimposed by two or more components. However, in the present case where the complete TRV is evaluated across the circuit-breaker, the sum of three different components is considered: the source side TRV, the ITRV of the source side and the line side TRV.

For the calculation of the source-side contribution u_s* at the time t_T two different cases shall be distinguished:

– without ITRV requirements (see figure A.1)

$$u_s^* = \left(\frac{du}{dt}\right)_{SLF} \times (t_T - t_d) \qquad \text{(A.18)}$$

and

$$u_T = u_L^* + u_s^* \qquad \text{(A.19)}$$

– with ITRV requirements (see figure A.2):

$$u_s^* = u_{i0}\left(\frac{du}{dt}\right)_{SLF} \times (t_T - t_d) \qquad \text{(A.20)}$$

and again

$$u_T = u_{L^*} + u_{S^*} \qquad \text{(A.21)}$$

For ITRV requirements (as given in table 3), the following formulas apply:

$$u_{\mathrm{i}} = f_{\mathrm{i}} I_{\mathrm{L}} = k_{\mathrm{i}} L_{\mathrm{B}} \frac{\mathrm{d}i}{\mathrm{d}t} \qquad \text{(A.22)}$$

where

k_{i} = 1,4 (peak factor);

f_{i} is the multiplying factor according to table 3.

Then the bus-bar voltage drop u_{i0} becomes

$$u_{\mathrm{i0}} = u_{\mathrm{i}} / k_{\mathrm{i}} \qquad \text{(A.23)}$$

and the bus-bar inductance

$$L_{\mathrm{B}} = u_{\mathrm{i0}} / (\mathrm{d}i / \mathrm{d}t) \qquad \text{(A.24)}$$

A.4 Examples of calculations

As examples of calculations the three basic types of test circuits (see 6.109.3) are calculated. The results are given in A.4.1 to A.4.3:

– source side and line side with time delay (A.4.1);

– source side with ITRV and line side with time delay (A.4.2);

– source side with time delay and line side without time delay (A.4.3).

A.4.1 Source side and line side with time delay (L_{90} and L_{75} for 245 kV, 50 kA, 50 Hz)

Parameters	Equation	Test parameters		
		Unit	L_{90}	L_{75}
Power frequency source side				
Rated voltage U_r	---	kV	245	245
Rated short-circuit current I_{sc}	---	kA	50	50
Rated frequency f_r	---	Hz	50	50
Driving supply voltage U_G	A.1	kV	141,5	141,5
Source side reactance X_S	---	Ω	2,83	2,83
Source side inductance L_S	A.2a	mH	9,01	9,01
Power frequency line side				
Specified line setting	---	%	90	75
Short-line fault breaking current I_L	---	kA	45	37,5
di/dt at the instant of current interruption	---	A/μs	20	16,7
Line side voltage U_L	A.4	kV	14,2	35,4
Line side reactance X_L	---	Ω	0,316	0,944
Line side inductance L_L	A.2c	mH	1,0	3,0
TRV parameters on line side				
Voltage at the instant of current interruption u_0	A.8	kV	20	50
Peak factor k	---	p.u.	1,6	1,6
Peak value of first peak of line side TRV u_L*	A.9	kV	32	80
Time delay t_{dL}	---	μs	0,5	0,5
Rate-of-rise of line side TRV du_L/dt	A.10	kV/μs	9	7,5
Specified line surge impedance Z	---	Ω	450	450
Rise time t_L	A.11	μs	3,56	10,7
TRV parameters on source side				
Time delay t_d	---	μs	2	2
Rate of rise at rated short-circuit breaking current I_{sc} $(du/dt)_{TF}$	---	kV/μs	2	2
Rate of rise at short-line fault breaking current I_L $(du/dt)_{SLF}$	A.16	kV/μs	1,8	1,5
Voltage at instant of current interruption u_X	A.6a	kV	180	150
Transient peak voltage u_m	A.14	kV	272	260
Transient factor u_m/U_m	A.15a	p.u.	1,36	1,3
Total first peak across the circuit-breaker				
Time coordinate to first peak t_T	A.17a	μs	4,56	11,7
Source side contribution u_S* to TRV at time t_T	A.18	kV	4,6	14,6
First peak voltage u_T	A.19	kV	36,6	94,6

A.4.2 Source side with ITRV, line side with time delay (L_{90} for 245 kV, 50 kA, 50 Hz)

Parameter	Equation	Test parameters	
		Unit	L_{90}
Power frequency source side	Same as in A.4.1		
Power frequency line side	Same as in A.4.1		
TRV parameters on line side	Same as in A.4.1		
TRV parameters on source side	Same as in A.4.1		
ITRV parameters on source side			
Time coordinate t_i	Table 3	μs	0,6
Multiplying factor f_i	Table 3	kV/kA	0,069
Initial peak voltage u_i	A.22	kV	3,1
Bus-bar voltage drop u_{i0}	A.23	kV	2,21
Bus inductance L_B	A.24	μH	111
Total first peak voltage across the circuit-breaker			
Time coordinate t_T to first peak	A.17a	μs	4,56
Source side contribution u_S* to TRV at time t_T	A.20	kV	6,8
First peak voltage u_T	A.21	kV	38,8

A.4.3 Source side with time delay, line side without time delay (L_{90} for 245 kV, 50 kA, 50 Hz) – Calculation carried out using a simplified method

Parameter	Equation	Test parameters	
		Unit	L_{90}
Power frequency source side (bus inductance neglected)	Same as in A.4.1		
Power frequency line side	Same as in A.4.1		
TRV parameters on line side	Same as in A.4.1		
TRV parameters on source side	Same as in A.4.1		
Total first peak voltage across the circuit-breaker			
Time coordinate t_T to first peak	A.17b	μs	4,06
Source side contribution u_S* to TRV at time t_T	A.18	kV	3,7
First peak voltage u_T	A.19	kV	35,7

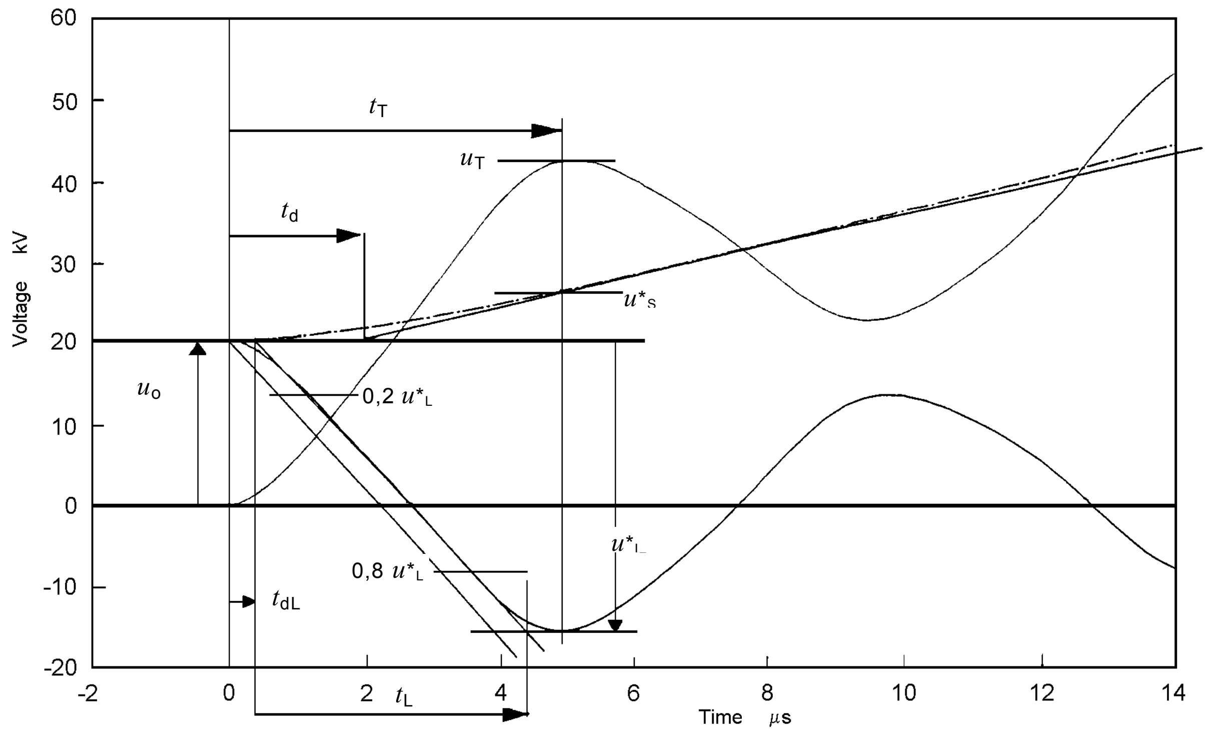


Figure A.1 – Typical graph of line and source side TRV parameters – Line side and source side with time delay

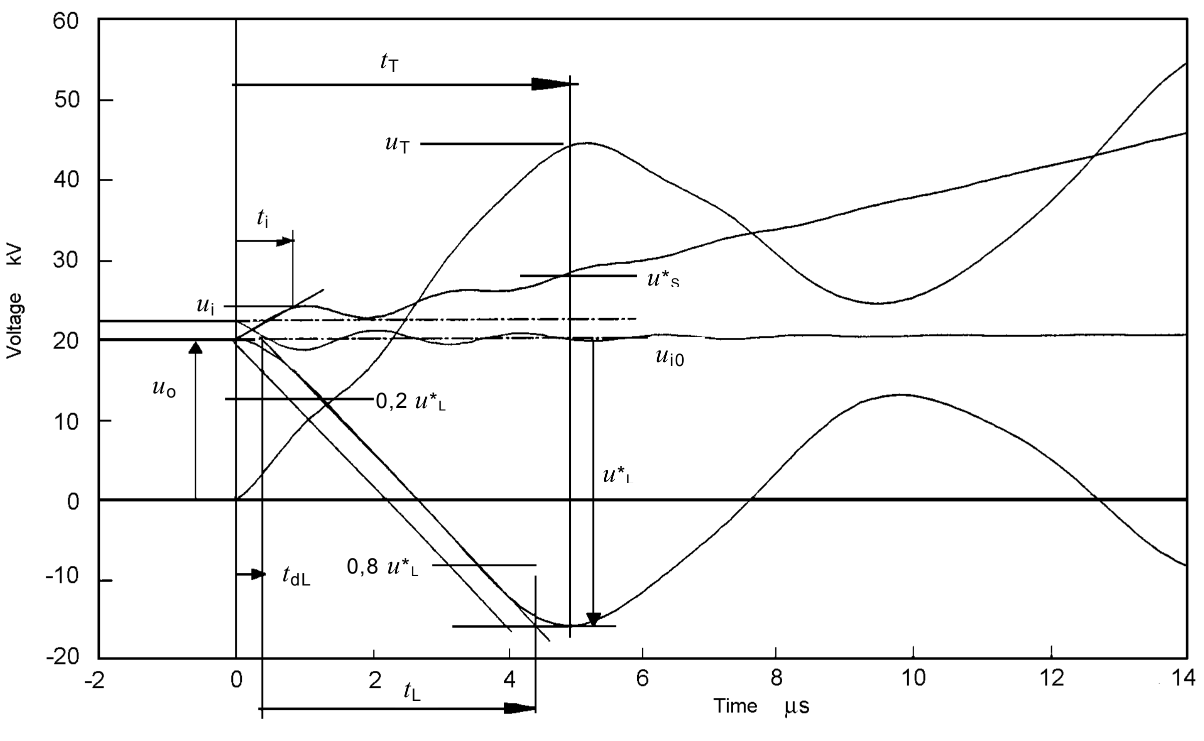


Figure A.2 – Typical graph of line and source side TRV parameters – Line side and source side with time delay, source side with ITRV

Annex B
(normative)

Tolerances on test quantities during type tests

During type tests, the following types of tolerances may normally be distinguished:

– tolerances on test quantities which directly determine the stress of the test object;

– tolerances concerning features or the behaviour of the test object before and after the test;

– tolerances on test conditions;

– tolerances concerning parameters of measurement devices to be applied.

In the following table B.1, only tolerances on test quantities are considered.

A tolerance is defined as the range of the test value specified in this standard within which the measured test value should lie for a test to be valid. In certain cases (see 6.105.5 and table 15) the test may remain valid even if the measured value falls outside the tolerance.

Any deviation of the measured test value and the true test value caused by the uncertainty of the measurement are not taken into account in this respect.

The basic rules for application of tolerances on test quantities during type tests are as follows:

a) testing stations shall aim wherever possible for the test values specified;

b) the tolerances on test quantities specified shall be observed by the testing station. Higher stresses of the circuit-breaker exceeding those tolerances are permitted only with the consent of the manufacturer. Lower stresses render the test invalid;

c) where, for any test quantity, no tolerance is given within this standard, or the standard to be applied, the type test shall be performed at values not less severe than specified. The upper stress limits are subject to the consent of the manufacturer;

d) if, for any test quantity, only one limit is given, the other limit shall be considered to be as close as possible to the specified value.

Table B.1 – Tolerances on test quantities for type tests

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.2	Dielectric tests				
6.2.6.1 and 6.2.7.1	Power-frequency voltage tests	Test voltage (r.m.s. value)	Rated short-duration power-frequency withstand voltage	± 1 %	IEC 60694, IEC 60060
		Frequency	--	45 Hz to 65 Hz	IEC 60060
		Wave shape	Peak value / r.m.s. value = √2	± 5 %	
6.2.6.2 and 6.2.7.3	Lightning impulse voltage tests	Peak value	Rated lightning impulse withstand voltage	± 3 %	
		Front time	1,2 µs	± 30 %	
		Time to half-value	50 µs	± 20 %	
6.2.7.2	Switching impulse voltage tests	Peak value	Rated switch impulse withstand voltage	± 3 %	
		Front time	250 µs	± 20 %	
		Time to half-value	2 500 µs	± 60 %	
6.2.11	Voltage test as condition check using standard switching impulse voltage				
		Peak value of switching impulse voltage	See 6.2.11	± 3 %	IEC 60060
		Front time	250 µs	± 20 %	
		Time of half-value	2 500 µs	± 60 %	
	Using TRV circuit of T10	Peak value of switching impulse voltage	See 6.2.11	± 3 %	
		Time to peak	Standard value for T10 (see table 14)	$^{+200}_{-10}$ %	
6.3	Radio interference voltage tests	Test voltage	See 6.3 of IEC 60694	± 1 %	IEC 60060
6.4	Measurement of the resistance of the main circuit	DC test current I_{DC}	--	50 A ≤ I_{DC} ≤ rated normal current	IEC 60694

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.5	Temperature-rise tests	Ambient air velocity	--	≤ 0,5 m/s	IEC 60694
		Test current frequency	Rated frequency	$^{+2}_{-5}$ %	
		Test current	Rated normal current	$^{+2}_{0}$ % These limits shall be kept only for the last two hours of the testing period.	
		Ambient air temperature T	--	+ 10 °C < T < 40 °C	
6.6	Short-time withstand current and peak withstand current tests	Test frequency	Rated frequency	± 10 %	IEC 60694
		Peak current (in one of the outer phases)	Rated peak withstand current	$^{+5}_{0}$ %	
		Average of a.c. component of three-phase test current	Rated short-time withstand current	± 5 %	
		AC component of test current in any phase/average	1	± 10 %	
		Short-circuit current duration	Rated short-circuit duration	See tolerances for I^2t	
		Value of I^2t	Rated value I^2t	$^{+10}_{0}$ %	
6.101.3	Low and high temperature tests	Deviation of ambient air temperature over height of test object	--	≤ 5 K	
		Ambient air temperature for recording characteristics before test	20 °C	± 5 K	
		Minimum and maximum ambient air temperature during tests	According to class of circuit-breaker (see IEC 60694)	± 3 K	
6.101.4	Humidity test	Minimum temperature of a cycle	25 °C	± 3 K	
		Maximum temperature of a cycle	40 °C	± 2 K	
6.101.6	Guide for static terminal load test	Forces	As specified in 6.101.6	$^{+10}_{0}$ %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.102	Miscellaneous provisions for making, breaking and switching tests	Maximum arcing time to be controlled Medium arcing time to be controlled	Specified test value	± 0,5 ms ± 1 ms	
6.103	Test circuits for short circuit making and breaking tests	Power factor (average)	--	≤ 0,15	
		Power factor of any phase / average	--	± 25 %	
		Frequency	Rated frequency	± 8 %	
6.104	Short-circuit test quantities				
6.104.1	Applied voltage before short-circuit making tests	Applied voltage	See 6.104.1	$^{+10}_{0}$ %	
		Applied phase voltage / average (three-phase)	1	± 5 %	
6.104.3	Short-circuit breaking current	AC component of any phase / average	1	± 10 %	
		AC component of the prospective current at final arc extinction in last-pole-to-clear	Specified breaking current for the relevant test-duty	≥ 90 %	
6.104.4	DC component of short-circuit breaking current	DC component in T10, T30, T60, T100s	-- For circuit-breakers preventing controlled opening	≤ 20 % ≥ 20 %	
		DC component in T100a	See 6.104.2	≥ 90 % of specified value	
		Average d.c. component T100a	Breaking current (see 6.401.2)	≥ 100 % of specified value	
6.104.5	Transient recovery voltage (TRV) for terminal fault tests	Peak value of TRV: - for circuit-breakers ≤ 52 kV - for circuit-breakers > 52 kV	 See table 13 See tables 13 and 14	 $^{+10}_{0}$ % $^{+5}_{0}$ %	
		Rate of rise of TRV: - for circuit-breakers ≤ 52 kV - for circuit-breakers > 52 kV	 See table 13 See tables 13 and 14	 $^{+15}_{0}$ % 1) $^{+8}_{0}$ %	
		Time delay t_d	See tables 13 and14	± 20 %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.104.7	Power frequency recovery voltage (RV)	Power frequency recovery voltage	Specified values according to 6.104.7	± 5 %	
		RV of any pole at the end of the time / average	1	± 20 %	
6.106	Basic short-circuit test-duty	Breaking current in T10	10 % of rated short-circuit breaking current	± 20 %	
		Breaking current in T30	30 % of rated short-circuit breaking current	± 20 %	
		Breaking current in T60	60 % of rated short-circuit breaking current	± 10 %	
		Breaking current in T100s and T100a	100 % of rated s.-c. breaking current	$^{+5}_{0}$ %	
		Peak short-circuit current in T100s and T100a	Rated short-circuit making current	$^{+10}_{0}$ %	
		DC component of breaking current in T10, T30, T60, T100s	≤ 20 %, exceptions see 6.104.4	Upper limit 25 %	
		DC component of breaking current in T100a	According to 4.101.2	Average of the d.c components of the individual tests not less than the specified value; tolerance of the individual tests –10 % (once), +5 %	
6.107	Critical current tests	Breaking current	See 6.107.2	± 20 %	
		DC component of breaking current	≤ 20 %	Upper limit 25 %	
6.108	Single-phase and double earth fault tests	Breaking current	See figure 45	$^{+5}_{0}$ %	
		DC component of breaking current	≤ 20 %	Upper limit 25 %	
		Peak value of TRV: - for circuit-breakers ≤ 52 kV - for circuit-breakers > 52 kV	See 6.108.2 and tables 13 and 14	 $^{+10}_{0}$ % $^{+5}_{0}$ %	
		Rate of rise of TRV – for circuit-breakers ≤ 52 kV – for circuit-breakers > 52 kV	See 6.108.2 and tables 13 and 14	 $^{+15}_{0}$ % $^{+8}_{0}$ %	

Table B._1 (continued)_

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.109	Short-line fault tests	DC component of breaking current	≤ 20 %	Upper limit 25 %	
		Breaking current L_{90}	90 % of rated short-circuit breaking current	90 % to 92 %	
		Breaking current L_{75}	75 % of rated short-circuit breaking current	71 % to 79 %	
		Breaking current L_{60}	60 % of rated short-circuit breaking current	55 % to 65 %	
		Surge impedance	450 Ω	± 3 %	
		Peak value of line side voltage		$^{+20}_{0}$ %	
		Rate of rise of line side voltage	See table 4 and annex A	$^{+5}_{0}$ %	
		Time delay t_{dl}		$^{0}_{-10}$ %	
6.110	Out-of-phase making and breaking tests	Power factor	--	≤ 0,15	
		DC component of breaking current	≤ 20 %	Upper limit 25 %	
		Applied voltage and power frequency recovery voltage	As specified in 6.110.2	± 5 %	
		Peak value of TRV:			
		- for circuit-breakers ≤ 52 kV	See table 1a	$^{+10}_{0}$ %	
		- for circuit-breakers > 52 kV	See tables 1a, 1b and 1c	$^{+5}_{0}$ %	
		Rate of rise of TRV:			
		- for circuit-breakers ≤ 52 kV	See table 1a	$^{+15}_{0}$ %	
		- for circuit-breakers > 52 kV	See tables 1a, 1b and 1c	$^{+8}_{0}$ %	
		Instant of closing in OP2	At crest of applied voltage in one pole	± 15°	
		Breaking current for OP1	30 % of rated out-of-phase breaking current	± 20 % of specified value	
		Breaking current for OP2	100 % of rated out-of-phase breaking current	$^{+10}_{0}$ %	

Table B.1 *(continued)*

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/ limits of test values	Reference to
6.111	Capacitive current switching tests	Power frequency voltage variation: – for LC1, CC1, BC1 – for LC2, CC2, BC2		 ≤ 2 % ≤ 5 %	
		Voltage decay of recovery voltage 300 ms after arc extinction		≤ 10 %	
		R.m.s value / r.m.s. value of fundamental component	--	≤ 1,2	
		Test voltage	As specified in 6.111.7	$^{+3}_{0}$ %	
		Frequency of the recovery voltage	Rated frequency	± 2 %	
		Breaking current / rated capacitive breaking current	LC1, CC1, BC1 LC2, CC2, BC2	10 % to 40 % ≥ 100 %	
		Damping factor of inrush current	Circuit-breakers < 52 kV	≥ 0,75	
			Circuit-breakers ≥ 52 kV	≥ 0,85	
		Back-to-back current switching: peak value of inrush making current	BC2	± 10 %	
		Back-to-back current switching: frequency of inrush making current	BC2	± 10 %	

1) If for T10 and T30 the upper limit is exceeded, the smallest value possible shall be used.

