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TECHNICAL SPECIFICATION

High-voltage switchgear and controlgear –
Part 319: Alternating current circuit-breakers intended for controlled switching

IEC TS 62271-319:2024-09(en)

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colour inside

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CONTENTS

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FOREWORD

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IEC TS 62271-319 has been prepared by subcommittee 17A: Switching devices, of IEC technical committee 17: High-voltage switchgear and controlgear. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
17A/1404/DTS	17A/1411/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

This document is to be read in conjunction with IEC 62271-100:2021, to which it refers and which is applicable unless otherwise specified.

A list of all parts of IEC 62271 series, under the general title *High-voltage switchgear and controlgear,* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

This part of IEC 62271, which is a Technical Specification, clearly segregates normative requirements which are presented in the main text, from informative and advisory information which is presented in a series of annexes. Using this approach all information pertaining to the topic of circuit-breakers intended for controlled switching can be consolidated into this single reference document. The IEC considers that this approach best meets the market need by presenting all relevant information in the most concise and readily usable form.

For the purposes of this document, it has been assumed that there is no significant interaction between the effects of the various parameters (for example ambient temperature, control voltage, etc.) which are considered to affect the mechanical performance of the circuit-breaker. This has not been proven for all combinations, however service experience with controlled switching suggests this assumption is valid in practice for commonly used drive technologies.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 319: Alternating current circuit-breakers intended for controlled switching

1 Scope

This part of IEC 62271, which is a Technical Specification, is applicable to alternating current circuit-breakers with intentional non-simultaneous pole operation designed for indoor or outdoor installations and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V. This document provides additional ratings and type tests to be conducted for this type of circuit-breaker and is intended to be used in conjunction with IEC 62271-100:2021. Intentional non-simultaneous pole operation can be implemented by mechanical or electrical means and both methods are within the scope of this document.

Satisfactory service performance of controlled switching systems is influenced by the inherent performance capabilities of the switching device and by the choice of a suitable controller (relay) and requires proper integration of these devices. Consequently, practical applications of controlled switching require a coordinated approach to system integration.

This document addresses the performance capabilities of the switching device and establishes suitability for controlled switching when applied with an appropriate controller. Type tests are defined, and guidance is provided to establish the switching device capabilities and parameters required to facilitate proper system integration, but this document does not address the performance requirements of the controller. In summary, compliance and testing in accordance with the requirements and guidance presented herein verify the ability of the switching device to meet defined switching accuracy requirements only when applied with a suitably specified controller.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-441:1984, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*
IEC 60050-441:1984/AMD1:2000

IEC 62271-1, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

IEC 62271-100:2021, *High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers*
IEC 62271-100:2021/AMD1:2024

IEC 62271-101:2021, *High-voltage switchgear and controlgear – Part 101: Synthetic testing*

IEC 62271-110, *High-voltage switchgear and controlgear – Part 110: Inductive load switching*

IEC TR 62271-306:2012, *High-voltage switchgear and controlgear – Part 306: Guide to IEC 62271-100, IEC 62271-1 and other IEC standards related to alternating current circuit-breakers*
IEC TR 62271-306:2012/AMD1:2018

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-441 and IEC 62271-100 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1 General terms and definitions

3.1.101
idle time
time interval between consecutive operations (either between a close and open or open and close operation)

3.1.102
compensation
predictive correction for changes in operating time taking account of ambient, drive and supply conditions

3.2 Assemblies of switchgear and controlgear

3.2.101
controlled switching system
combination of circuit-breaker, controller and necessary sensors and auxiliary equipment required to achieve controlled switching as defined in 3.6.101

Note 1 to entry: Necessary sensors refers to those required to provide inputs to the controlled system and may include voltage transformers, current transformers, temperature sensors etc.

3.3 Parts of assemblies

No particular definitions.

3.4 Switching devices

No particular definitions.

3.5 Parts of switchgear and controlgear

No particular definitions.