NOTE The priority parameter for short-line fault testing is the waveshape of the line side voltage and not the surge impedance of the line.

Annex C
(normative)

Records and reports of type tests

C.1 Information and results to be recorded

All relevant information and results of type tests shall be included in the type test report.

Oscillographic records in accordance with C.2 shall be made of all short-circuit operations and included in the type test report.

The type test report shall include a statement concerning the uncertainty of the measurement systems used for the tests. This statement shall refer to internal procedures of the laboratory through which traceability of the measuring uncertainty is established.

The type test report shall include a statement of the performance of the circuit-breaker during each test-duty and of the condition of the circuit-breaker after each test-duty, in so far as an examination is made, and at the end of the series of test-duties. The statement shall include the following particulars:

a) condition of circuit-breaker, giving details of any replacements or adjustments made and condition of contacts, arc control devices, oil (including any quantity lost), statement of any damage to arc shields, enclosures, insulators and bushings;
b) description of performance during test-duty, including observations regarding emission of oil, gas or flame.

C.2 Information to be included in type test reports

C.2.1 General

a) date of tests;
b) reference of report number;
c) test numbers;
d) oscillogram numbers.

C.2.2 Apparatus tested

Subclause 6.1.3 of IEC 60694 is applicable.

C.2.3 Rated characteristics of circuit-breaker, including its operating devices and auxiliary equipment

The values of rated characteristics specified in clause 4 and the minimum opening time shall be given by the manufacturer.

C.2.4 Test conditions (for each series of tests)

a) number of poles;
b) power factor;
c) frequency, in Hz;
d) generator neutral (earthed or isolated);
e) transformer neutral (earthed or isolated);
f) short-circuit point or load side neutral (earthed or isolated);
g) diagram of test circuit including connection(s) to earth;
h) details of connection of circuit-breaker to the test circuit (e.g. orientation);
i) pressure of fluid for insulation and/or interruption;
j) pressure of fluid for operation.

C.2.5 Short-circuit making and breaking tests

a) operating sequence and time intervals;
b) applied voltage, in kV;
c) making current (peak value), in kA;
d) breaking current:
   1) r.m.s. value of a.c. component in kA for each phase and average;
   2) percentage d.c. component;
e) power frequency recovery voltage, in kV;
f) prospective transient recovery voltage;
   1) compliance with requirement a) of 6.104.5.1; voltage and time coordinates may be quoted;
   2) compliance with requirement b) of 6.104.5.1;
g) arcing time, in ms;
h) opening time, in ms;
i) break time, in ms;
   Where applicable, break-times up to the instant of extinction of the main arc and up to the instant of the breaking of resistance current shall be given;
j) closing time, in ms;
k) make time, in ms;
l) behaviour of circuit-breaker during tests, including, where applicable, emission of flame, gas, oil or occurrence of NSDDs, etc;
m) condition after tests;
n) parts renewed or reconditioned during the tests.

C.2.6 Short-time withstand current test

a) current
   1) r.m.s. value, in kA,
   2) peak value, in kA;
b) duration, in s;

c) behaviour of circuit-breaker during tests;

d) condition after tests;

e) resistance of the main circuit before and after tests, in μΩ.

C.2.7 No-load operation

a) before making and breaking tests (see 6.102.6.1);

b) after making and breaking tests (see 6.102.9.3).

C.2.8 Out-of-phase making and breaking tests

a) breaking current in each phase, in kA;

b) making current in each phase, in kA;

c) voltage across each phase, in kV;

d) prospective transient recovery voltage;

e) arcing time, in ms;

f) opening time, in ms;

g) break-time, in ms;

h) closing time, in ms;

i) make-time, in ms;

j) duration of resistor current (where applicable), in ms;

k) behaviour of circuit-breaker during tests including, where applicable, emission of flame, gas, oil or occurrence of NSDDs, etc;

l) condition after tests.

C.2.9 Capacitive current switching tests

a) test voltage, in kV;

b) breaking current in each phase, in A;

c) making current in each phase, in kA;

d) peak values of the voltage between phase and earth, in kV:

  1) supply side of circuit-breaker;

  2) load side of circuit-breaker;

e) number of restrikes (if any);

f) details of point-on-wave setting, arcing time in ms;

g) closing time, in ms;

h) make time, in ms;

i) behaviour of circuit-breaker during tests;

j) condition after tests.

C.2.10 Oscillographic and other records

Oscillograms shall record the whole of the operation. The following quantities shall be recorded. Certain of these quantities may be recorded separately from the oscillograms, and several oscillographs with different time scales may be necessary:

a) applied voltage;
b) current in each pole;
c) recovery voltage (voltages on supply and load side of circuit-breaker for charging current tests);
d) current in closing coil;
e) current in opening coil;
f) amplitude and timing scale appropriate for the required accuracy;
g) mechanical travel characteristics (where applicable).

All cases in which the requirements of this standard are not strictly complied with and all deviations shall be explicitly mentioned at the beginning of the test report.

Annex D
(normative)

Determination of short-circuit power factor

There is no method by which the short-circuit power factor can be determined with precision, but, for the purpose of this standard, the determination of the power factor in each phase of the test circuit may be made with sufficient accuracy by whichever of the two following methods is the more appropriate.

D.1 Method I – Calculation from d.c. component

The angle φ (phase angle between voltage vector and current vector) may be determined from the curve of the d.c. component of an asymmetrical current wave between the moment of short-circuit initiation and the moment of contact separation, as shown below:

D.1.1 Formula for the d.c. component

The formula for the d.c. component is as follows:

$$i_d = I_{d0} \times e^{-\frac{R}{L}t} = I_{d0} \times e^{-\frac{t}{\tau}}$$

where

i_d is the value of the d.c. component at any instant;

I_{d0} is the initial value of the d.c. component;

$\tau = L/R$ is the time constant of the circuit, in seconds;

t is the time interval, in seconds, between i_d and I_{d0};

e is the base of Napierian logarithms.

The time constant L/R can be ascertained from the above formula as follows:

a) measure the value of I_{d0} at the instant of short-circuit and the value of i_d at any other time t before contact separation;

b) determine the value of $e^{-Rt/L}$ by dividing i_d by I_{d0};

c) from values of e^{-x} determine the value of $-x$ corresponding to the ratio i_d/I_{d0};

d) the value x then represents Rt/L, from which L/R can be determined.

D.1.2 Phase angle φ

Determine the phase angle φ from:

$$\varphi = \arctan\left(\omega \frac{L}{R}\right)$$

where ω is 2π times the actual frequency.

D.2 Method II – Determination with pilot generator

When a pilot generator is used on the same shaft as the test generator the voltage of the pilot generator on the oscillogram may be compared in phase, first with the voltage of the test generator and then with the current of the test generator.

The difference between the phase angles between pilot generator voltage and main generator voltage on the one hand, and pilot generator voltage and test generator current on the other hand gives the phase angle between the voltage and current of the test generator, from which the power factor can be determined.

Annex E
(normative)

Method of drawing the envelope of the prospective transient recovery voltage of a circuit and determining the representative parameters

E.1 Introduction

A transient recovery voltage wave may assume different forms, both oscillatory and non-oscillatory.

The wave may be defined by means of an envelope made up of three consecutive line segments; when the wave approaches that of a damped oscillation at one single frequency, the envelope resolves itself into two consecutive line segments. In all cases, the envelope should reflect as closely as possible the actual shape of the transient recovery voltage. The method described here enables this aim to be achieved in the majority of practical cases with sufficient approximation.

NOTE Nevertheless, some cases may arise where the proposed construction would lead to parameters quite obviously more severe than would be justified by the transient recovery voltage curve. Such cases should be dealt with as exceptions and, as a consequence, form the subject of an agreement between the manufacturer and user or the test laboratory.

E.2 Drawing the envelope

The following method is used for constructing the line segments forming the envelope of the prospective transient recovery voltage curve.

a) The first line segment passes through the origin O, is tangential to the curve and does not cut the curve (see figures E.1 to E.3, segment OB and figure E4, segment OA).

   In the case of curves whose initial portion is concave towards the left, the point of contact is often in the vicinity of the first peak (see figures E.1 and E.2, segment OB).

   If the concavity is towards the right, as in the case of an exponential curve, the point of contact is near the origin (see figure E.3, segment OB).

b) The second line segment is a horizontal line tangential to the curve at its highest peak (see figures E.1 to E.4, segment AC).

c) The third line segment is tangential to the curve at one or more points situated between the first two points of contact, and does not cut the curve.

   There are three possible cases for drawing this latter line segment.

   1) One single line segment can be drawn touching the curve at two points (or possibly at more than two points).

      In this case, it forms part of the envelope (see figure E.1, segment BA).

      The four-parameter envelope O, B, A, C, is then obtained.

   2) Several segments can be drawn which touch the curve at two points (or possibly at more than two points) without cutting it.

      In this case, the segment to be used for the envelope is that which touches the curve at one point only, situated so that the areas on either side of this point between the curve and the envelope are approximately equal (see figure E.2, segment BA).

      The four-parameter envelope O, B, A, C is then obtained.

3) No segment can be drawn touching the curve at more than one point without cutting it.

   In this case, the following distinction should be made.

   i) The point of contact of the first line segment and the highest peak are comparatively far apart from each other. This is typically the case for an exponential curve or a curve approximating to an exponential.

      In this case, the line segment shall be tangential to the curve at a point such that the areas on either side of this point between the curve and the envelope are approximately equal, as in case c)2) of E.2 (see figure E.3, segment BA).

      The four-parameter envelope O, B, A, C is then obtained.

   ii) The point of contact of the first line segment and the highest peak are comparatively close to each other.

      This is the case for a curve representing a damped oscillation of single frequency or a curve of similar shape.

      In this case, a third line segment is not drawn, and representation by two parameters, corresponding to the first two line segments, is adopted (see figure E.4).

      The two-parameter envelope O, A, C is then obtained.

E.3 Determination of parameters

The representative parameters are, by definition, the coordinates of the points of intersection of the line segments constituting the envelope.

When the envelope is composed of three line segments, the four parameters u_1, t_1, u_c and t_2 shown in figures E.1, E.2 and E.3 can be obtained as coordinates of the points of intersection B and A.

When the envelope is composed of two line segments only, the two parameters u_c and t_3 shown in figure E.4 can be obtained as coordinates of the point of intersection A.

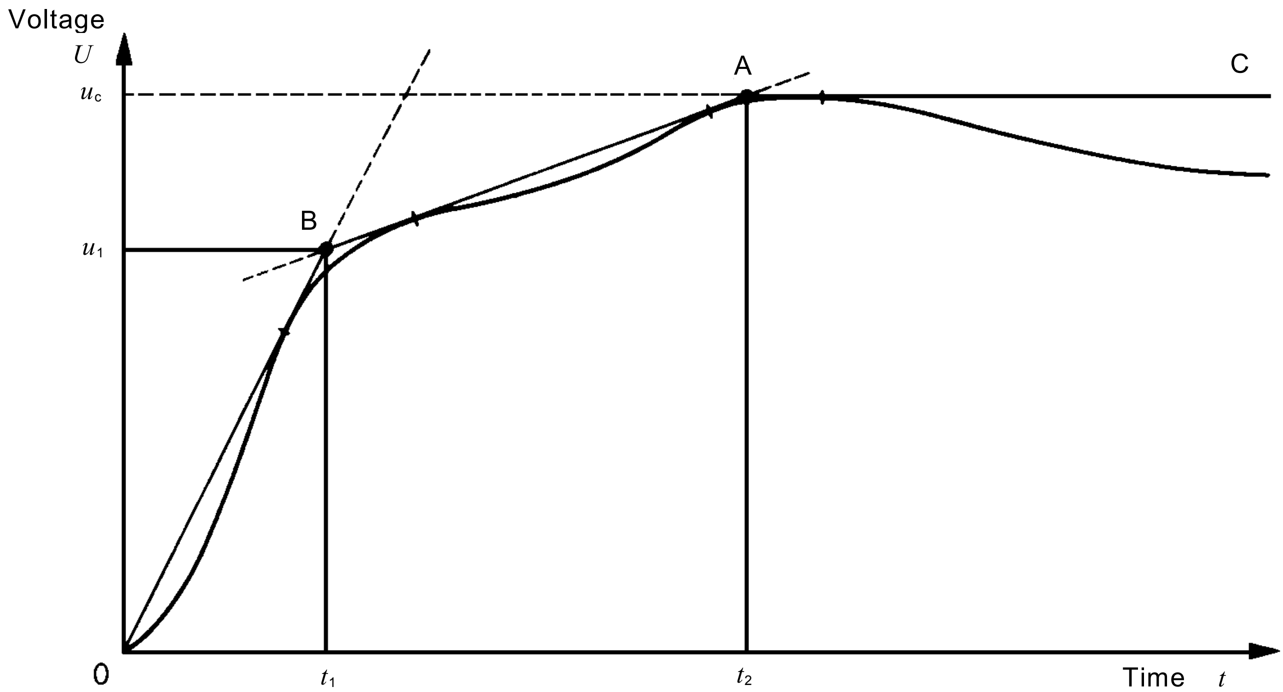


Figure E.1– Representation by four parameters of a prospective transient recovery voltage of a circuit – Case E.2 c) 1)

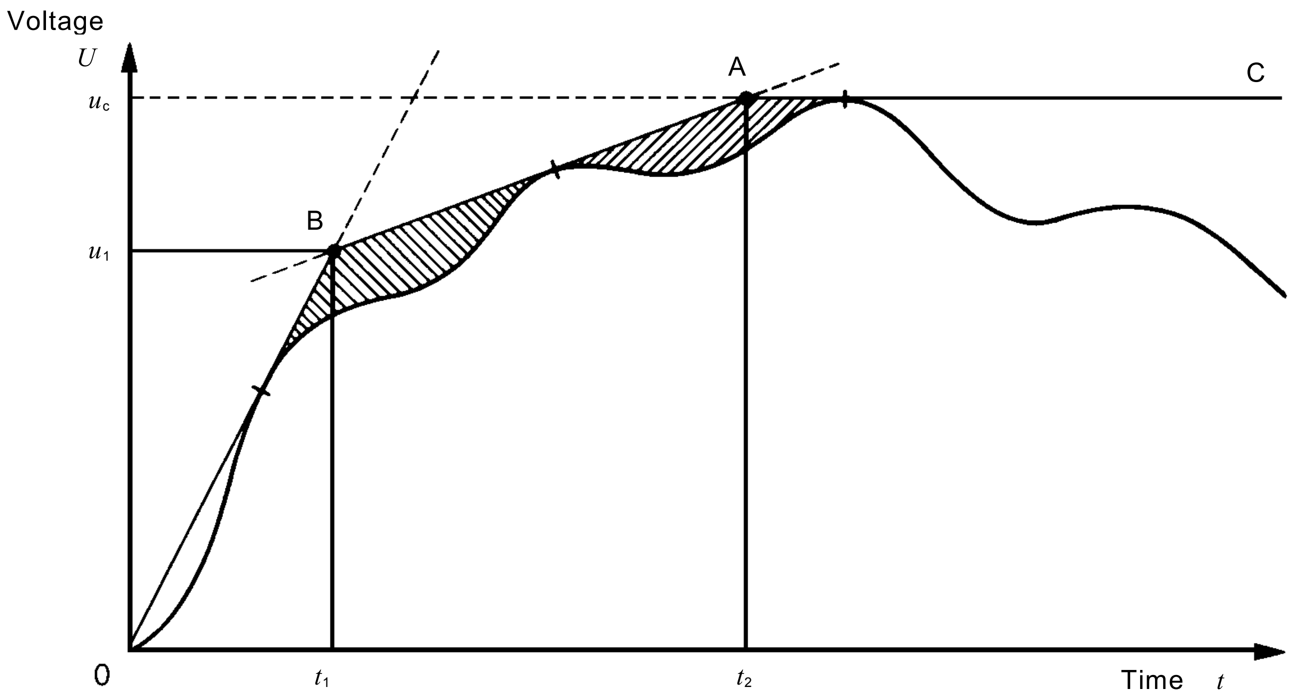


Figure E.2 – Representation by four parameters of a prospective transient recovery voltage of a circuit – Case E.2 c) 2)