3.6 Operational characteristics of switchgear and controlgear

3.6.101
controlled switching
intended operation of a circuit-breaker at a specific, pre-determined point in relation to the power frequency current or voltage

Note 1 to entry: The terms point-on-wave switching and point-on-cycle switching are also in widespread use to describe controlled switching.

3.6.102
intentional non-simultaneous pole operation
operation of a circuit-breaker with a specific, pre-determined time delay or delays between the operation of the individual poles

Note 1 to entry: Non-simultaneity is typically measured and expressed in electrical degrees with relation to the phase taken as reference e.g. 0°, 0°, 90° for each pole.

3.6.103
mechanically staggered circuit-breaker
circuit-breaker with fixed, mechanically implemented, non-simultaneous pole operation

3.6.104
controller
device used to define the instant of switching of a circuit-breaker and to operate each pole independently according to a predefined sequence

3.7 Characteristic quantities

3.7.101
opening time
<of a mechanical switching device>
interval of time between the specified instant of initiation of the opening operation and the instant when the arcing contacts have separated in all poles

Note 1 to entry: The instant of initiation of the opening operation, i.e. the application of the opening command (for example energizing the release, etc.) is given in the relevant specification.

Note 2 to entry: Time from the instant of coil energization to arcing contact separation. Any delay introduced by a controller is not considered.

[SOURCE: IEC 60050-441:1984+AMD1:2000, 441-17-36, modified – Notes 1 and 2 to entry added]

3.7.102
closing time
interval of time between the initiation of the closing operation and the instant when the contacts touch in all poles

Note 1 to entry: Time from the instant of coil energization to arcing contact touch. Any delay introduced by a controller is not considered.

[SOURCE: IEC 60050-441:1984+AMD1:2000, 441-17-41, modified – Note 1 to entry added]

3.7.103
close-open time
interval of time between the instant when the arcing 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

[SOURCE: IEC 60050-441:1984+AMD1:2000, 441-17-42, modified – addition of "arcing"]

3.7.104
minimum close-open clearing time
sum of the minimum close-open time when a trip command comes after a minimum relay time of half a cycle after the arcing contacts touch in the first two poles during a closing operation and the shortest arcing time of a minor loop breaking in the last phase to make

Note 1 to entry: For convenience of testing, the manufacturer may declare that the minimum close-open clearing time is equal to sum of the minimum close-open time and the shortest arcing time of a minor loop breaking in the last phase to make.

3.7.105
mechanical scatter
random statistical variation of the mechanical operating time of a circuit-breaker, given by the ±3σ interval at rated conditions, excluding the influence of external variables and the effect of long-term wear and/or drift

Note 1 to entry: For the purposes of this definition the term "external variables" includes all variables which could have a systematic effect on the operating time for example ambient temperature, operating pressure, control voltage.

3.7.106
rate-of-decrease of dielectric strength
RDDS
voltage withstand reduction as a function of time or arcing contacts gap during closing of a circuit-breaker

3.7.107
rate-of-rise of dielectric strength
RRDS
voltage withstand increase as a function of time or arcing contacts gap during opening of a circuit-breaker

3.7.108
re-ignition free arcing time window
period of arc duration during a breaking operation during which the arcing contacts of a mechanical switching device reach sufficient distance to exclude re-ignition

3.7.109
target point for opening
prospective instant of arcing contact separation during a controlled opening operation of a circuit-breaker

3.7.110
target point for closing
prospective instant of arcing contact touch during a controlled closing operation of a circuit-breaker

3.7.111
target point for making
prospective instant of current initiation during a controlled closing operation of a circuit-breaker

3.7.112
making window
time interval around the target point for making

Note 1 to entry: Making within a correctly chosen making window will lead to a pre-determined making voltage. For practical values of RDDS, the centre of the making window may not correspond to the target point for making.