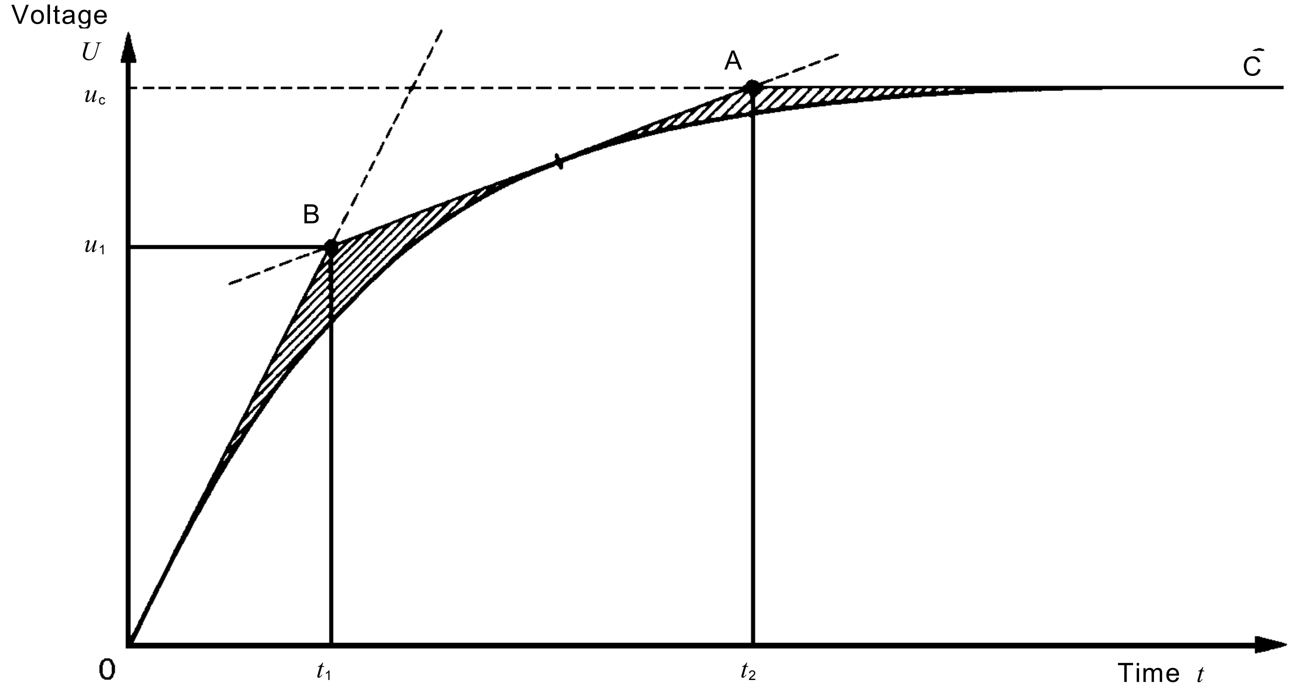


Figure E.3 – Representation by four parameters of a prospective transient recovery voltage of a circuit – Case E.2. c) 3) i)

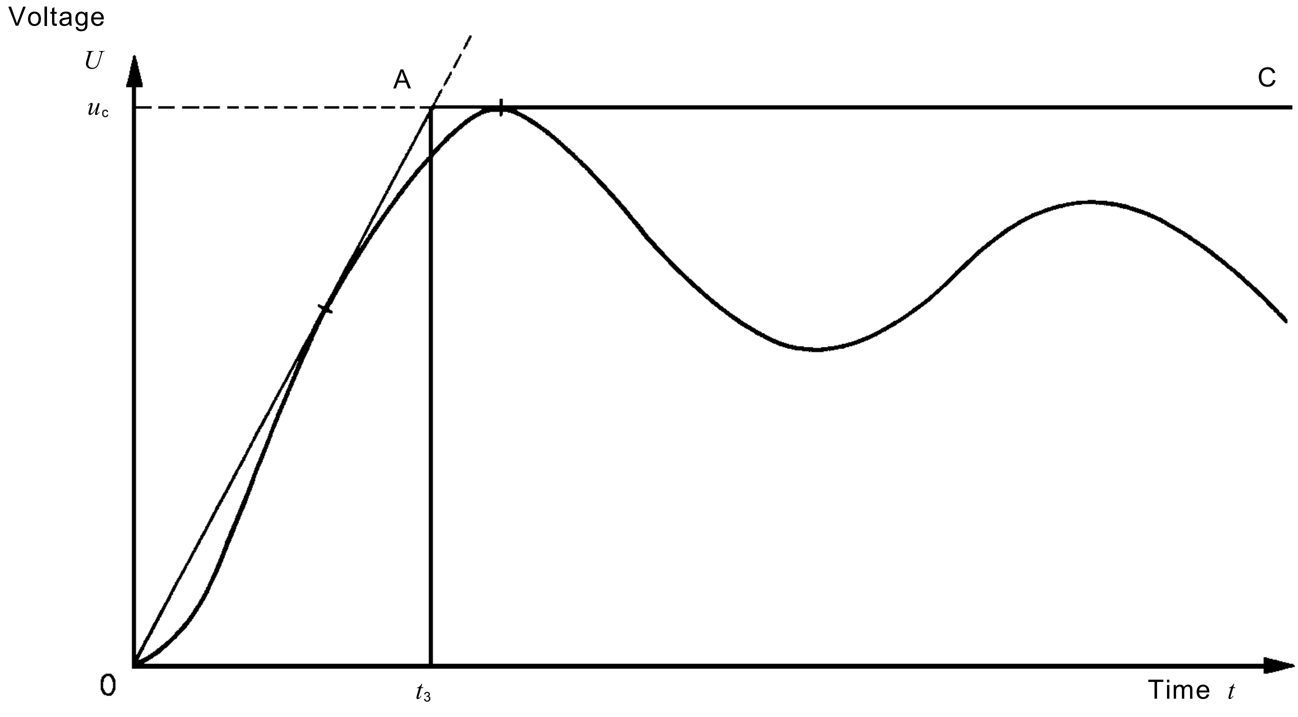


Figure E.4 – Representation by two parameters of a prospective transient recovery voltage of a circuit – Case E.2. c) 3) ii)

Annex F
(normative)

Methods of determining prospective transient recovery voltage waves

F.1 Introduction

The waveforms of the transient recovery voltage (TRV) resulting from the breaking of short-circuit currents depend on two main groups of factors, namely: those dependent on the circuit characteristics (inductance, capacitance, resistance, surge impedance, etc.), and those arising from the circuit-breaker characteristics (arc voltage, post-arc conductivity, capacitors and switching resistors, etc.).

Methods are recommended for determining the waveform of the TRV as produced solely by the circuit characteristics, this being the "prospective TRV".

Since any measuring device will have some effect upon the waveform of the prospective TRV, suitable precautions and, possibly, corrections are necessary.

Methods are available for the evaluation of the prospective TRV of both short-circuit test plant circuits and power systems, and the recommended methods are enumerated and briefly described, taking into account the TRV characteristics which are specified for rating and testing.

Experience on testing plants and also on systems has shown that following the breaking of a short-circuit current, not only is a single or multi-frequency oscillation superimposed on the power-frequency voltage wave, but exponential components of substantial size and duration are also present. The latter have time constants which are dependent upon the characteristics of the components of the circuit, for example generators, transformers, lines, etc. These exponential components have the effect of depressing the peak value of the TRV and the rate-of-rise to below those which would have occurred if the oscillatory components alone had been superimposed on the power-frequency voltage. This is shown in figure F.1 and any method used for measurement should take this effect into account.

Measurements have shown that the inductance of the various circuit components varies with frequency, owing to the screening effects of eddy currents within the conductors, the earth and the magnetic circuits. Together with other factors tending to reduce instantaneous voltages, this introduces a time constant varying from hundreds of microseconds for some generators down to tens of microseconds for transformers, the exact values depending upon the design of the particular equipment and the frequency of the components of the TRV. In some cases, this can result in a depression of the peak value of the TRV by as much as 25 %.

It is therefore important that these factors are taken into account when assessing the prospective TRV of either a test plant or system, and that guidance is given in connection with the recommended methods.

Irrespective of the method used, the actual values measured in the test plant for the prospective TRV shall be in accordance with the values specified in this standard.

Where the time t_2 of the crest of the TRV exceeds, say, 1 250 μs, then, in addition to the effects described above, the instantaneous power-frequency voltage will, in any case, have decreased by more than 6 % at 50 Hz and more than 10 % at 60 Hz. Consequently, this further effect shall be taken into consideration when using methods for determining the prospective TRV which involve a power-frequency recovery voltage, or where calculations are made using circuit constants.

The instantaneous value of the power-frequency component immediately following current zero is also dependent upon the short-circuit power factor and upon the percentage d.c. component of the last half-cycle of current, and may thus be less than the full crest value. For symmetrical currents and short-circuit power factors of 0,15 or less, the reduction is not more than 1,5 %, and so is of little importance on test plant circuits; it may be of significance, however, at higher power factors which may occur in service.

For the TRV for terminal faults (see 4.102), a time delay has been introduced to allow for the influence of local capacitance on the source side of the circuit-breaker. Corresponding time delays have also been specified for the relevant test circuits (see 6.104.5), and the method used for measuring the TRV should be capable of resolving these time delays.

For some circuit-breakers the characteristics for short-line faults are also specified (see 4.105), and during short-line fault tests the corresponding resulting TRV has been specified. Local capacitance between the circuit-breaker and the line will also produce a time delay in the line side TRV component. During testing, it is desirable to measure and record the line side time delay and the method used should be suitable for evaluating this.

F.2 General summary of the recommended methods

The basic methods for determining prospective TRV waveforms are classified as follows:

– group 1 – Direct short-circuit breaking;
– group 2 – Power-frequency current injection;
– group 3 – Capacitor current injection;
– group 4 – Model networks;
– group 5 – Calculation from circuit parameters;
– group 6 – No-load switching of test circuits including transformers;
– group 7 – Combination of different methods.

Groups 1, 4 and 5 are recommended for power systems.

Groups 2 and 3 can be used for portions of power systems.

Only groups 1 to 3 or a combination of these are suitable for assessing the prospective TRV of circuits used in short-circuit test plants.

When using groups 1, 2, 3, 4, 6 or 7, the voltage recording circuits should be carefully checked to ensure that the overall calibration is constant over the range of TRV frequencies to be recorded, and that time deflections are linear. The oscillograph and any voltage divider should then be calibrated against a known voltage. Where cathode-ray oscillographs with a sweep time base are used, the deflection/time scale should be accurately known, and preferably this should be linear to avoid replotting for comparative purposes, etc.

Where applicable, the injected current and the voltage across the circuit under investigation should be recorded using a time base of suitable velocity and, in addition, high-speed records of current and voltage at the current-zero should be taken. The TRV should be recorded by an oscillograph of suitable sensitivity and with an appropriate time scale.

F.3 Detailed consideration of the recommended methods

F.3.1 Group 1 – Direct short-circuit breaking

This method involves the breaking of an actual short-circuit current, established by means of a solid metallic connection in the system under investigation and recording the resultant TRV by an oscillograph. Ideally, the current broken should be symmetrical, or allowance made for the change in di/dt if there is appreciable asymmetry. With this method, it is essential to allow for the influence of the circuit-breaker. The most important characteristics in this respect are arc voltage and post-arc conductivity.

Due to the voltage of the arc, the voltage across the circuit-breaker contacts may not be zero at the instant of current interruption, and hence the TRV does not rise from zero voltage but from the value of the arc voltage at current zero. The TRV thus begins below the voltage zero axis and then crosses it (see figure F.3).

As a result, the peak voltage is higher than in the case of an ideal circuit-breaker (zero arc voltage) (see figure F.2). A similar but more pronounced effect results from interruption at a markedly premature current zero (current chopping) which may occur if the current is small (see figure F.4). Furthermore, if the prospective TRV comprises several oscillatory components, current chopping may produce a waveform which is markedly different from that which would be obtained with an "ideal" circuit-breaker.

Thus a circuit-breaker with a low arc voltage immediately before current zero and which does not exhibit current chopping is the most suitable for use with direct short-circuit breaking.

The influence of the arc voltage may be compensated for as shown in figure F.6.

In principle, compensation for the arc voltage is only suitable for TRVs having a single-frequency transient component; nevertheless, it may also be used as a good approximation for multi-frequency transients if the amplitude of the main oscillatory component is predominant.

The post-arc current, i.e. the current flowing through the arc-gap during the rise of the TRV, can influence the waveform of the latter by damping, thus reducing its rate-of-rise and peak value (see figure F.5). A similar effect results from the use of resistors in parallel with the interrupting chambers of the circuit-breaker.

It follows, therefore, that in addition to the requirements relating to low arc voltage and absence of current chopping, any circuit-breaker used for the direct short-circuit breaking method should not be fitted with shunt resistors and should not exhibit significant post-arc conductivity.

Particularly, where the test plant can be operated at a suitably reduced excitation, vacuum interrupters can often be used as nearly "ideal" circuit-breakers. However, it should be ascertained that any device used does not exhibit significant current chopping in the particular circuit under investigation.

The characteristics of circuit-breakers used for direct short-circuit breaking can sometimes be appropriately improved, for example by delaying the instant of contact separation to produce a short arcing time and low arc voltage.

With this method, an actual short-circuit current is broken in the circuit under investigation and the recorded TRV will take into account, more or less, the effects contributing to depression of the recovery voltage. For this reason, the direct short-circuit breaking method can be, depending upon the characteristics of the circuit-breaker, the most suitable means of obtaining an assessment of the prospective TRV, and is frequently used as the basis for checking other methods. However, the direct short-circuit breaking method is less suited for measuring time delays, particularly the time delay of the line-side TRV, in the case of short-line fault.

F.3.2 Group 2 – Power-frequency current injection

This method is only used with the circuit de-energised and is therefore mainly of use in test plants, or where part of a system can be analysed whilst de-energised. It does not take into account corona or magnetic saturation phenomena.

The basis of this method is the injection of a relatively small current into the circuit and the recording of the response of the circuit when the current is switched off by an ideal switching device, i.e. a device having negligible arc voltage and post-arc current.

A suitable source of injected current is a single-phase transformer operated from the local low-voltage mains, the secondary giving, for example, a range of currents and voltages between 2 A at 200 V and 300 A at 25 V. This range will cover the impedances of the majority of circuits to be assessed. A schematic diagram as an example of the application of this method is shown in figure F.7 together with details of the components. Figure F.8 shows the sequence of operation of the scheme.

Care should be taken to ensure that the inherent capacitances of the supply and measuring devices do not influence the results.

The voltage response should be measured at the input terminals of the circuit and, when applicable, one terminal of the circuit should be earthed. In those cases where the circuit is not earthed at one of its terminals, it is essential that the measuring and injection equipment are completely isolated from earth. This can be achieved by using an auxiliary generator insulated from earth and having negligible capacitance to earth.

The most convenient switching device for this scheme is a semiconductor diode. In general, semiconductor diodes with reverse recovering times not exceeding 100 ns have been found to be suitable. Longer times are acceptable where the TRV has a low equivalent natural frequency. To obtain the correct current-carrying capacity, several diodes may be operated in parallel.

NOTE The characteristics of diodes are dependent on a number of factors, for example the value of the current in the forward direction, the waveform and value of the reverse voltage, and the manufacturer's data which are dependent on the methods employed to determine the characteristics.

To achieve a symmetrical current wave, it may be necessary for the current to flow for a time of up to 20 cycles. During most of this time, the diodes will be by-passed by a switch which is opened at the end of this time thus allowing the current to pass through the diodes which will interrupt the current at the following current-zero.

To assess the time delay accurately, it is necessary to amplify the voltage and time scales for the initial part of the wave.

The lower speed record of the current shows whether the current was symmetrical when broken, and the high speed record gives the rate-of-change, di/dt, immediately before current-zero. It also shows whether or not there was any appreciable post-zero current to cause damping of the TRV, or appreciable suppression of the current, likely to affect the TRV amplitude.

The TRV record represents the natural transient oscillation of the circuit under investigation, and takes into account most of the factors causing voltage depression.

The values can be determined using a voltage calibration in terms of the full power of the circuit. Detailed explanations are given in F.3.4.

F.3.3 Group 3 – Capacitor current injection

This method is similar to group 2 except that the current through the circuit being considered is obtained from the discharge of a capacitor. Thus, the frequency of the injected current will depend upon the values of the capacitor and the inductance of the circuit.

Since the frequency of the injected current is usually much higher than the power frequency, this method does not take into account the factors causing voltage depression.

As the frequency of the discharge current should be one-eighth of the equivalent natural frequency of the circuit, this means that the method is suitable for measuring the TRV of circuits containing components with high natural frequencies. It is particularly useful for measuring the characteristics of the components on the line side of short-line fault test circuits, the natural frequencies of which are very high, with correspondingly small time delays.

Figure F.9 provides a schematic diagram of an example of a capacitor current injection circuit together with details of the components. Figure F.10 shows the sequence of operation of the schema.

The same precautions and method of calibration are used as for group 2, and these are detailed in F.3.4.

F.3.4 Groups 2 and 3 – Methods of calibration

From the measured value of the rate-of-change, di/dt, of the injected current immediately before zero, calculate the equivalent r.m.s. value of the injected current I_i.

$$I_i = \frac{\frac{di_i}{dt}}{2\pi f_i \sqrt{2}}$$

where f_i is the frequency of the injected current.

In this calculation, it is assumed that:

$$i_i = I_i \sqrt{2} \sin(2\pi f_i t) \cong I_i \sqrt{2} \times \pi f_i t$$

This is approximately valid when t_2 < 1 250 µs (or when t_2 < 1 000 µs on a 60 Hz basis).

On the basis of the above approximations, the following rule may be derived:

The frequency of the injected current should be ≤ 1/8th of the equivalent natural frequency of the circuit being measured. For cases where the coordinate t_2 of the prospective TRV is greater than 1 250 µs (1 000 µs for 60 Hz), the frequency of the injected current should equal the rated power frequency.

NOTE If the factor is 1/8, during the interval ($t_2 - t_0$) a maximum deviation of the slope of the injection current from a straight line of 15 % would occur. A factor 1/14 would give a maximum deviation of 5 %.

If the r.m.s. value of the maximum short-circuit current of the circuit is I_{sc}, then the voltage calibration V_{sc}(in mm) for the TRV corresponding to I_{sc} will be:

$$V_{sc}\text{(in mm)} = V_i\text{(in mm)} \times (I_{sc}/I_i) \times (f_{sc}/f_i)$$

where f_{sc} is the frequency of the short-circuit current.

Subject to the provisions given above concerning prospective TRV with long times t_2, for those cases where the deviation of the curve of the current from the sinusoidal, symmetrical form is too significant to be neglected, the following basic formula should be used:

$$V_{sc}\text{ (in mm)} = V_i\text{ (in mm)} \frac{\left(\frac{di_{sc}}{dt}\right)_{i_{sc\to 0}}}{\left(\frac{di_i}{dt}\right)_{i_{sc\to 0}}}$$

where $\left(\frac{di_{sc}}{dt}\right)_{i_{sc}\to 0}$ is the rate-of-change of the power frequency short-circuit current at current zero, with the current function:

$$i_{sc} = I_{sc} \sqrt{2}\sin(2\pi f_{sc} t) \cong I_{sc} \sqrt{2} \times 2\pi f_{sc} t$$

This formula applies particularly to the method of capacitor current injection where the current is of a slightly damped oscillatory form.

To determine the calibration for short-line fault tests, the following method is suitable:

From the high-speed recording measure:

$\frac{du_i}{dt}$ = RRRV of the TRV at zero of the injected current;

u_i = first voltage peak of the injected current;

$\left(\frac{di_i}{dt}\right)_{i_i \to 0}$ = rate-of-change of the injected current at its zero.

The value of the surge impedance Z is then obtained by the following calculation:

$$Z = \frac{\dfrac{\mathrm{d}u_\mathrm{i}}{\mathrm{d}t}}{\left(\dfrac{\mathrm{d}i_\mathrm{i}}{\mathrm{d}t}\right)_{i_\mathrm{i} \to 0}}$$

F.3.5 Group 4 – Model networks

In this method, a model network is assembled from units which shall be true representations of the components of the full-scale circuit. It is usually necessary to imitate the components of the full-scale circuit which have distributed parameters by model units having lumped parameters. In addition, it is essential that the impedance (especially reactance and resistance) characteristics of the model units shall be, as near as possible, a true imitation of those characteristics of the full-scale components at frequencies up to at least that corresponding to the TRV under consideration.

The accuracy of this method depends upon having exact data for the parameters of the circuit to be imitated, and these are frequently difficult to obtain and to simulate on a small model component.

This applies particularly to parameters which vary with frequency, so that this method in general does not directly take into account the depression of the TRV, and tends to give values which are somewhat higher than those obtained with direct short-circuits on a full-scale system.

The method is mainly useful for investigating power systems since it does not require the system to be taken out of service, and will give useful guidance provided that its limitations are recognised.

F.3.6 Group 5 – Calculation from circuit parameters

When the data concerning the parameters of the components of the circuit are known, as for group 4, it is often convenient to calculate the waveform of the TRV, particularly if the circuit is not too complex.

In general, the method does not take into account depression effects, although some allowance can be made for these if the relevant data for the circuit are available; similarly the decrement of the power-frequency component for those TRV where the time t_2 exceeds 1 250 µs (1 000 µs for 60 Hz), can be taken into account.

The method is subject to the limitations of group 4, plus the errors inherent in calculations unless experience has been gained in checking results with actual TRV obtained from tests using the techniques of groups 1, 2, 3 or 6.

F.3.7 Group 6 – No-load switching of test circuits including transformers

This method consists of connecting the test transformer on the open circuit and recording, by oscillograms, the behaviour of the transient voltage at the open gap of the secondary circuit.

The method is very useful in those test stations where the short-circuit current is obtained by generators. However, the circuit-breaker used for the switching shall have no shunt resistance, be free of any appreciable pre-striking and be located in close proximity to the circuit-breaker under test. Furthermore, this method has a limited application to those circuits producing single frequency TRV and does not reproduce the exponential component which is related to eddy currents.

F.3.8 Group 7 – Combination of different methods

If a synthetic test circuit is applied in which different circuits are combined, it may be necessary to use a combination of the proposed methods. This is always the case, if the TRV is superimposed by the outputs of different sources (up to three different sources are usual). For example, in a voltage injection test circuit, it is possible to check the TRV from the current source separated from the TRV from the voltage injection circuit. This means that each of the separate circuits can be checked by one of the proposed methods. For the different circuits, different methods may be applied. The overall TRV (sum of the TRVs from the different circuits), can be constructed by mathematical methods. If digital recording equipment is used, it is also possible to construct the overall TRV by combining the digital data obtained by the different methods.

In the case of a combined use of the proposed methods, the specific limits of the methods, given in table F.1, shall be taken into account.

F.4 Comparison of methods

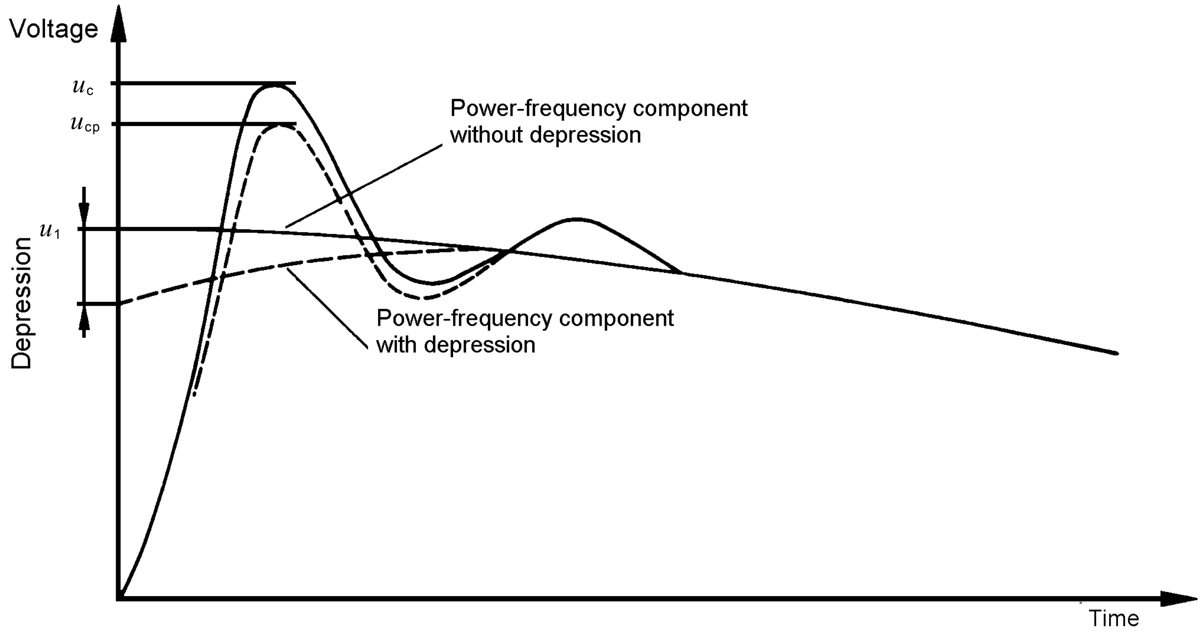
The various methods are listed in table F.1, with their characteristics, advantages and disadvantages.

Table F.1 – Methods for determination of prospective TRV

Method	Theoretical limitations	Practical limitations
F.1.1 Full scale tests with an ideal circuit-breaker	None. All phenomena are correctly represented	Non-existence of an ideal circuit-breaker to cover the full range of requirements
F.1.2 Power-frequency tests at full voltage with a limited current disturbance. (Either an ideal circuit-breaker test or a "close" test is feasible)	Does not account for non-linearities which may exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	Non-existence of an ideal circuit-breaker to cover the full range of requirements. Extraction of the TRV requires sophisticated measurement techniques: otherwise, it is difficult to interpret results in the presence of a large power-frequency voltage component For making tests, the most suitable current limiting device is a perfect inductance; otherwise an element of the test circuit may be used where it is available (e.g. resistor or capacitor). Elements used are likely to be bulky and expensive
F.1.3 Power-frequency tests at reduced voltage with an ideal circuit-breaker on an otherwise unmodified test circuit (i.e. low excitation tests)	Does not account for non-linearities which may exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	Whilst ideal circuit-breakers to cover the whole range are not yet available, the selection of the ideal circuit-breaker to be used is limited With circuits employing more than one generator, synchronization can be difficult to achieve Excitation should be sufficiently high to avoid waveform distortion Generally not possible in a network station
F.1.4 Full scale tests with a conventional circuit-breaker	Difficulty of separating the circuit-breaker effects from the TRV characteristics recorded during test	Choice of suitable circuit-breakers having a low arc-voltage producing negligible current distortion at current zero, negligible post-arc current and no shunt impedances. In cases where the above cannot be made, errors are introduced and there is the possibility of lack of uniformity between testing stations due to the use of circuit-breakers having different characteristics

Table F.1 *(continued)*

Method	Theoretical limitations	Practical limitations
F.2 Ideal circuit-breaker tests on a "dead" circuit with power frequency current injection	Does not account for non-linearities which may exist in the circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	In a network-fed testing station, only applicable on "dead" circuit elements, for example short-line fault components, or where the impedance of the network is negligible compared with the remainder of the circuit impedance Generators shall be at rest to avoid remanent voltages Position of rotor may be important if there is a considerable difference between direct and quadrature reactances. The reverse recovery time of switching diodes as used instead of an ideal circuit-breaker, capable of carrying the necessary injected power-frequency current, may affect the TRV where this contains high frequency components, for example in short-line fault test circuits Interference from external sources induced in the "dead" circuit may affect the TRV where the measuring voltage is relatively small due to very low circuit reactance, for example as associated with short-line faults
F.3 Ideal circuit-breaker tests on a "dead" circuit with current injection at a frequency above power frequency	Does not account for non-linearities which may exist in the circuit. Does not give power frequency impedance directly. Gives correct waveform and values for the TRV of single and multi-frequency circuits from zero to the first maximum only, provided that the injection frequency is above power frequency and well below the frequency of the TRV. It is not possible to evaluate amplitude factor correctly	In a network-fed testing station, only applicable on "dead" circuit elements, e.g. short-line fault components, or where the impedance of the network is negligible compared with the remainder of the test circuit impedance. Generators shall be at rest to avoid remanent voltages. Position of rotor may be important if there is a considerable difference between phase and quadrature reactances
F.4 Model network tests (transient net work analysers)	Precise information of non-linear and frequency-dependent characteristics of the network is not always available. Exact knowledge of circuit components and their stray parameters is necessary	Adequate representation of circuit components in the transient network analyser elements, including their non-linear and lime-dependent characteristics, is necessary
F.5 Calculation from circuit parameters	Precise information on non-linear and frequency-dependent characteristics of the network is not always available. Exact knowledge of circuit components and their stray parameters is necessary	Where the network impedance is not negligible compared with the test station impedance, complete knowledge of the relevant momentary network conditions is necessary Accurate or adequate representation of the circuit components, including their non-linear and time-dependent characteristics and particularly the stray parameters
F.6 No-load switching of testing transformers	Corrections necessary for power frequency voltage wavefront unless the transformers are energized at or near the peak of the voltage wave	Requires actual short-circuit test circuits Applicable only for single-frequency circuits



u_c = peak value of specified TRV
u_{cp} = TRV measured with depression
u_1 = peak value of power frequency voltage without depression

Figure F.1 – Effect of depression on the peak value of the TRV

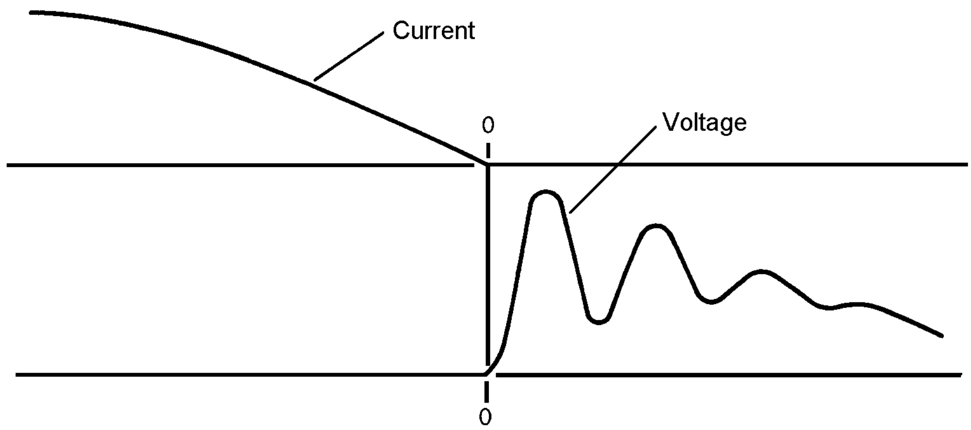


Figure F.2 – TRV in case of ideal breaking

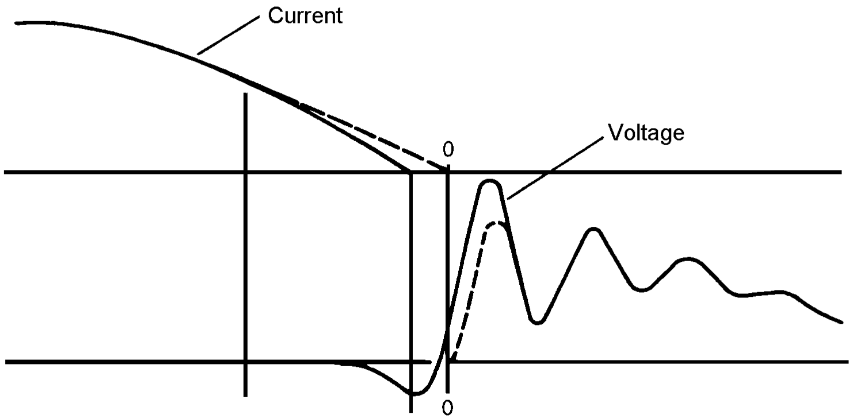


Figure F.3 – Breaking with arc-voltage present

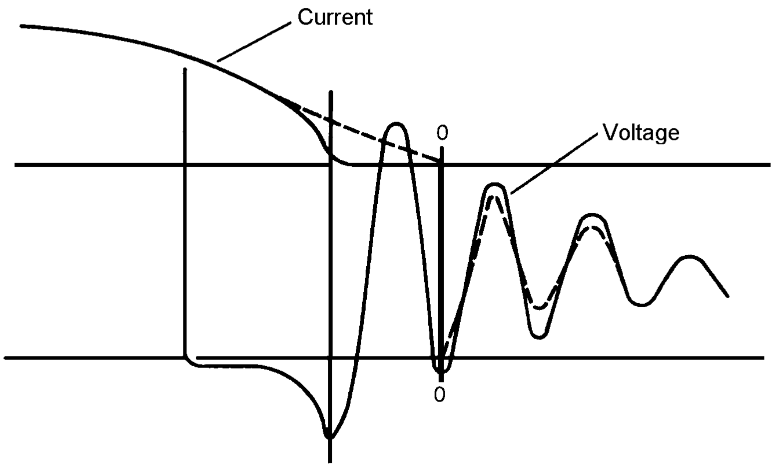


Figure F.4 – Breaking with pronounced premature current-zero

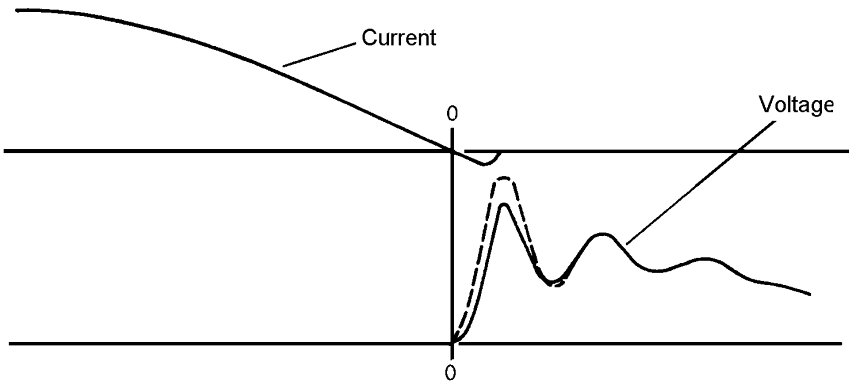
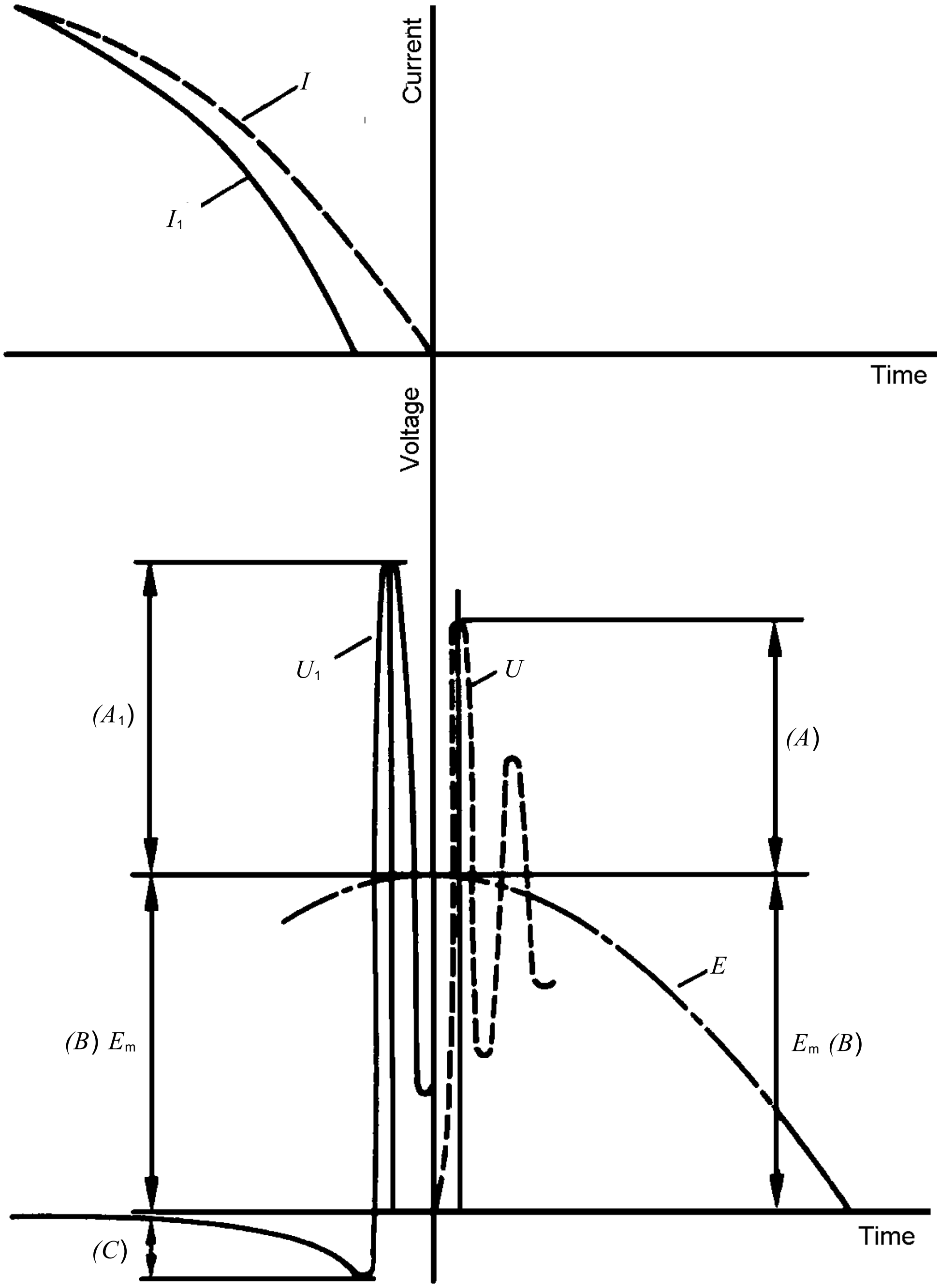


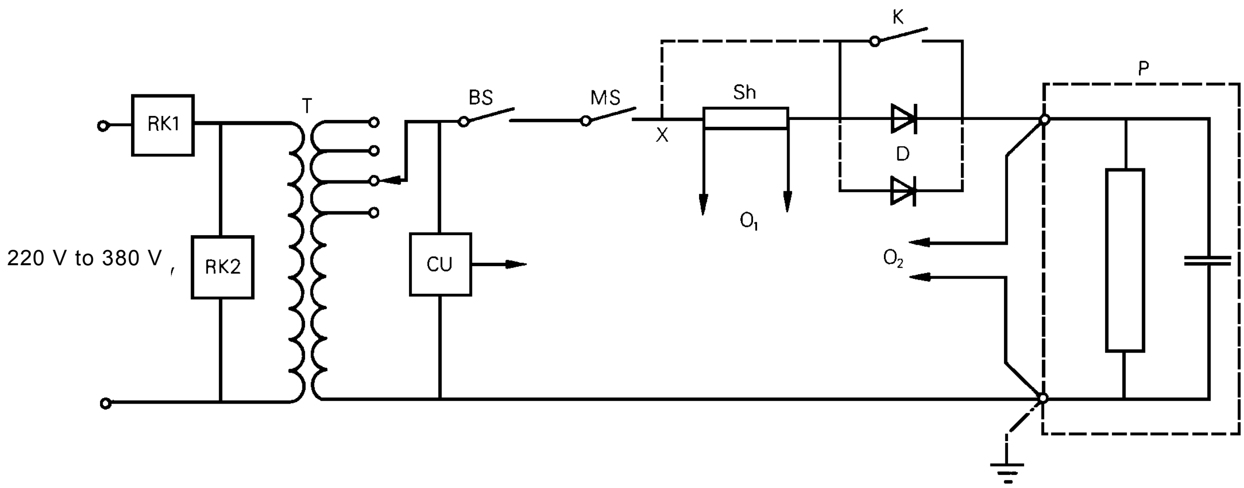
Figure F.5 – Breaking with post-arc current

NOTE Influence of the arc, of premature current-zero and of post-arc conductivity on the transient recovery voltage. The chain-dotted lines in figures F.3 to F.5 represent the behaviour following ideal breaking.