3.7.113
closing window
time interval around the target point for closing

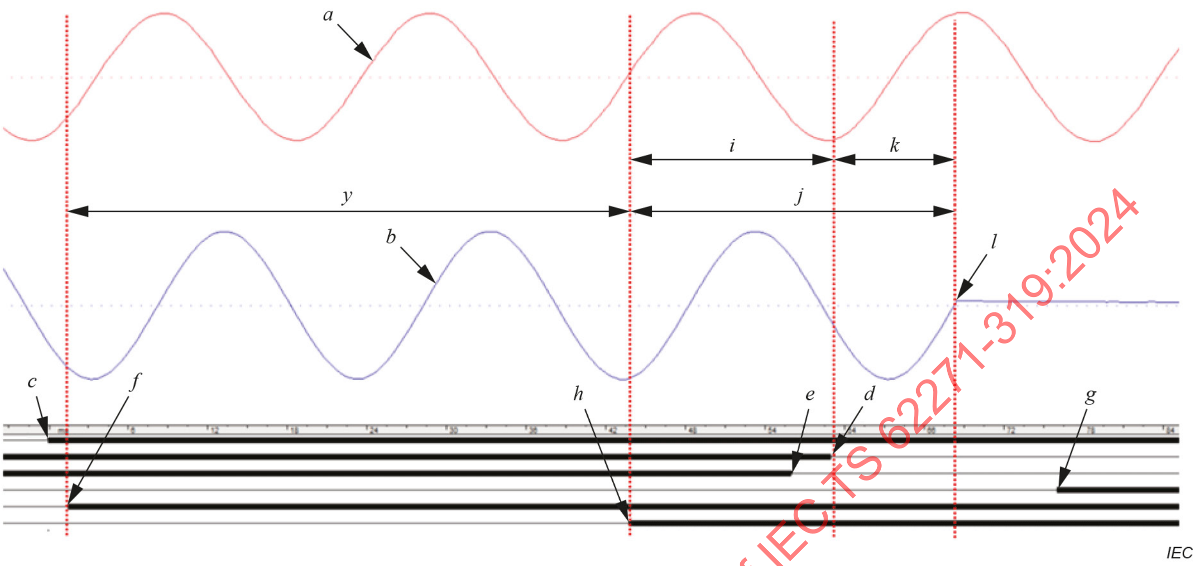
3.7.114
making voltage
voltage at which current is initiated during the closing operation of a circuit-breaker

3.7.115
delta c, auxiliary contacts (Δc_{aux})
time difference between the operation of the arcing contacts and the operation of auxiliary contacts

Note 1 to entry: Auxiliary contacts include position sensor contacts.

3.8 Graphical illustrations of key definitions

Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5 give graphical illustrations of key definitions.



Key

a – system voltage

b – current through the circuit-breaker

c – open command initiation (from control room/SCADA)

d – arcing contact separation instant

e – auxiliary contact 'a' changeover instant

f – start of the controller for evaluation of command output

g – auxiliary contact 'b' changeover instant

h – trip command initiated by the controller

i – opening time

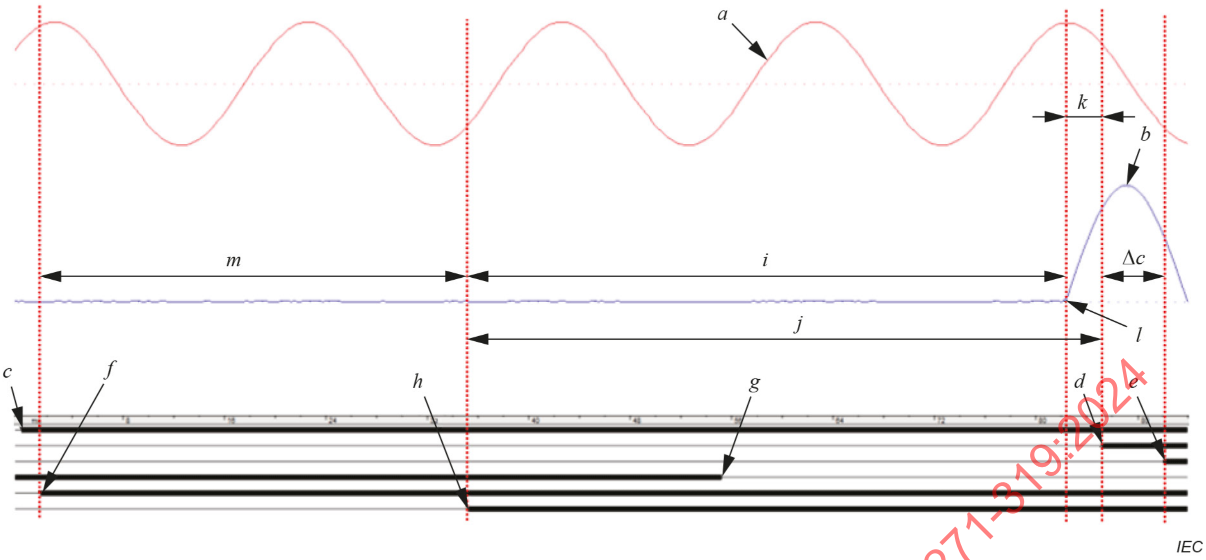
j – break time

k – arcing time

l – current breaking instant

y – delay introduced by the controller

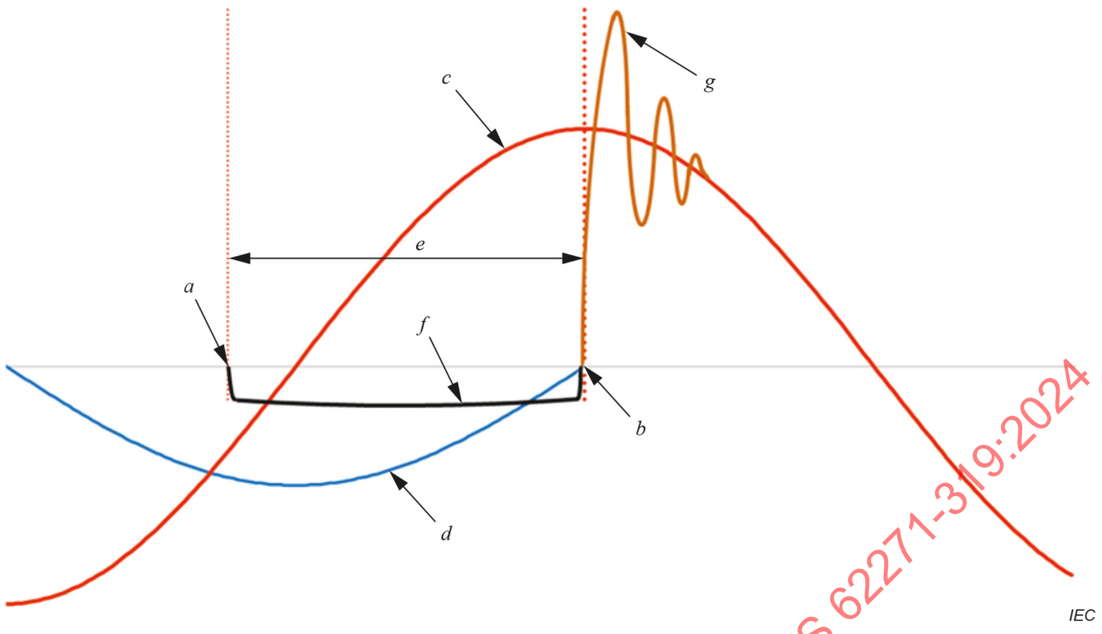
Figure 1 – Example of a controlled opening operation



Key

a – system voltage
b – current through the circuit-breaker
c – close command initiation (from control room/SCADA)
d – arcing contacts touch instant
e – auxiliary contact 'a' changeover instant
f – start of the controller for evaluation of command output
g – auxiliary contact 'b' changeover instant
h – close command initiated by the controller
i – make time
j – closing time
k – pre-arcing time
l – making instant
Δc – delta c, time between arcing contacts touch and auxiliary contacts (Δc_{aux})
m – delay introduced by the controller