I_1, U_1	=	current and voltage, respectively, obtained in test
I, U	=	prospective current and voltage, respectively, of system
E	=	power frequency recovery voltage
$A+B=A_1\dfrac{B}{B+C}+B$	=	peak value of transient recovery voltage

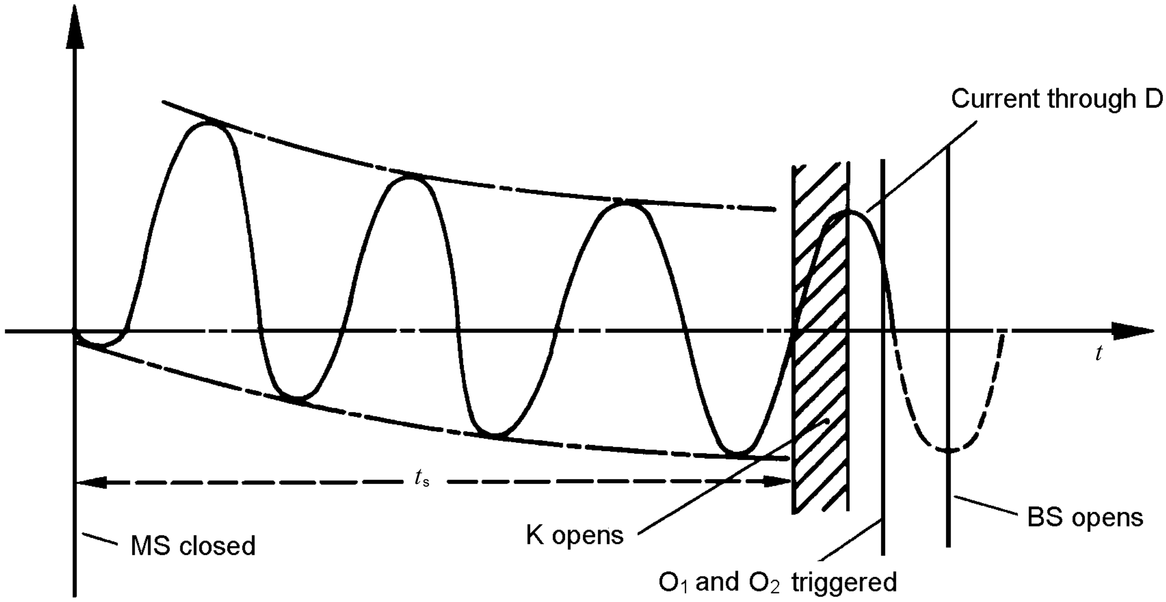
Figure F.6 – Relationship between the values of current and TRV occuring in test and those prospective to the system



RK1, RK2	=	where required, series and parallel resonant circuits for harmonic suppression purposes
T	=	transformer to isolate injection circuit from supply and to provide an adjustable output voltage
BS	=	back-up switch
MS	=	making switch
K	=	diode by-pass switch
X	=	alternative connection for K to permit use of a shunt having relatively low time-current rating
D	=	parallel connection of up to five fast silicon switching diodes
Sh	=	current measuring shunt
O_1	=	cathode-ray oscillograph, trace 1 recording magnitude and linearity of current for checking the diode operation
O_2	=	cathode-ray oscillograph, trace 2 recording the response of the circuit
P	=	circuit the prospective TRV of which is to be measured
CU	=	control unit to provide the sequence of operation given in figure F.8

NOTE The measurement of the injected current may equally be made at earth potential.

Figure F.7 – Schematic diagram of power-frequency current injection apparatus



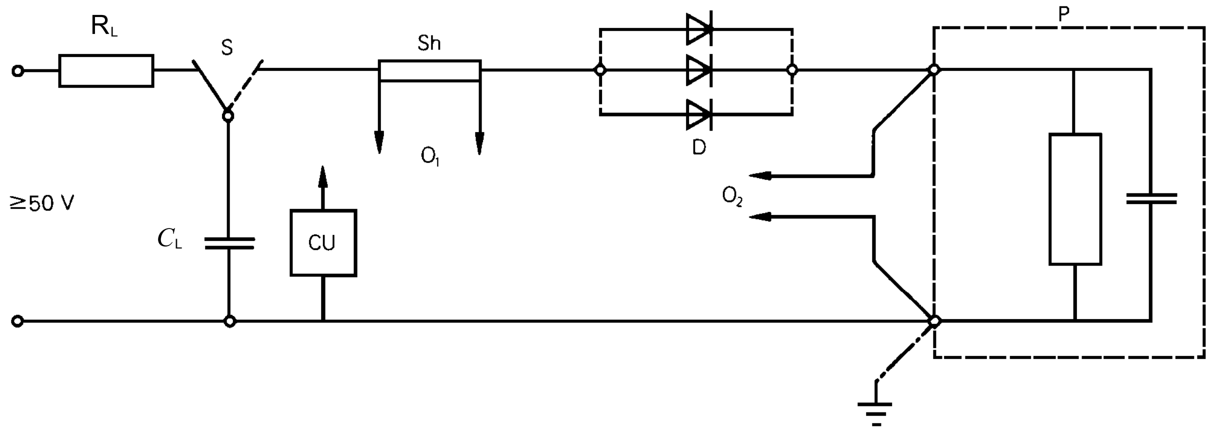
Quiescent state: BS and K closed, MS open.

t_s = duration of current flow prior to operation of switch K

Typical values lie between 10 and 20 cycles of injected current.

The main criterion is that the d.c. component of current, if any, shall have decayed to a value less than 20 % of the a.c. component.

Figure F.8 – Sequence of operation of power-frequency current injection apparatus



R_L = charging resistor

S = switching relais

C_L = source capacitance

NOTE When the charged capacitance C_L is connected to the circuit P via relay S an oscillatory current, of frequency f_1, flows. The value of C_L should be adjusted so that:

$f_1 \leq \frac{f_e}{8}$, where f_e is the natural frequency of circuit P, $f_e = \frac{1}{2T_e / 2}$

f_1 shall be such that the superimposed current oscillations will have disappeared before the instant of current zero.

Sh = current measuring shunt

O_1 = cathode-ray oscillograph, trace 1 recording magnitude and linearity of the current and checking the diode operation

O_2 = cathode-ray oscillograph, trace 2 recording the response of the circuit

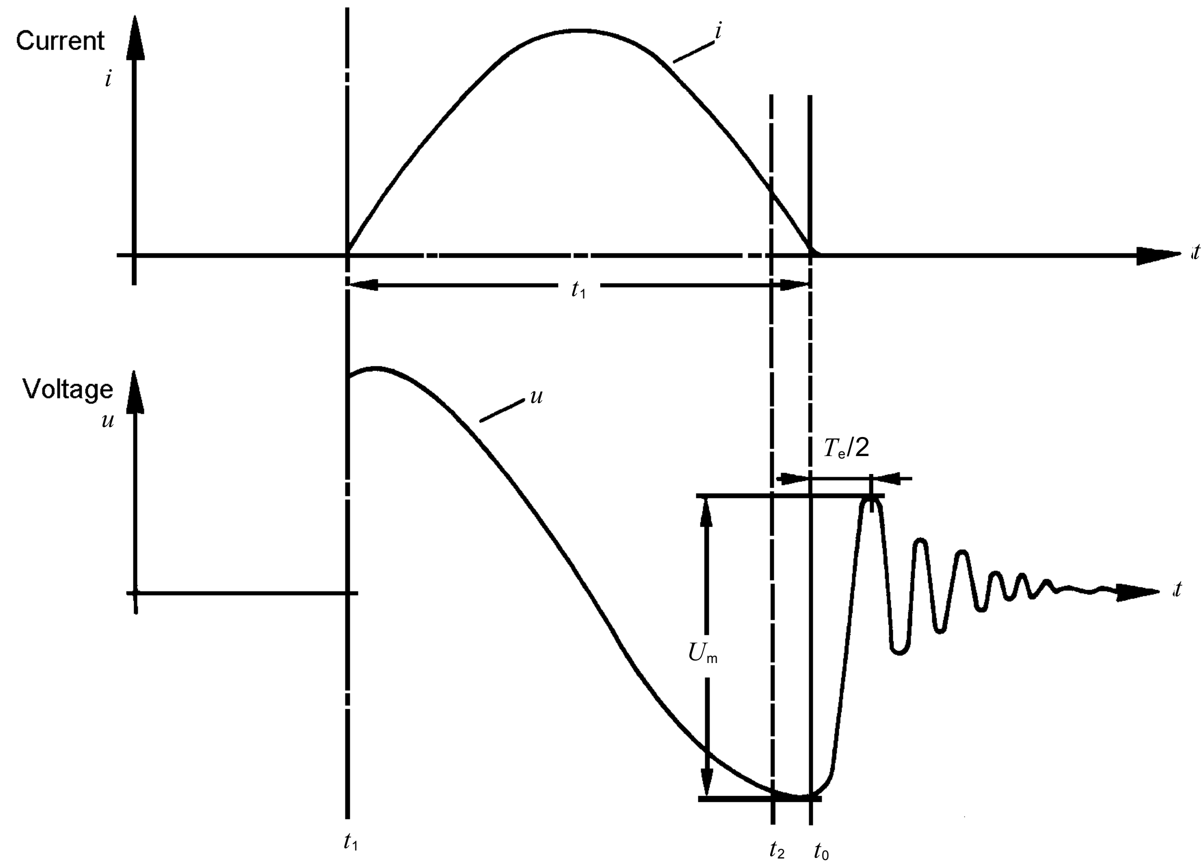
D = parallel connection of up to 100 fast silicon switching diodes

P = circuit the prospective TRV of which is to be measured

CU = control unit to provide the sequence of operation given in figure F.10

NOTE The measurement of the injected current may equally be made at earth potential.

Figure F.9 – Schematic diagram of capacitance injection apparatus



t_1 = switching of S

t_2 = tripping of the cathode-ray oscillograph

u = voltage curve across the terminals of the circuit P

i = waveform of the injected current

U_m = maximum voltage stressing of the diodes

t_0 = time where current passes through zero (beginning of the TRV oscillation)

t_1 = duration of current through diode D, $f_1 = \dfrac{1}{2t_1}$

$\dfrac{T_e}{2}$ = duration of half-cycle of TRV

Figure F.10 – Sequence of operation of capacitor-injection apparatus

Annex G
(normative)

Rationale behind introduction of circuit-breakers class E2

It should be noted that the introduction class E2 circuit-breakers is restricted to distribution circuit-breakers. This standard already has cases where some tests are restricted to voltage ranges, so no problems should arise in adding the electrical endurance test only to circuit-breakers of rated voltages up to and including 52 kV.

The majority of circuit-breakers manufactured today are of the sealed type or closed type, only anticipating top-up of gas (where applicable), not internal maintenance. Traditional circuit-breakers do not need to fulfil low-maintenance requirements, but the user may wish (and in very many cases does wish) to specify a circuit-breaker class E2 for sound economic reasons.

There are therefore two choices: either to use a circuit-breaker having maintainable internal parts and maintain as needed during its expected working life, or to use a circuit-breaker class E2 but expect a more onerous testing regime to check its capability.

The proposed electrical endurance test for cable-connected networks is a full series of test-duties T10 to T100a without intermediate maintenance. It is almost certain that all distribution circuit-breakers of the sealed SF_6 or vacuum type have been tested like this for a number of years. No extra tests are therefore required beyond the normal short-circuit type test.

For overhead-line networks, the standard test shall be performed separately. The proposed extra test is a user requirement based on statistical service experience.

Care needs to be taken in comparing different test programmes. The current versus wear relationship is not as simple as it may appear.

Finally, it should be noted that the extra tests are optional, at the user's request, to satisfy these applications.

Annex H
(informative)

Inrush currents of single and back-to-back capacitor banks

H.1 General

Switching on a capacitor bank by closing a circuit-breaker causes transient phenomena resulting from bank charging. The oscillating load provokes an overcurrent (inrush current) with an amplitude and frequency which are functions of the network, the bank characteristics and the instant of switching on. Amplitude and wave shape of the inrush current are functions of the applied voltage, the capacitances of the circuit, the values and location of the inductances in the circuit, the charges on the capacitors at the time the circuit is closed and the damping of the switching transients. Calculations of inrush current are usually made on the assumption that the capacitor bank has no initial charge and that the circuit is closed at a time which produces the maximum inrush current.

When closing onto a pre-charged capacitor bank, the inrush current can be higher than when closing onto an uncharged capacitor bank. An estimate of the factor by which the current may be increased can be obtained from:

$$\frac{\text{voltage change on pre-charged bank while being energised}}{\text{voltage change on uncharged bank while being energised}}$$

It should be noted that restriking circuit-breakers can also impose hazardous stresses on capacitors.

The inrush current can be calculated knowing the network impedances. Figure H.3 shows the three different cases of connection of a capacitor bank when zero, one and n banks, respectively are already connected to the busbar.

Normally the simplified calculations in figures H.3b) and H.3c) are acceptable.

When two or more capacitor banks are connected close to each other and the inductances between them are small, it may be necessary, both from capacitor and circuit-breaker point of view, to reduce the inrush current by inserting impedances in series with the capacitors. Usually, an inductance is inserted so that the inrush current peak and the inrush current frequency are below acceptable values.

In practice, the inductance is calculated using the principle that the resulting di/dt of the inrush current is less than that given by the preferred values stated in table 5. The di/dt is proportional to the product of the inrush current peak and the inrush current frequency (20 kA and 4 250 Hz, respectively).

Two examples of calculation are described in H.2 and H.3.

H.2 Example 1 – One capacitor to be switched in parallel (see figure H.1)

H.2.1 Description of the capacitor banks to be switched

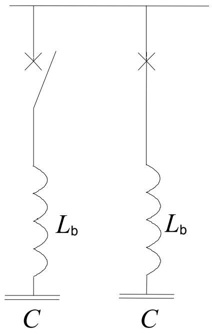


Figure H.1 – Circuit diagram for example 1

- rated voltage U_r = 145 kV
- rated frequency f_r = 50 Hz
- power of a single capacitor bank Q_b = 16 MVar (three phases at 126 kV r.m.s.)
- total length of conductors between banks l = 40 m
- inductance per length L' = 1 μH/m

From these values the capacitance C and the inductance L_b are calculated.

C = 3,2 μF and L_b = 20 μH

H.2.2 Calculation without any limitation device

Using the equations stated in figure H.3 the peak inrush current $\hat{\imath}$ and the inrush current frequency f_{ib} are determined:

$$\hat{\imath} = U_r \sqrt{\frac{C}{6 L_b}} = 145 \times 10^3 \sqrt{\frac{3{,}2 \times 10^{6}}{6 \times 20 \times 10^{6}}} = 23{,}7 \times 10^3 \text{ A} = 23{,}7 \text{ kA}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{L_b C}} = \frac{1}{2\pi\sqrt{3{,}2 \times 10^{6} \times 20 \times 10^{6}}} = 19\,900 \text{ Hz}$$

These values are far above the ratings. Therefore, some limitation devices must be used. In some cases, the second bank may be already fully charged at the inverse polarity at the instant when the prestrike in the closing circuit-breaker occurs. Then the value of $\hat{\imath}$ is doubled.

H.2.3 Calculation of limitation devices

The inductance L_a to be added on the bus-bar should be such that the value of the inrush current peak and of the inrush current frequency are below the preferred values stated in table 5. It is considered as equivalent to keep the product of the actual values of the inrush current peak and of the inrush current frequency below the product of the preferred values stated in table 5 (20 kA and 4 250 Hz).

$$U_r \sqrt{\frac{C}{6(L_a + L_b)}} \times \frac{1}{2\pi\sqrt{(L_a + L_b)C}} \leq 20 \times 10^3 \times 4\,250$$

$$L_a \geq \frac{U_r}{20 \times 10^3 \times 4\,250} \times \frac{1}{2\pi\sqrt{6}} - L_b \quad \text{and} \quad L_a \geq 91 \text{ μH}$$

With this value, it is easy to check:

$\hat{\imath}$ = 10 kA and f_{ib} = 8 445 Hz

H.3 Example 2 – Two capacitors to be switched in parallel (see figure H.2)

H.3.1 Description of the capacitor banks to be switched

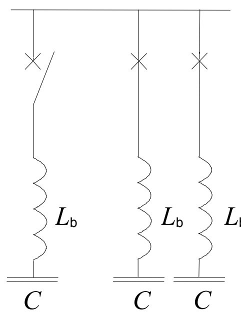


Figure H.2 – Circuit diagram for example 2

- rated voltage U_r = 24 kV
- rated frequency f_r = 50 Hz
- power of a single capacitor bank Q_b = 5 MVar (three phases at 22 kV r.m.s.)
- length of each conductor between banks l = 5 m
- inductance per length L' = 1 μH/m

From these values the capacitance C and the inductance L_b are calculated:

C = 32,9 μF and L_b = 5 μH

H.3.2 Calculation without any limitation device

Using the equations stated in figure H.3 the peak inrush current $\hat{\imath}$ and the inrush current frequency f_{ib} are determined:

$$\hat{\imath} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3L_b}} = 24 \times 10^3 \times \frac{2}{3}\sqrt{\frac{2 \times 32{,}9 \times 10^{-6}}{3 \times 5 \times 10^{-6}}} = 33{,}5 \times 10^3 \text{ A} = 33{,}5 \text{ kA}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{L_b C}} = \frac{1}{2\pi\sqrt{32{,}9 \times 10^{-6} \times 5 \times 10^{-6}}} = 12\,400 \text{ Hz}$$

These values are far above the ratings. Therefore, some limitation devices must be used. In some cases, the capacitor bank(s) already in service may be fully charged at the inverse polarity at the instant when the prestrike in the closing circuit-breaker occurs. Then the value of $\hat{\imath}$ is doubled.