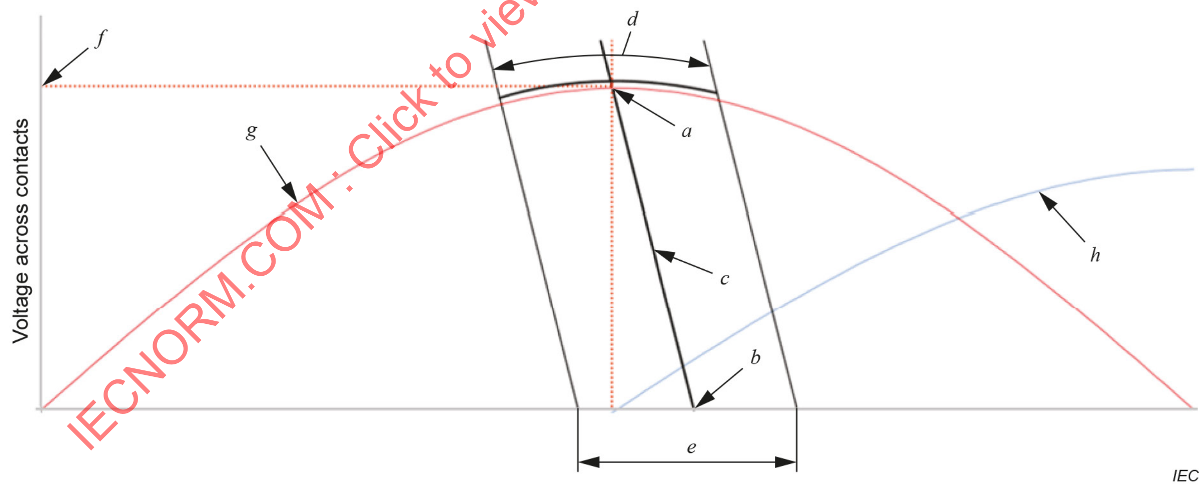
Figure 2 – Example of a controlled closing operation



Key

a – target point for opening (as per definition 3.7.109)
b – current breaking instant
c – system voltage
d – current through the circuit-breaker
e – arcing time
f – arc voltage
g – recovery voltage across the circuit-breaker contacts

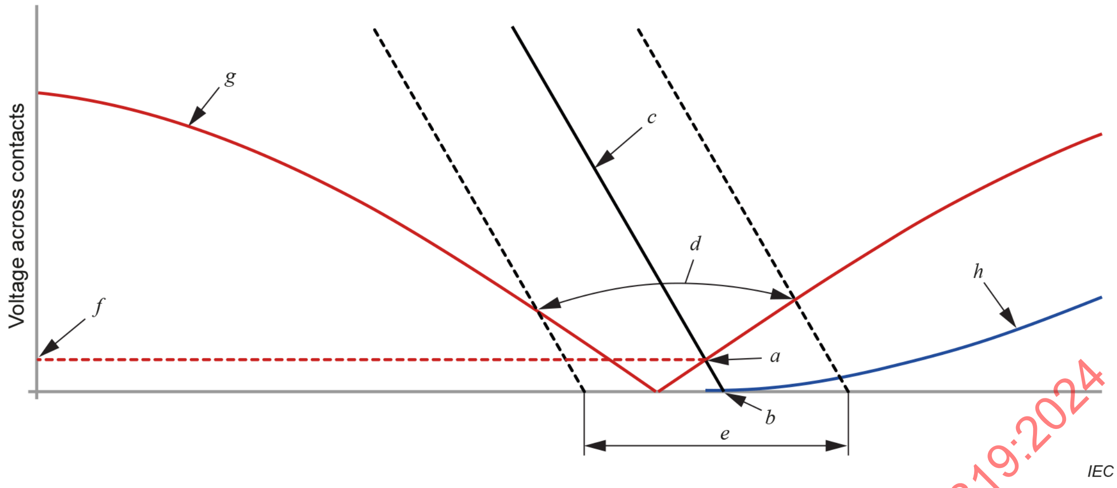
Figure 3 – Current interruption definitions in a switching device



Key

a – target point for making in vicinity of voltage peak (as per definition 3.7.111)
b – target point for closing (as per definition 3.7.110)
c – rate-of-decrease of dielectric strength (RDDS)
d – making window
e – closing window
f – making voltage
g – system voltage
h – current through the circuit-breaker