H.3.3 Calculation of limitation devices

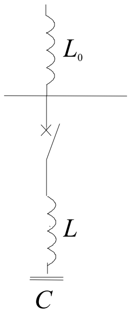
The inductance L_a to be added on the busbar should be such that the value of the inrush current peak and of the inrush current frequency are below the preferred values stated in table 5. It is considered as equivalent to keep the product of the actual values of the inrush current peak and of the inrush current frequency below the product of the preferred values stated in table 5 (20 kA and 4 250 Hz).

$$U_r \frac{n}{n+1}\sqrt{\frac{2C}{3(L_a + L_b)}} \times \frac{1}{2\pi\sqrt{(L_a + L_b)C}} \leq 20 \times 10^3 \times 4\,250$$

$$L_a \geq \frac{U_r}{20 \times 10^3 \times 4\,250} \times \frac{1}{2\pi} \times \sqrt{\frac{2}{3}} \times \frac{n}{n+1} - L_b \quad \text{and } L_a \geq 20\ \mu\text{H}$$

With this additional inductance the actual inrush current and its frequency are

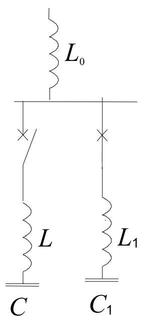
$\hat{\imath}$ = 15 kA and f_{ib} = 5 550 Hz



a) Connection of a single bank

$$\hat{\imath} = U_r \sqrt{\frac{2}{3}\frac{C}{L_0 + L}} \approx U\sqrt{\frac{2}{3}\frac{C}{L_0}} \qquad L_0 >> L$$

$$f_{ib} = \frac{1}{2\pi\sqrt{C(L_0 + L)}} \approx \frac{1}{2\pi\sqrt{CL_0}}$$



b) Connection when one bank is already connected

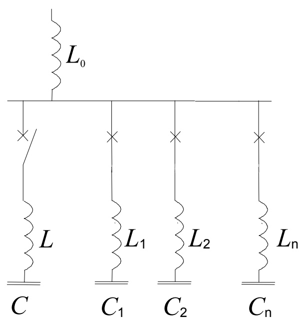
$$\hat{\imath} = U_r \sqrt{\frac{2}{3}\frac{C_1 C}{(C_1 + C)} \times \frac{1}{(L_1 + L)}}$$

$$f_{ib} = \frac{1}{2\pi\sqrt{\frac{C_1 C}{(C_1 + C)}\ (L_1 + L)}}$$

$$S = \frac{U_r}{L_1 + L}\sqrt{\frac{2}{3}}$$

When $L_1 = L$ and $C_1 = C$ then:

$$\hat{\imath} = U_r \sqrt{\frac{C}{6L}} \quad \text{and} \quad f_{ib} = \frac{1}{2\pi\sqrt{LC}}$$



c) Connection when n banks are already connected

$$L' = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \cdots \frac{1}{L_n}} \quad \text{et} \quad C' = C_1 + C_2 + \cdots C_n$$

If $L_1 = L_2 = ... = L_n = L$ and $C_1 = C_2 = ...= C_n = C$, then

$$L' = \frac{L}{n} \quad \text{and} \quad C' = nC$$

$$\hat{\imath} = U_r \frac{n}{n+1}\sqrt{\frac{2C}{3L}} \quad \text{and} \quad f_{ib} = \frac{1}{2\pi\sqrt{LC}}$$

L' and C' substitute L_1 and C_1 in figure H.3 b). The calculation is correct if $L_1 \times C_1 = L_2 \times C_2 = ...=L_n \times C_n$; in other cases it is an approximation.

Components

U_r	rated voltage	L	inductance in series with switched capacitor bank
$\hat{\imath}$	inrush current peak	C	capacitance of switched capacitor bank (equivalent star value)
f_{ib}	inrush current frequency	$L_1, L_2 ... L_n$	inductances in series with capacitor banks on source side
S	inrush current rate-of-rise	$C_1, C_2 ... C_n$	bank capacitances (equivalent star values) on source side
L_0	source inductance		

Figure H.3 – Equations for the calculation of capacitor bank inrush currents

Annex I
(informative)

Explanatory notes

I.1 General

Pending the issue of a guide to the use of this standard all the explanatory notes, existing or future, are collected in this annex.

I.2 Explanatory note regarding the d.c. component of the rated short-circuit breaking current (4.101.2)

I.2.1 Advice for the choice of the appropriate time constant

A time constant of 45 ms is adequate for the majority of actual cases. Special case time constants, related to the rated voltage of the circuit-breaker, shall cover such cases where the standard time constant 45 ms is not sufficient. This may apply, for example, to systems with very high rated voltage (for example 800 kV systems with higher X/R ratio for lines), to some medium voltage systems with radial structure or to any systems with particular system structure or line characteristics. Special case time constants have been defined, taking into account the results of the survey by CIGRE WG13.04 (I.2.2).

When specifying a special case time constant, the following considerations should be taken into account:

a) The time constants referred to in this standard are only valid for three-phase fault currents. The single-phase to ground short-circuit time constant is lower than that for three-phase fault currents.
b) For maximum asymmetrical current, the initiation of the short-circuit current has to take place at system voltage zero in at least one phase.
c) The time constant is related to the maximum rated short-circuit current of the circuit-breaker. If, for example, higher time constants than 45 ms are expected but with a short-circuit current lower than rated, such a case may be covered by the asymmetrical rated short-circuit current test using a 45 ms time constant.
d) The time constant of a complete system is a time-dependent parameter considered to be an equivalent constant derived from the decay of the short-circuit currents in the various branches of that system and is not a real, single time constant.
e) Various methods for the calculation of the d.c. time constant are in use, the results of which may differ considerably. Caution should be taken in choosing the right method.
f) When choosing a special case time constant, it has to be kept in mind, that the circuit-breaker is stressed by the asymmetrical current after contact separation. The time instant of contact separation corresponds to the opening time of the circuit-breaker and the reaction time of the protection relay. In this standard this relay time is one half-cycle of power frequency. If the protection time is longer this should be taken into account.

g) The choice of a single special case value of the d.c. time constant minimises the number of tests required to demonstrate the capability of the equipment. However, at present no specific equivalence criteria nor testing method can be given to demonstrate the validity of a test carried out at a rated short-circuit current, with its associated rated d.c. time constant, for a different rated short-circuit current with its associated time constant. For example, a test carried out on a circuit-breaker at 63 kA with a d.c. time constant of 45 ms does not automatically cover the requirements for demonstrating a rating of 50 kA with a d.c. time constant of 60 ms.

Nevertheless, some general important aspects can be considered. The parameters stated below have to be examined carefully in relation to the interrupting technology used:

1) amplitude of the last current loop before interruption;
2) duration of the last current loop before interruption;
3) arcing time window;
4) arc energy;
5) DC component of the short-circuit current at the instant of contact separation;
6) di/dt at current interruption;
7) TRV peak voltage u_c and first reference voltage u_1, as applicable.

Explanations as to the origin of asymmetrical currents, their effect on the breaking capability of circuit-breakers, the determination and the use of a special case time constant as well as background information on this subject will form part of a common application guide to this standard and is under consideration.

I.2.2 Reprint of the CIGRE paper "Specified time constants for testing asymmetric current capability of switchgear"

At the IEC SC 17A meeting in Frankfurt (DE) in June, 1998 it was agreed to reprint the entire publication "Specified Time Constants for Testing Asymmetric Current Capability of Switchgear", published in Electra, No. 173, August 1997, pages 19 – 31. This publication contains background information on the stipulation of the special case time constants.

SPECIFIED TIME CONSTANTS FOR TESTING ASYMMETRIC CURRENT CAPABILITY OF SWITCHGEAR

Foreword

The following document summarises discussions and conclusions of a CIGRE WG 13-04 Task Force considering the time constants to be used when testing the asymmetric switching capability of circuit-breakers and switchgear. These discussions have been based on existing IEC and CIGRE documents with the intention of producing some conclusions & recommendations from the wide range of views which exist in this field.

Aim

To make recommendations regarding the most appropriate and representative combinations of short-circuit current and d.c. time constant to be applied during testing in order to adequately cover the IEC notional 90 % criterion.

Introduction and general discussion

This document primarily summarises and draws conclusions from published information, which in many cases, is contradictory in nature. There is no intention of presenting large quantities of technical information which can be obtained from the source documents if required.

IEC standards are intended to provide specification and type testing procedures which are adequate to encompass 90 % or more of applications. While this 90 % criterion is impossible to accurately quantify, the spirit in which it is intended is clearly that of addressing the majority of "normal" requirements without resultant over-specification on the basis of unusual or uncommon cases.

The ongoing revision of IEC 60056 has raised the question of whether the presently specified single time constant of 45 ms adequately covers the appropriate proportion of system requirements and, more importantly, whether it will continue to do so in the foreseeable future. As a result, IEC requested CIGRE to review the situation in this regard and make recommendations.

The presently specified value of time constant (45 ms) is heavily influenced by the inherent time constant of HV overhead lines. Asymmetric testing to IEC 60056 is performed at full short-circuit rating only, using this value of time constant. The underlying assumptions made in choosing this combination are that it is a most onerous asymmetric condition and that a) high short-circuit levels (approaching 100 %) do not occur in combination with higher time constants, and b) the high time constant, limited current (e.g. 30 % of rating) capability is adequately proven by the existing full rating asymmetric test.

Network equipment considerations

It is clear that each discreet item in a power transmission or distribution system has identifiable values of resistance, R, and Inductance, L. The ratio of these values define the appropriate d.c. time. In generic terms, the time constants of plant can be approximated as follows.

	1 MVA	10 MVA	100 MVA	1 000 MVA
Transformers	20-40 ms	50-150 ms	80-300 ms	200-400 ms
Generators	60-120 ms	200- 600 ms	200-600 ms	300-500 ms
	<72,5 kV	72,5-420 kV	420/525 kV	>525 kV
Overhead lines	<20 ms	15-45 ms	35-53 ms	58-77 ms

Background data regarding cables having relatively high capacitances indicates that their time constants are consistently lower than overhead lines in the equivalent voltage range. The time constant is, for any cable design, primarily related to the conductor cross-sectional area ranging from close to zero for small CSA (<200 mm^2) through to maybe 40 ms for a 2 000 mm^2 conductor at 220 kV or above.

Similarly the inductance of overhead lines is fairly constant at around 1 mH/km with variations in time constant being dominated by changes to resistance as a result of variations of material, dimensions or construction.

In the event of a power system fault the overall decay of any d.c. offset will be dictated by the combined time constant of all fault infeeds and this is the practical condition, combined with the practical maximum fault current, for which circuit-breakers must be tested. The combination of various fault infeeds and the complex summation of branched and series X and R values makes the use of a single exponential decay during testing a significant compromise from the real situation. However, provided that the exponential decay time constant is well chosen, this approach is not considered to present significant problems and this general approach is not being questioned.

There are a number of general trends in equipment being installed by utilities, particularly at the highest (transmission) voltage levels, which are of importance for assessment of these conditions. These include:

– an increasing tendency to use large, low loss power transformers with relatively high time constants which contribute to the minimisation capitalised losses;
– the installation of power transformers with high short-circuit reactances aimed at limiting short-circuit levels at the expense of requiring extensive tapping capability to combat voltage drop. (Up to 32 % impedance reported by Canada);
– a move towards the use of large cross-section, multi conductor bundled transmission lines with time constants towards the higher end of the quoted range;
– greater use of reactive components for system control including short-circuit limiting reactors.

All of these developments, combined in some cases with increasing degrees of interconnection and divergence of smaller generation within networks, are tending to increase the time constant of individual fault infeeds and contribute to an overall increase in system time constants. Conversely there are presently few widespread developments leading to time constant reductions.

Network design considerations

Network can be broadly divided into a number of categories based on their voltage rating and their basic topology.

Considering voltage level first, three basic classifications have been identified, namely:

– medium voltage networks operating up to about 52 kV;

– high voltage networks operating in the range 72,5 kV to 420 kV;

– high voltage networks operating above 420 kV i.e. 525 kV and above.

Considering topological factors, two basic classifications can be identified, namely:

– meshed networks which are heavily dominated by line and cable connections resulting in d.c. time constants of around 45 ms or less, possibly in combination with high short-circuit levels;

– networks which are dominantly supplied by power transformers. In such cases the d.c. time constant is defined almost exclusively by the power transformer(s) and generally exceeds 45 ms with values possibly extending to 150 ms. In such cases it is relatively low.

Taking each of the above voltage classifications in turn and giving consideration to their "typical" network topologies, certain general trends can be identified.

Medium voltage networks operating up to about 52 kV are often, but not always, transformer dominated. In such cases, significantly higher d.c. time constants are often associated with relatively low short-circuit current levels. In such cases, significantly higher d.c. time constants must be considered during testing, possibly in excess of 100 ms. It is important to note that such high d.c. time constants are often associated with low short-circuit current levels.

The majority of high-voltage networks operating in the range 72,5 kV to 420 kV are line and cable dominated and a d.c. time constant of around 45 ms covers the broad majority of such applications. However, it is noteworthy that there are certain reported network configurations and line designs which result in higher time constants of the order of 60 ms in combination with high short-circuit currents. The results of a typical short-circuit level study of 275 kV network are shown in table 1.

Due to their relative scarcity, the d.c. time constant applicable to networks operating at 525 kV and above are not well defined. Since installations at these voltages are typically long distance transmission circuits utilising novel line designs and terminated in large power transformers, there is a tendency towards higher d.c. time constants. Reported examples are 55 ms at 550 kV, 75 ms at 765 kV and 110 ms at 1 100 kV.

Circuit-breaker considerations

Circuit-breaker design techniques have improved dramatically over time leading to benefits of reduced size, weight, energy requirements and cost. This progression is also perceived to have led to an inevitable reduction in inherent design margins such that much of the older equipment, for which extensive operating experience is available, may have considerable margins in hand-over and above modern equipment. This trend is not problematic in itself but further emphasises the need for future testing regimes to be fully representative of the system conditions in which the equipment needs to function correctly.

In technologies where the interruption capability is fundamentally constant regardless of the switching duty, interpolation of test evidence is relatively simple and accepted. However, in technologies where the basic interruption characteristics of the device are duty dependant, such interpolations are far more difficult to achieve simply and it is quite conceivable that critical fault duties may be identified at fractional short-circuit levels. In principle, the high energies and relatively low di/dt values associated with an asymmetrical duty make it less onerous for such a device than an equivalent symmetrical duty. However, the effect of low energy minor loops and the possibility of extended arcing periods, in what are generally very short overall travel times, are factors which might prove particularly critical.

Ultimately equipment testing should consider the equipment under test to be a "black box" model regardless of the technology being employed, but this presents obvious difficulties if varying design technologies have specific sensitivities.

It must be stressed at this point that there is no intention to cast doubt on the capabilities of particular equipment design philosophies merely to emphasise that as refined design techniques lead to minimised designs so the importance of well constructed and realistic testing regimes increases.

An obvious, but non-preferred, solution to problems of asymmetric switching is to increase circuit-breaker operating times, although this does not alleviate the duty on other associated equipment and may be inconvenient from an overall system viewpoint. This contrary to the tendency for reducing protection times in modern equipment.

Utility viewpoints

From a utility point of view it is important to have confidence that "standard order" equipment will be capable of meeting both present system needs and those which are likely to develop in the foreseeable future. Historically there is a very strong argument to support the fact that there are extremely few reported failures which can be attributed to the effects of asymmetric breaking conditions. This does not necessarily indicate that no failures have occurred. Additionally, as mentioned above, it is believed that many power networks are only now approaching their design levels and that equipment technologies are being constantly developed and advanced. Thus, there is a strong possibility that the very condition in which we are interested will, in the foreseeable future, and for the first time, become a widespread practical consideration. With this in mind the extrapolation of historical data must be treated with caution.

The practical occurrence of rapid protection times such as those assumed for testing purposes are also an area where equipment is likely to be working closer to the margins.

Additionally, a number of utilities have, where doubt exists, had policies of either performing special type tests, purchasing obviously over-rated equipment or perform rating "trade offs" which, whilst not being technically elegant, give a degree of confidence within certain limits.

An example of this approach is the UK practice of purchasing equipment tested to 63 kA/time constant = 45 ms to meet a 57,5 kA/time constant = 60 ms single phase requirement. A German utility has reported a 63 kA/50 ms location where 80 kA equipment has been installed although the vast majority of their high short-circuit requirements are covered by 45 ms with values up to 57 ms being reported for fractional duties.

At this point data available from a number of other networks can be summarised as follows.

A French utility have indicated a maximum requirement for 60/70 ms at 420 kV, 160 ms at 245 kV and 200 ms at lower levels. The 70 ms value in particular is associated with a 63 kA fault level in a particular part of the network where generation is concentrated.

An Italian utility have indicated that in the northern part of Italy their 380 kV network gives time constants in the range 46-63 ms and averaged at about 54 ms for fault currents in excess of about 30 kA.

In addition to the above information, the same German utility has also reported that at 10 and 20 kV, voltage levels time constants of 80-100 ms are experienced.

A Canadian utility has indicated that their 315 kV network has a time constant consistently greater than 45 ms, and that at 735 kV the time constant exceeds 77 ms. On this basis, and taking into consideration that at less than 315 kV, time constants of 45-160 ms exist, they have proposed use of a series of preferred values such as 45 ms, 60 ms, 80 ms and 120 ms.

Japan have summarised their network at 550 kV as being heavily meshed, but at lower voltages a more radial pattern exists. Example rating combinations which are quoted are 550 kV/63 kA/118 ms; 300/42,8/190; 300/31,5/128; 168/30,5/136; 168/20/96; 72/26, 3/97 and 72/12,5/48. Despite the apparent very high time constants, no failures have occurred which have been attributed to an inability to clear faults with a high d.c. component.

A particular US utility have supplied data in four categories which can be summarised as follows:

– 500 kV: short-circuit levels less than 40 kA with time constants up to about 130 ms but with the majority being less than or equal to about 80 ms;
– 230 kV: majority of short-circuit levels less than or equal to 40 kA with time constants up to about 93 ms but with the majority being less than or equal to about 66 ms;

– 115 kV: majority of short-circuit levels less than 35 kA with majority of very low time constants albeit with a few rare examples up to 100 ms;
– 69 kV and below: low short-circuit currents (typically 5-10 kA) albeit with a wide spread of time constants from very low values through to about 240 ms.

The degree of correlation between high short-circuit levels and high time constants is not clear from the supplied data.

In the UK, it has been estimated that at 15 % of their locations at 275 kV and above, a requirement for greater than 60 % of short-circuit rating with a time constant of greater than 45 ms exists. These values are associated with a number of factors such as generation concentration, increased network meshing, and the use of line constructions such as 2 x 850 mm^2 giving a time constant in the region of 53 ms. It is also noteworthy that NGC experiences enhanced initial peak conditions over and above those which are normally tested for.

The above examples generally highlight the worst case scenarios reported by utilities and it is important to note that where such high d.c. time constant values exist, they are the extreme rather than the more generally applicable conditions.

Informed users are generally able to identify their own special requirements and specify testing accordingly but this will tend to mask any incipient weaknesses of the standardised testing regime. This is of lesser importance to these informed users who have a reasonably good understanding of their networks and the requirements for equipment installed in it. However, it can be safely assumed that there are a large number of relatively uninformed users, especially in the lower voltage markets, who will inevitably rely far more heavily on the content of IEC standards and it is in this area that any incipient weaknesses in the testing regime become of the utmost importance.

Probability considerations

Historically, a good deal of consideration has been given to the probability of actually experiencing a fully offset fault. It is not intended to repeat the details of this here, only to report that this probability is generally small due to the requirement for the fault to be initiated at voltage zero. This means that the main scenarios where fully offset faults might be experienced are lightning strikes and re-closures onto faults or maintenance earthing where the point on wave is fundamentally random.