Figure 4 – Target definitions for a controlled closing operation in the vicinity of voltage peak



Key

a – target point for making in the vicinity of voltage zero (as per definition 3.7.111)
b – target point for closing (as per definition 3.7.110)
c – rate-of-decrease of dielectric strength (RDDS)
d – making window
e – closing window
f – making voltage
g – system voltage
h – current through the circuit-breaker

Figure 5 – Target definitions for a controlled closing operation in the vicinity of voltage zero

4 Normal and special service conditions

Clause 4 of IEC 62271-100:2021 is applicable.

5 Ratings

5.1 General

Subclause 5.1 of IEC 62271-100:2021 is applicable with the following additions:

Rated characteristics for circuit-breakers for intentional non-simultaneous pole operation

- rated short-circuit making current for non-simultaneous closing.

5.2 Rated short-circuit making current (I_{mc}) for intentional non-simultaneous closing

Circuit-breakers intended for non-simultaneous pole closing, with targeting angles of 0, 0 and +90 electrical degrees for each pole (hereafter referred to as °), may, in the event of closing onto a three-phase fault experience higher peak making current in one of the first two poles, than what is specified in IEC 62271-100. This would typically occur when closing the first two poles at phase-to-phase voltage zero and the third pole 90° later for applications such as:

- capacitive loads in non-effectively earthed neutral systems;
- isolated neutral capacitive loads in effectively earthed neutral systems.

The short-circuit making current rating of the circuit-breaker designed for non-simultaneous closing, with the intended closing sequence as described above, shall be chosen from Table 1 taking into account the rated frequency and the specified DC time constant of the network.

NOTE 1 Non-effectively earthed neutral systems are specified up to 170 kV in IEC 62271-100.

Table 1 – Peak making factors for the short-circuit making current for circuit-breakers for use in non-effectively earthed neutral systems or isolated neutral capacitive loads when closing the first two poles at zero phase-to-phase voltage and the third pole 90° later

Time constant ms	Peak making factor (50 Hz or 60 Hz) I_{mc}
45	3,0
60	3,1
75	3,1
120	3,2

NOTE 2 For circuit-breakers intended to be used for voltage zero closing in effectively earthed neutral systems and earthed neutral capacitive loads no enhanced making current will occur however full asymmetry will be developed in each phase when closing onto a pre-existing fault.

NOTE 3 Equipment connected in series with the circuit-breaker will also be exposed to enhanced peak currents if they occur.

NOTE 4 Due to the making conditions explained above, higher asymmetry will result (see 7.2.2).

Circuit-breakers rated according to IEC 62271-100 may be suitable for such applications without additional short-circuit making current test as per 7.2.4, if the specified short-circuit making current, at the circuit-breaker location, is less than or equal to the rated short-circuit making current multiplied by the de-rating factor as specified in Table 2.

Table 2 – Short-circuit making current de-rating factors in non-effectively earthed neutral systems when closing the first two poles at zero phase-to-phase voltage and the third pole 90° later

Time constant	De-rating factor	
ms	50 Hz	60 Hz
45	0,83	0,87
60	0,84	0,87
75	0,87	0,87
120	0,84	0,84

NOTE 5 The de-rating factors in Table 2 are defined as ratios between the peak factors for rated peak withstand current given in Table 5 of IEC 62271-1:2017 and the peak factors in Table 1.

NOTE 6 It is assumed that the circuit-breaker is fully type tested according to IEC 62271-100.

6 Design and construction

6.1 General

Clause 6 of IEC 62271-100:2021 is applicable with the following additions:

6.2 Mechanical scatter

Mechanical scatter shall be given for both opening and closing operations.

The recommended procedure to determine mechanical scatter is given in Annex B.

6.3 RDDS

RDDS shall be given for both positive and negative polarities.

The recommended procedure to determine RDDS is given in Annex C.

6.4 Auxiliary and control equipment and circuits

Intended pole non-simultaneity shall not compromise any control equipment and circuits such as for anti-pumping and pole discrepancy.