Whilst this is inevitably a genuine scenario it is not necessarily pertinent to consideration of testing requirements. Using the IEC 90 % criterion, it is proposed that a standard circuit-breaker should be fully suited for the worst foreseeable faults at 90 % of system locations rather than 90 % of faults at any given location. The fact that fully asymmetric faults are rare should not be of importance. If this probability route were pursued to its extreme far more than 90 % of circuit-breaker in-service operations probably involve little or no rated fault operations, and therefore no rated fault interruption tests need be performed. It is suggested that this is not the true intention of the 90 % criterion and that the 90 % in this case should refer to a proportion of network locations only!

Supplier/manufacturer considerations

Primary concerns from the manufacturer's point of view are inevitably associated with the effect of changes to standards and testing on both the present and future designs of equipment. Any increase in specified time constant can be seen as an increase, albeit marginal, in the specified requirements. The effect of this needs to be considered for two separate cases namely: a) the repercussions of changes on the ability of present and in development equipment to meet specified requirements, and also b) the repercussions for future designs.

As is the case for the utilities, there are benefits to manufacturers in supplying, as far as is possible, a standard product. This being the case, and considering case i) above, there are two possible scenarios which may result from a change to the specification. The simplest and least troublesome is that the existing standard product can be satisfactorily re-tested for the new requirement, in which case the added burden of a specification change is largely limited to testing costs. More troublesome is the scenario where the standard equipment is unable to meet the new requirement. In this case, significant development and re-testing costs may ensue which may place the manufacturer in a poor market position, both financially and technically, for a subsequent period. Alternatively, it may become necessary to offer a higher rated equipment again detrimentally affecting competitiveness. This could obviously be construed as "changing the rules" but a technically justifiable change which may have safety and reliability implications should not, ultimately, be impeded by financial pressures, although it is equally important that utilities are seen to treat all manufacturers in an equitable fashion.

Presupposing this equitable approach, the effect on future designs will be of far less consequence since the criteria against which the design is developed will be clear and fixed.

For the above reasons it is important, in addition to meeting real system requirements, to avoid unnecessary over-testing which is ultimately costly for all parties.

Testing considerations

Having identified the possibility of testing at a different time constant to that used at present, it is important to consider the practicalities of this with respect to testing station capabilities. The obvious question is that of the availability of suitable short-circuit currents with appropriate time constant capabilities. Reported time constant from testing station supplies vary widely between 20 ms for certain network supplies, through to well in excess of 100 ms (several hundred in rare cases) for some generator designs. Hence, it is very difficult to generalise and to consider a time constant for a "typical" short-circuit testing facility. What is clear is that testing stations already make extensive use of short-circuit reactors and transformers to modify these inherent time constants. In practice small changes in specified time constant (e.g. from 45 ms to 60 ms at full fault current rating) are unlikely to pose any major difficulties for testing stations. From available information, it is less clear whether much higher time constants (in excess of 100 ms or so) are so widely achievable and, consequently, whether the adoption of a fractional rating high time constant tests would be prejudicial in favour of some testing facilities over others. This requires further investigation.

Available information suggests that time constants of up to 60 ms are fairly readily achievable across a wide range of currents at a majority of testing stations and figure 1 summarises data supplied by a range of testing stations.

Another equipment consideration is that short-circuit transformers without any requirement for low losses tend to use less copper and consequently have a reduced value of X and time constant.

Apart from time constant control, the other aspect of testing methods which must be considered is the way in which a particular test condition is applied. Where it is not possible or not practical to achieve precisely the correct current/decay characteristic, the option of varying individual components such as the a.c. current component in order to achieve correct peaks/loop lengths, etc. exists. Care must be exercised when considering such an option to ensure that a) the breaker is not significantly overstressed either before, after or during the test, and that b) critical factors such as maximum arc duration are fully represented. The use of "equivalence testing" has to be examined very carefully.

Main points and recommendations

1. Network d.c. time constants can be broadly classified in the following categories:

a) medium voltage networks rated up to 52 kV;

b) high voltage networks rated from 72,5 kV to 420 kV;

c) high voltage networks rated 525 kV and above;

d) generator circuits.

Within each of these categories, the d.c. time constant also varies with the magnitude of the short-circuit current.

2. Medium voltage networks rated up to 52 kV

Consideration of the d.c. time constants in networks rated up to 52 kV can be divided into two further categories by application.

– circuit-breakers which are connected via lines and cables in a meshed network resulting in a d.c. time constant of 45 ms or less,

– Circuit-breakers which are connected to a busbar which itself is supplied solely by one or two power transformers. In this case, the d.c. time constant is determined solely by the power transformer(s) and will generally be higher than 45 ms and possibly up to 150 ms.

Recommendations

For circuit-breakers up to 52 kV the d.c. time constant can be divided into two classes:

1) A time constant of 45 ms is sufficient for circuit-breakers in distribution networks which are fed by lines and cables.

2) A time constant of 120 ms is recommended for circuit-breakers in a transformer-fed substation where the short-circuit current requirement is equal to the rated short-circuit breaking current. In cases where the short-circuit current requirement is lower than the rated short-circuit breaking current of the circuit-breaker by at least one class within the R10 series, a circuit-breaker tested with a time constant of 45 ms may fulfil the requirements. For example, a 50 kA circuit-breaker tested with a time constant of 45 ms may be adjudged to be adequate for a 40 kA location with a higher time constant.

3. High voltage networks rated from 72,5 kV to 420 kV

The d.c. time constants in HV networks rated from 72,5 kV to 420 kV are dominated by lines and investigations suggest that the existing value of 45 ms adequately covers the broad majority of such applications. However, certain network configurations and line designs produce higher time constants, up to maybe 60 ms, in combination with high short-circuit currents. Additionally, applications with lower short-circuit breaking current requirements often have higher d.c. time constants due to the significant part of the short-circuit current which is fed from transformers.

Recommendations

1) The existing time constant of 45 ms is generally sufficient for circuit-breakers in the range 72,5 kV to 420 kV and shall be maintained.
2) For network configurations and line designs resulting in a higher time constant up to 60 ms, the time constant for testing shall be the subject of a separate agreement.
3) For transformer-dominated applications, the specified time constant for testing might be increased but it must be borne in mind that the short-circuit current of such applications will be limited to well below the rated short-circuit breaking current.
4) In cases where the short-circuit current requirement is lower than the rated short-circuit breaking current of the circuit-breaker by at least one class within the R10 series, a circuit-breaker tested with a time constant of 45 ms may fulfil the requirement for a higher time constant. For example, a 50 kA circuit-breaker tested with a time constant of 45 ms may be adjudged to be adequate for a 40 kA location with a higher time constant.

4. High voltage networks rated 525 kV and above

The d.c. time constant in networks rated 525 kV and above are not well defined but tend to increase with increasing voltage and are generally higher than 45 ms. For example, values of 55 ms at 550 kV, 75 ms at 765 kV and 110 ms at 1 100 kV are reported.

Recommendations

1) The d.c. time constant specified for testing shall be considered on an individual basis and shall be the subject of a separate agreement.
2) In cases where the short-circuit current requirement is lower than the rated short-circuit breaking current of the circuit-breaker by at least one class within the R10 series, a circuit-breaker tested with a time constant of 45 ms may fulfil the requirement for a higher time constant. For example, a 50 kA circuit-breaker tested with a time constant of 45 ms may be adjudged to be adequate for a 40 kA location with a higher time constant.

5. Generator circuits

Consideration of circuit-breakers for application to generator circuits has been limited to those associated with small (e.g. 20 MVA), local power plants connected to medium voltage distribution networks since these applications are likely to involve the use of standard circuit-breakers rather than specialised generator circuit-breakers. Circuit-breakers associated with large high voltage connected generation and small industrial generation are not addressed. For the above category of equipment, connection of generation may result in increases in local time constant to values in excess of 45 ms.

Recommendations

1) Consideration should be given to testing with a time constant of around 100 ms.
2) In cases where the short-circuit current requirement is lower than the rated short-circuit breaking current of the circuit-breaker by at least one class within the R 10 series, a circuit-breaker tested with a time constant of 45 ms may fulfil the requirements. For example, a 50 kA circuit-breaker tested with a time constant of 45 ms may be adjudged to be adequate for a 40 kA location with a higher time constant.

6. Testing station ability

Time constants which are available within short-circuit testing laboratories vary widely, depending on factors such as whether the circuit is network or generator fed. This aspect must be taken into consideration when specifying testing requirements and when assessing the acceptability of performing tests at higher r.m.s. currents using a lower time constant to prove ability at lower current with an increased time constant.

References

The majority of documents used in preparing this document were internal Working Group documents of CIGRE WG 13.02. However, the following published documents were also referred to.

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– A. Sabot, A. Giard, & Y. Maugin: Decay of d.c. component of the short-circuit currents on the 420 kV and 245 kV networks of Eletricité de France. 4th International Symposium on short-circuit currents in Power Systems, Liege (Belgium), September 1990, paper 1.17

– M. Ishikawa, K. Suzuki, N. Miyake, K. Hisamatsu, H. Toda, T. Yokota: Study of equivalent short-circuit testing methods for long damping time constant of large d.c. component. IEE Japan Power and Energy '94 Proc. Fifth Annual Conference Tokyo July 1994, Vol 2, pp.155-159

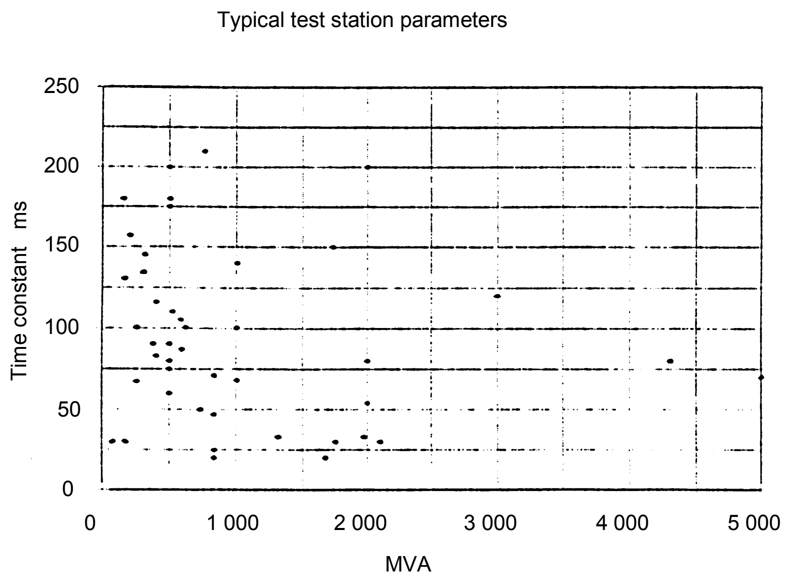

Figure 1 – Typical short-circuit testing station parameter combinations

Table 1 – Circuit specific fault level study results for 275 kV transmission substation

Fault type	Circuit	X/R ratio	Initial RMS current [kA]	Initial peak current [kA]	Transient RMS current [kA]	Break time [ms]	RMS break current [kA]	DC break current [kA]	Peak break RMS [kA]	Asymmetric break [kA]
1 phase	BAR	12,07	35,96	90,75	34,71	70	34,93	8,22	66,14	36,88
3 phase	BAR	15,72	36,49	94,43	32,86	70	33,49	12,74	67,88	36,5
1 phase	B619	12,57	27,96	70,86	27,19	70	27,33	6,88	52,05	29,56
3 phase	B619	17,77	26,85	70,17	24,82	70	25,18	11,02	52,01	28,72
1 phase	B621	15,97	29,68	76,89	28,91	70	29,04	10,59	57,94	32,22
3 phase	B621	19,56	29,31	77,13	27,18	70	27,55	13,47	58,02	31,87
1 phase	F613	10,89	28,87	72,01	27,94	70	28,1	5,42	52,23	30
3 phase	F613	14,5	30,46	78,27	27,63	70	28,12	9,45	55,95	31,25
1 phase	F617	11,16	29,29	73,27	28,34	70	28,51	5,77	53,21	30,5
3 phase	F617	14,7	30,73	79,05	27,87	70	28,37	9,73	56,6	31,57
1 phase	BAR	12,1	36,14	91,23	34,89	70	35,10	8,31	66,51	37,09
3 phase	BAR	15,7	36,66	94,85	33,02	70	33,66	12,78	68,19	36,67
1 phase	B625	15,87	29,92	77,49	29,15	70	29,28	10,59	58,35	32,56
3 phase	B625	19,49	29,49	77,57	27,35	70	27,72	13,49	58,34	32,06
1 phase	B623	12,65	27,96	70,89	27,18	70	27,32	6,95	52,1	29,57
3 phase	B623	17,77	26,8	70,04	24,77	70	25,13	10,99	51,91	28,65
1 phase	F614	10,93	28,98	72,34	28,06	70	28,22	5,48	52,49	30,15
3 phase	F614	14,48	30,62	78,68	27,79	70	28,28	9,49	56,25	31,41
1 phase	F618	11,21	29,49	73,82	28,54	70	28,71	5,87	53,63	30,73
3 phase	F618	14,7	30,92	79,54	28,06	70	28,56	9,79	56,96	31,78

I.3 Explanatory note regarding behaviour of circuit-breaker during tests (6.102.8 and 6.111.11)

When switching capacitive currents in a three-phase test circuit with isolated neutral, a distinction between NSDD and restrike cannot be made, since the appearance of both different events on the oscillogram is the same, To avoid putting circuit-breakers showing NSDDs at a non-justified disadvantage, the valuation of the test results given in 6.102.8 was established for the following reasons.

If the circuit-breaker is able to withstand the first crest of the recovery voltage in capacitive current switching tests, it has shown that it is able to withstand the maximum voltage occurring in this test, applied at a certain position of the contacts during the opening movement. At any later instant of time, the contact distance is longer, i.e. the electrical field stress between the contacts is lower. If a breakdown of the voltage occurs after passing this first voltage crest, the probability is high that this event is a NSDD and not a restrike. Therefore, the following method of evaluation of capacitive current switching tests is used, taking all the other rules given in 6.102.8 into account:

Time interval *t* from current zero to voltage breakdown in the relevant phase	**Assessment of the event**
$t <$ ¼ cycle	Re-ignition
¼ cycle $\leq t \leq$ ½ cycle	Restrike
$t >$ ½ cycle	NSDD

I.4 Explanatory note regarding capacitive current switching tests (6.111)

I.4.1 Restrike performance

As all circuit-breakers have a certain restrike probability in service, it is not possible to define a restrike-free circuit-breaker. Instead, it appears more logical to introduce the notion of a restrike performance in service.

The level of restrike probability also depends on the service conditions (e.g. insulation coordination, number of operations per year, maintenance policy of the user, etc.), so it is impossible to introduce a common probability level related to service condition.

To classify their restrike performance, two classes of circuit-breakers are therefore introduced: class C1 and class C2.

I.4.2 Test programme

In defining the test programme for these two classes, the following elements have been taken into account:

– the average number of operations per year carried out by circuit-breakers switching capacitive loads;
– the ability to reduce the number of tests by performing an increased number of switching operations at the minimum arcing time, usually the most difficult capacitive switching operation for circuit-breakers, thus keeping a high level of reliability;

The expected restrike probability is exclusively related to the type tests. Due to the severity of the type tests, an improved switching performance in service can be expected.

The proposed number of tests may be questioned because of different assumptions for probability calculations. Nevertheless, these values represent a good compromise (which is the role of the standard where conflicting views exist), reflecting the needs of users (in response to market demand) and above all they avoid unrealistic demands. These tests are not reliability tests but type tests to demonstrate the satisfactory capacitive current switching capability of the equipment in service.

I.4.3 Referring to table 5

Not all actual cases of capacitive current switching are covered by table 5. The values for lines and cables cover most cases, the values of the current for capacitor banks (single and back-to-back) are typical and representative of actual values in service.

I.4.4 Referring to 6.111.1

Since a lot of circuit-breakers are used on cable circuits from 12 kV and above, it is reasonable to request cable-charging switching tests for circuit-breakers rated 12 kV and above.

I.4.5 Referring to 6.111.3

The paragraph concerning factor k/f_{φ} has been deleted because there is neither use nor need for testing.

The variation of the power frequency voltage has been chosen as 5 % for test-duty 2 (LC2, CC2 and BC2) and 2 % for test-duty 1 (LC1, CC1 and BC1). These values are a compromise, taking limitations of testing laboratories into account. Considering the type test as a whole, because of the different stresses in the individual test-duties, any undue reduction of the electric stress during the tests is avoided. The actual values for the power frequency voltage variation (depending on the short-circuit power of the system and the capacitive load) is in the range of 1 % to 2 %.

I.4.6 Referring to 6.111.5

The interval after final arc extinction, in which the voltage decay shall not exceed 10 %, has been changed from 100 ms to 300 ms based on service conditions.

I.4.7 Referring to 6.111.9.1.1

Performing these capacitive current switching tests for class C2 equipment on a preconditioned circuit-breaker is, on the one hand, a recommendation of the corresponding CIGRE working group; on the other hand, it draws closer to the real conditions of service, without prejudice as to whether this preconditioning improves the capacitive current switching performance of the circuit-breaker or not.

Close-open operating cycles may be performed with no-load closing operations. In any case, the complete cycle shall be tested in order to test the circuit-breaker during opening in a dynamic condition, i.e. during the motion of the fluid caused by the previous closing operation.

I.4.8 Referring to 6.111.9.1.1 and 6.111.9.2.1

The tolerance of the testing current values for test-duty 1 (LC1, CC1 and BC1) were increased from the old range 20 % to 40 % to the new range 10 % to 40 % in order to give more freedom during testing for combined test-duties for different applications.

The test sequences have been tested in a laboratory (particularly the adjustment of the minimum arcing time by steps of 6°) and are well adapted to the philosophy of the tests.

Performing some tests at rated pressure is a more pragmatic approach to the notion of type testing, knowing that the circuit-breaker is usually at its normal operating conditions when in service.

I.4.9 Referring to 6.111.9.1.2 and 6.111.9.1.3

In test-duty 2 of single-phase line-charging and cable-charging tests (LC2 and CC2), the tests are split into open operations and close-open operating cycles (6.111.9.1.3) to follow more or less the actual service conditions. However, for practical reasons, due to the small number of tests, in three-phase tests (6.111.9.1.2) in test-duty 2 (LC2 and CC2), close-open operating cycles are performed exclusively.

I.4.10 Referring to 6.111.9.1.2 to 6.111.9.1.5

Close-open operating cycles are important for capacitor bank switching because of the effect of inrush current. Close-open operating cycles are not significant for line- or cable-switching applications, therefore for line- and cable-switching tests, only a small number of close-open operating cycles are requested.

Where due to limitations of the test plant it is not possible to comply with the specified requirements during the CO operating cycles, a series of separate making tests is necessary in order to produce the wear caused by the inrush making current (capacitor bank switching tests only) and to verify the assigned prestrike behaviour (i.e. commutation from one set of contacts to the other one without producing undue wear, prestrike taking place between the arcing contacts and not between the main contacts, etc.).

A rough parity of the number of three-phase and single-phase tests has been maintained.

The mandatory order for capacitor bank switching tests is due to the necessity to introduce the effect of inrush current at the beginning of the tests.

I.4.11 Referring to 6.111.9.1.4 and 6.111.9.1.5

Because of the large number of operations in actual service compared with the limited number of operations during type testing, a high number (80 or 120 respectively) of close-open operating cycles shall be carried out in capacitor bank tests to simulate the wear in service even if the close-open operating cycle is not the normal switching sequence.

For capacitor bank switching tests test-duty 1 (BC1) also needs to be performed, even if the actual service switching duty is always at 100 % nominal current, for the following reasons:

– the tests at 10-40 % nominal current cover an increased number of actual currents;
– knowledge of the capacitive current switching performance is improved.

I.4.12 Referring to 6.111.9.2

Requirements for class C1 tests are derived from ANSI/IEEE C37.012 [11].

Annex J
(informative)

Test current and line length tolerances for short-line fault testing

The line reactance corresponding to the standardised line length can be calculated as follows:

$$X_{L,stand} = \frac{1 - \frac{I_{L,stand}}{I_{sc}}}{\frac{I_{L,stand}}{I_{sc}}} X_{source}$$

where

$I_{L,stand}$ is the short-line fault breaking current corresponding to the standardised line length;

$X_{L,stand}$ is the line reactance corresponding to the standardised line length;

X_{source} is the reactance corresponding to the rated short-circuit breaking current.

If the reactance of the line applied in practice differs from the reactance corresponding to the standardised line length within the tolerances of –20 % for L_{90} and ±20 % for L_{75} and L_{60}, as stated in 6.109.2, the related current values can be calculated as follows:

$$I_{L,act} = \frac{U_r}{\sqrt{3}\,(X_{L,act} + X_{source})}$$

where

$I_{L,act}$ is the short-line fault breaking current corresponding to the actual line length;

$X_{L,act}$ is the line reactance corresponding to the actual line length.

The actual line length is calculated considering the standardised line length and the percentage deviation of the actual line length from the standardised one:

$$l_{act} = l_{stand}\left(1 + \frac{d}{100}\right)$$

where

l_{stand} is the standardised line length;

I_{act} is the actual line length

d is the deviation of the actual line length from the standardised one in percent.

The actual line reactance is calculated using the following equation:

$$X_{L,act} = X_{L,stand} \times \frac{l_{act}}{l_{stand}} = X_{L,stand}\left(1 + \frac{d}{100}\right)$$

The actual percentage short-line fault breaking current $I_{perc,act}$ is determined by the following equation:

$$I_{perc,act} = \frac{I_{L,act}}{I_{sc}} \times 100 = \frac{I_{perc,stand}}{1 + \frac{d}{100} \times \left(1 - \frac{I_{perc,stand}}{100}\right)}$$

In table J.1 the actual percentage short-line fault breaking currents are stated for each standardised short-line fault breaking current $I_{perc,stand}$ taking the maximum tolerances for the line length into account.

Table J.1 – Actual percentage short-line fault breaking currents

Standardised short-line fault breaking current $I_{perc,stand}$ %	**Deviation** d %	**Actual short-line fault breaking current** $I_{perc,act}$ %
90	–20	91,8
90	0	90
75	–20	78,9
75	+20	71,4
60	–20	65,2
60	+20	55,5

Annex K
(informative)

List of symbols and abbreviations used in IEC 62271-1

Symbol/ abbreviation	Exemplary reference	Meaning
% dc	4.101.2	Percentage value of the d.c. component
τ	4.101.2	Time constant
ω	Table 3	Angular frequency
τ_1	Figure 9	Standard time constant
τ_2	Figure 9	Special case time constant
τ_3	Figure 9	Special case time constant
τ_4	Figure 9	Special case time constant
Δt_1	6.102.10.2.1.2	Duration of the major loop
Δt_2	6.102.10.2.1.2	Duration of the minor loop
A	Table 22	Designation of a terminal of a circuit-breaker
A	6.101.6.2	Direction of horizontal force
a	Table 22	Designation of a terminal of a circuit-breaker
B	Table 22	Designation of a terminal of a circuit-breaker
b	Table 22	Designation of a terminal of a circuit-breaker
B_1	6.101.6.2	Direction of horizontal force
B_2	6.101.6.2	Direction of horizontal force
BC1	6.111.9	Capacitor bank current, test-duty 1
BC2	6.111.9	Capacitor bank current, test-duty 2
BS	Figure F.7	Back-up switch
C	Table 22	Designation of a terminal of a circuit-breaker
c	A.2	Speed of the travelling wave propagation
c	Table 22	Designation of a terminal of a circuit-breaker
C	H.2.1	Capacitance of a single capacitor bank
C	Table 8	Closing operation
C.B.	Fig. 12 a	Circuit-breaker
C_1	Figure H.3	Capacitance of a first capacitor bank being connected
C_1	6.101.6.2	Direction of vertical force
C1	3.4.114	Class of circuit-breaker with low restrike probability
C_2	Figure H.3	Capacitance of a second capacitor bank being connected
C_2	6.101.6.2	Direction of vertical force
C2	3.4.115	Class of circuit-breaker with very low restrike probability
CC1	6.111.9	Cable-charging current, test-duty 1
CC2	6.111.9	Cable-charging current, test-duty 2
C_d	Fig. 12 a	Time delaying source side capacitance
C_dL	Figure 15	Time delaying line side capacitance
C_L	Figure F.9	Source capacitance
C_n	Figure H.3	Capacitance of a n-th capacitor bank being connected

Symbol/ abbreviation	Exemplary reference	Meaning
CO	4.104	Close-opening operating cycle
CU	Figure F.7	Control unit to provide the sequence of operation
D	Figure F.7	Parallel connection of switching diodes
D		Drive, operating mechanism
d	Annex J	Deviation of actual line length from standardised one
$d\alpha$	6.102.10.2.1.1	Angle difference used for determination of arcing times
$\mathrm{d}u/\mathrm{d}t_{\mathrm{SLF}}$	A.3	Rate of rise of the source side TRV for SLF
$\mathrm{d}u/\mathrm{d}t_{\mathrm{TF}}$	A.3	Rate of rise for terminal fault T100s
$\mathrm{d}u_{\mathrm{L}}/\mathrm{d}t$	6.109.3	Rate-of-rise of line side TRV
E	Figure F.6	Power frequency recovery voltage
E1	3.4.112	Class of circuit-breaker with basic electrical endurance
E2	3.4.113	Class of circuit-breaker with extended electrical endurance
F	Table 22	Designation of the frame of a circuit-breaker
f_{bi}	Table 5	Frequency of the inrush current (back-to-back)
f_{i}	Table 3	Multiplying factor to determine ITRV waveshape
f_{inrush}	4.107.5	Frequency of the inrush current (single capacitor bank)
f_{r}	4.3	Rated frequency
F_{shA}	6.101.6.1	Terminal load, horizontal force
F_{shB}	6.101.6.1	Terminal load, horizontal force
F_{sv}	6.101.6.1	Terminal load, vertical force
F_{th}	Table 9	Static horizontal force
F_{thA}	Table 9	Static horizontal force, longitudinal
F_{thB}	Table 9	Static horizontal force, transversal
F_{tv}	Table 9	Static vertical force
$\hat{I}$	Table 10	Peak current related to the peak value of the short-circuit current
$\hat{\imath}$	H.2.2	Peak inrush current
I_{AC}	Figure 8	Peak value of the a.c. component of the current
I_{bb}	Table 5	Rated back-to-back capacitor bank breaking current
I_{bi}	Table 5	Rated back-to-back capacitor bank inrush making current
I_{c}	Table 5	Rated cable charging breaking current
i_{d}	D.1.1	Value of the d.c. current component at any instant
I_{d}	Table 6	Rated out-of-phase breaking current
I_{d0}	D.1.1	Initial value of the d.c. component
I_{DC}	Figure 8	D.C. component of the current
I_{i}	F.3.4	Injected current
i_{i}	F.3.4	Injected current
I_{k}	4.5	Rated short-time withstand current

Symbol/ abbreviation	Exemplary reference	Meaning
I_l	Table 5	Rated line charging breaking current
I_L	6.109.2	Test current for short-line fault
$I_{L,act}$	Annex J	Short-line fault breaking current corresponding to the actual line length
$I_{L,stand}$	Annex J	Short-line fault breaking current corresponding to the standardised line length
$i_{max\ peak}$	4.107.5	Peak inrush making current
I_{MC}	Figure 8	Making current
I_p	4.6	Rated peak withstand current
$I_{perc,act}$	Annex J	Actual percentage short-line fault breaking current
$I_{perc,stand}$	Annex J	Standardised short-line fault breaking current
I_r	4.4	Rated normal current
I_{sb}	Table 5	Rated single capacitor bank breaking current
I_{sc}	4.101	Rated short-circuit breaking current
i_{sc}	F.3.4	Short-circuit current
I_{sh}	4.107.5	Short circuit current at location of capacitor bank
I_{si}	Table 6	Rated capacitor bank inrush making current
ITRV	4.102.1	Initial transient recovery voltage
k	A.2	Peak factor (SLF)
k	4.107.5	Multiplier for calculation of peak inrush making current
K	Figure F.7	Diode by-pass switch
k_{af}	4.102.2	Amplitude factor (TRV)
k_c	6.111.7	Capacitive voltage factor
k_i	A.3	ITRV peak factor
k_p	6.102.10.2.5	Voltage factor for determination of the TRV in the individual pole
k_{pp}	4.102.2	First-pole-to-clear factor
L	Figure 15	Length of line to fault
l	H.2.1	Total length of conductors between capacitor banks
L'	H.2.1	Inductance per length
L_0	Figure H.3	Source side inductance of capacitor bank
L_1	Figure H.3	Inductance of a first capacitor bank being connected
L_2	Figure H.3	Inductance of a second capacitor bank being connected
L_{60}	6.109.2	SLF test-duty at 60 % of the rated short-circuit current
L_{75}	6.109.2	SLF test-duty at 75 % of the rated short-circuit current
L_{90}	6.109.2	SLF test-duty at 90 % of the rated short-circuit current
L_a	H.2.3	Additional busbar inductance
l_{act}	Annex J	Actual line length

Symbol/ abbreviation	Exemplary reference	Meaning
L_B	A.1	Inductance of busbar on source side
L_b	H.2.1	Inductance of a capacitor bank
LC1	6.111.9	Line-charging current, test-duty 1
LC2	6.111.9	Line-charging current, test-duty 2
L_f	6.109.3	Short-line fault current factor
L_L	A.1	Line side inductance
L_n	Figure H.3	Inductance of a n-th capacitor bank being connected
L_S	A.1	Source side inductance
l_{stand}	Annex J	Standardised line length
M	Table 6	Mass of the circuit-breaker
m	Table 6	Mass of fluid for interruption
M1	3.4.116	Class of circuit-breaker with basic mechanical endurance
M2	3.4.117	Class of circuit-breaker with extended mechanical endurance
MS	Figure F.7	Making switch
NSDD	3.1.126	Non-sustained disruptive discharge
O	4.104	Opening operation
O_1	Figure F.8	Cathode ray oscillograph, trace 1
O_2	Figure F.8	Cathode ray oscillograph, trace 2
O-t-CO	4.104	Open-close-opening operating sequence
OP1	6.110.3	Out-of-phase, test-duty 1
OP2	6.110.3	Out-of-phase, test-duty 2
p_{re}	Table 6	Rated pressure for interruption
p_{rm}	Table 6	Rated pressure for operation
Q_b	H.2.1	Power of a single capacitor bank
RRRV	Table 1a	Rate of rise of recovery voltage
S	Figure H.3	Inrush current rate-of-rise
s	Figure F.9	Switching relay
s	A.2	RRRV factor
SLF	6.104.5.2	Short-line fault
T	6.102.10.2.1.1	Period of the power frequency
$t_{arc\ max}$	6.102.10.2.1.1	Maximum arcing time
$t_{arc\ med}$	6.102.10.2.1.1	Medium arcing time
$t_{arc\ min}$	6.102.10.2.1.1	Minimum arcing time
$t_{arc\ new\ min}$	6.102.10.2.3	New minimum arcing time
$t_{arc\ ult\ max}$	6.102.10.2.3	Ultimate maximum arcing time
t'	4.102.2	Time to reach u' (construction of delay line)
t'	4.104	Time interval in the rated operating sequence
t''	4.104	Time interval in the rated operating sequence

Symbol/ abbreviation	Exemplary reference	Meaning
t_1	4.109.1	Maximum recorded break time during T30, T60 and T100s
t_1	4.102.2	Time to reach u_1 (TRV)
$t_{1,sp}$	6.108.2	Time to reach u_1 (TRV) in case of single-phase and double earth fault
t_2	4.109.1	Maximum recorded opening time during no-load
t_2	4.102.2	Time to reach u_c (four-parameter TRV)
$t_{2,sp}$	6.108.2	Time to reach u_c (four-parameter TRV) in case of single-phase and double earth fault
t_3	4.109.1	Rated opening time
t_3	4.102.2	Time to reach u_c (two-parameter TRV)
$t_{3,sp}$	6.108.2	Time to reach u_c (two-parameter TRV) in case of single-phase and double earth fault
T_A	6.101.3.3	Ambient air temperature
t_a	6.101.2.3	Time between two operations for mechanical operation test at ambient air temperature
t_a	6.108.3	Arcing time for single-phase breaking operation
$t_{a,100s}$	6.108.3	Minimum of arcing times of first-poles-to-clear in T100s
t_b	4.109.1	Rated break time
t_d	4.102.2	Time delay
t_{dL}	6.104.5.2	Line side time delay (short-line fault)
T_H	6.101.3.4	Maximum ambient air temperature
t_i	4.102.2	Time to reach u_i (ITRV)
t_k	4.7	Rated duration of short-circuit
T_L	6.101.3.3	Minimum ambient air temperature
t_L	A.2	Time to reach the first peak of line side TRV
T_{max}	6.101.4.2	High air temperature (humidity test)
T_{min}	6.101.4.2	Low air temperature (humidity test)
T_{op}	4.101.2	Opening time of first opening pole
T_{op}	6.106.5	Minimum opening time
T_r	4.101.2	Relay time, half cycle of rated frequency
t_T	A.3	Time to the peak of the line side TRV (SLF)
t_x	6.101.3.3	Time interval in low temperature test
u'	4.102.2	Reference voltage (construction of delay line)
u_0	A.1	Voltage drop across the line at the instant of current interruption (SLF)
u_1	4.102.2	First reference voltage (four-parameter reference line)
u_c/t_3	6.104.5.1	Rate of rise of recovery voltage (two-parameter reference line)
u_1/t_1	4.102.2	Rate of rise of recovery voltage (four-parameter reference line)
$u_{1,sp}$	6.108.2	First reference voltage in case of single-phase and double earth fault

Symbol/ abbreviation	Exemplary reference	Meaning
U_a	4.8	Rated supply voltage of auxiliary and control circuits
u_c	4.102.2	Reference voltage (TRV peak value)
$u_{c,sp}$	6.108.2	Reference voltage in case of single-phase and double earth fault
U_{CB}	Figure 12a	Voltage across circuit-breaker
U_{cp}	Figure F.1	TRV measured with depression
U_G	A.1	Supply voltage
u_i	4.102.2	Reference voltage (ITRV peak)
u_{i0}	A.3	Bus-bar voltage drop
U_L	A.1	Voltage drop along the line
u_L	A.2	Transient voltage drop along the line
u_{L^*}	6.109.3	Peak voltage across the line (SLF)
u_{L,mod^*}	6.109.3	Adjusted peak voltage across the line (SLF)
U_m	A.1	Crest value of the total induced voltage
U_{op}	Table 6	Rated supply voltage of operating devices
U_p	Table 6	Rated lightning impulse withstand voltage
U_r	4.1	Rated voltage
U_s	Table 6	Rated switching impulse withstand voltage
U_S	Figure 12a	Voltage across source side reactance
$u_S{}^*$	A.3	Source side voltage contribution at first peak
u_T	A.3	Total first peak voltage
U_X	A.1	Voltage drop across the source side (SLF)
u_X	A.1	Voltage drop across the source side (SLF) at the instant of current interruption (SLF)
V_{sc}	F.3.4	Voltage calibration for the TRV corresponding to the maximum short circuit current
X_B	Figure 12a	Power frequency busbar reactance
X_L	Figure 15	Power frequency line side reactance
$X_{L,act}$	Annex J	Line reactance corresponding to the actual line length
$X_{L,stand}$	Annex J	Line reactance corresponding to the standardised line length
X_N	Figure 13	Neutral reactance
X_S	Figure 12a	Power frequency source side reactance
X_{source}	Annex J	Reactance corresponding to the rated short-circuit breaking current
Z	Figure 15	Surge impedance of line
Z	6.103.3	Impedance
Z_0	6.103.3	Zero sequence impedance
Z_1	4.102.3	Positive sequence impedance
Z_a	Figure 13	Phase-to-phase impedance
Z_b	Figure 13	Phase-to-ground impedance
Z_i	Table 3	Busbar surge impedance
Z_i	Figure 12a	ITRV controlling components
Z_S	Figure 12a	Source side TRV control components

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[3] IEC 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

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[14] ANSI/IEEE, C37.09-1999, *Test procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

[15] IEC 62215, *High-voltage alternating current circuit-breakers – Guide for asymmetrical test duty T100a*

[3)] IEC 60186 and its amendments remains in force for capacitor voltage transformers. As far as inductive voltage transformers are concerned, it is replaced by IEC 60044-2.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-151	1978	International Electrotechnical Vocabulary (IEV) Chapter 151: Electrical and magnetic devices	-	-
IEC 60050-441	1984	Chapter 441: Switchgear, controlgear and fuses	-	-
IEC 60050-601	1985	Chapter 601: Generation, transmission and distribution of electricity - General	-	-
IEC 60050-604	1987	Chapter 604: Generation, transmission and distribution of electricity - Operation	-	-
IEC 60059	1999	IEC standard current ratings	EN 60059	1999
IEC 60060	Series	High-voltage test techniques	HD 588.1 S1 EN 60060-2	1991 1994
IEC 60071-2	1996	Insulation co-ordination Part 2: Application guide	EN 60071-2	1997
IEC 60129	1984	Alternating current disconnectors and earthing switches	EN 60129	1994
IEC 60137	1995	Insulated bushings for alternating voltages above 1 kV	EN 60137	1996
IEC 60255-3 (mod)	1989	Electrical relays Part 3: Single input energizing quantity measuring relays with dependent or independent time	EN 60255-3 + corr. Jan.	1998 1998
IEC 60296	1982	Specification for unused mineral insulating oils for transformers and switchgear	-	-
IEC 60376	1971	Specification and acceptance of new sulphur hexafluoride	-	-

Publication	Year	Title	EN/HD	Year
IEC 60427	1989	Synthetic testing of high-voltage alternating current circuit-breakers	EN 60427	1992 [1)
IEC 60480	1974	Guide to the checking of sulphur hexafluoride (SF_6) taken from electrical equipment	-	-
IEC 60529	1989	Degrees of protection provided by enclosures (IP Code)	EN 60529 + corr. May	1991 1993
IEC 60694	1996	Common specifications for high-voltage switchgear and controlgear standards	EN 60694 + corr. May	1996 1999
IEC 61233	1994	High-voltage alternating current circuit-breakers - 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	-	-
IEC 62271-308	[2)	High-voltage alternating current circuit-breakers - Guide for asymmetrical short-circuit breaking test duty T100a	-	-

[1) EN 60427:2000 is based on IEC 60427:2000.

[2) To be published.

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