6.5 Uncontrolled operations

Circuit-breakers tested in compliance with this technical specification and intended to be used with a controller shall be able to operate when the controller is rendered inoperable in contingency situations.

Circuit-breakers intended for capacitive switching shall minimally meet class C1 according to IEC 62271-100 for a given application.

For shunt reactor switching, the uncontrolled operation of the circuit-breaker can be harmful for the shunt reactor and the circuit-breaker (see 7.4, NOTE 3). Uncontrolled operations of shunt reactors at 245 kV and above should be avoided.

6.6 Nameplates

The nameplates of mechanically staggered circuit-breakers shall indicate the intended time delay between poles for opening and/or closing and a specific reference to this technical specification.

The nameplates of single-pole operated circuit-breakers intended for controlled switching shall have a specific reference to this technical specification if the final application is known.

6.7 Simultaneity of poles during closing and opening operations

6.7.1 Single-pole operated circuit-breakers intended for controlled switching

For single-pole operated circuit-breakers intended for controlled switching, the same requirements for simultaneity of poles during single closing and single opening operations (see 6.101 of IEC 62271-100:2021) shall apply, since the intentional non-simultaneity will be introduced electronically by the controller.

6.7.2 Mechanically staggered circuit-breakers intended for controlled switching

The manufacturer shall declare the intended pole operating sequence of the circuit-breaker for both opening and closing. The intended non-simultaneity and the associated tolerances shall be declared.

6.7.3 Non-simultaneity between individual making and breaking units (MBUs) of a pole

For controlled opening and closing targeting voltage peak, the permissible non-simultaneity between MBUs of a same pole defined by IEC 62271-100 is generally sufficient for most applications.

For controlled closing targeting voltage zero, the permissible non-simultaneity between making and breaking units of a same pole is highly dependent on the mechanical scatter of the circuit-breaker as shown in Annex M. Annex M can be used as a guide for the user to specify the permissible non-simultaneity between making and breaking units of a same pole.

Non-simultaneity between individual MBUs of a same pole shall be recorded during routine testing as specified in 8.1.

7 Type tests

7.1 General

Clause 7 of IEC 62271-100:2021 is applicable with the following additions:

Type tests for circuit-breakers with intentionally non-simultaneous poles are listed in Table 3. These type tests shall be performed only if the condition requiring the type test is met. These type tests verify conditions introduced by non-simultaneous pole operation which are not covered under IEC 62271-100.

Type testing requirements depend on the application as outlined in Table 3.

Table 3 – Type tests for circuit-breakers intended for controlled switching

Type tests dependent upon application, rating or design	Condition requiring type test	Subclauses
Test duty T100a	Controlled closing at phase-to-phase voltage zero for the first two phases and at voltage zero 90° later for the third phase (see 5.2) and subsequent interruption of asymmetrical current in non-effectively earthed neutral systems	7.2.3
Short-circuit making current	Controlled closing at phase-to-phase voltage zero for the first two phases and at voltage zero 90° later for the third phase (see 5.2) in non-effectively earthed neutral systems	7.2.4
Capacitive current switching	Controlled opening in non-effectively earthed neutral systems or controlled switching of capacitor banks	7.3
Inductive load switching	Controlled switching of a shunt reactor	7.4
Controlled closing	All controlled closing applications	7.5

7.2 Miscellaneous provisions for making and breaking tests

7.2.1 General

Subclause 7.102 of IEC 62271-100:2021/AMD1:2024 is applicable to all making and breaking tests unless otherwise specified in 7.2.2 to 7.3.

7.2.2 Identical nature of the MBUs

Subclause 7.102.4.2.3 of IEC 62271-100:2021 is applicable except for item (a).

7.2.3 Test duty T100a

Subclauses 7.104.2.2 and 7.104.2.3 of IEC 62271-100:2021 are applicable with the following additions:

This test duty applies only to circuit-breakers intended for controlled closing in non-effectively earthed neutral systems (see NOTE) when the intended closing sequence is as per 5.2.

When a circuit-breaker has already been tested as per IEC 62271-100, it may not be necessary to perform additional testing if it can be demonstrated that the product of "$\hat{I} \times \Delta t_1$" prior to current interruption of the major loop is equal to or greater than the product of "$\hat{I} \times \Delta t_1$" indicated in Table 4 and Table 5 below considering the minimum close-open clearing time. T100a tests according to 7.104.2.2 of IEC 62271-100:2021 may cover the required asymmetry criteria of Table 4 or Table 5, e.g. from tests with higher rated short-circuit breaking currents or higher DC time constants. In this case no additional tests need to be performed. IEC TR 62271-306 can be used as a guide for these calculations.

The test procedure follows IEC 62271-100 with exception of the required prospective values of the peak short-circuit current and loop duration that shall be attained by the last major loop prior to interruption. These values are provided in Table 4 or Table 5 of this document.

When employing a synthetic testing method, refer to Annex O.

In the case of three-phase testing of a three-pole operated circuit-breaker with non-simultaneous poles (including staggered pole operation) which is intended for operation in non-effectively earthed neutral systems the test procedure shall be agreed between manufacturer and user.

NOTE For three-phase testing or single-phase testing in substitution of three-phase conditions of a single-pole operated circuit-breaker with non-simultaneous poles which is intended for operation in non-effectively earthed neutral systems, it is assumed that the short-circuit is initiated at voltage zero of the phase-to-phase voltage of two phases and the subsequent voltage zero of the third phase (90° later). The initiation of the short-circuit is made by a closing operation of the same circuit-breaker that is intended to clear a three-phase fault.

Table 4 – Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test-duty T100a in non-effectively earthed neutral systems – Tests for 50 Hz operation

t	Minimum close-open clearing time	$\hat{I}$	k_{pp} = 1,5			
			Δt_1	Δt_{a1}	Δt_2	Δt_{a2}
ms	ms	p.u.	ms	ms	ms	ms
45	10,0 < t ≤ 27,7	1,71	15,3	4,9	16,9	12,4
	27,7 < t ≤ 48,5	1,45	13,0	4,3	14,7	10,8
	48,5 < t ≤ 69,0	1,29	11,9	4,0	13,6	9,9
	69,0 < t ≤ 89,3	1,19	11,2	3,7	12,9	9,3
60	10,0 < t ≤ 27,4	1,83	16,8	5,4	18,5	13,3
	27,4 < t ≤ 48,2	1,60	14,1	4,7	15,8	11,7
	48,2 < t ≤ 68,7	1,43	12,8	4,3	14,5	10,7
	68,7 < t ≤ 89,0	1,31	12,0	4,0	13,7	10,0
	89,0 < t ≤ 109,3	1,22	11,4	3,8	13,1	9,5
	109,3 < t ≤ 129,4	1,16	11,0	3,7	12,7	9,2
75	10,0 < t ≤ 27,2	No zero crossing between first two major loops				
	27,2 < t ≤ 48,0	1,70	15,1	5,0	16,7	12,4
	48,0 < t ≤ 68,5	1,54	13,6	4,6	15,3	11,4
	68,5 < t ≤ 88,8	1,41	12,7	4,3	14,4	10,6
	88,8 < t ≤ 109,1	1,32	12,0	4,0	13,7	10,1
	109,1 < t ≤ 129,2	1,24	11,6	3,9	13,2	9,7
	129,2 < t ≤ 149,4	1,19	11,2	3,7	12,8	9,3
120	10,0 < t ≤ 26,8	No zero crossing between first two major loops				
	26,8 < t ≤ 47,4	1,90	17,5	5,8	19,1	14,0
	47,4 < t ≤ 67,9	1,76	15,6	5,3	17,2	12,9
	67,9 < t ≤ 88,3	1,65	14,5	4,9	16,2	12,1
	88,3 < t ≤ 108,5	1,55	13,7	4,6	15,4	11,4
	108,5 < t ≤ 128,8	1,46	13,1	4,4	14,7	10,9
	128,8 < t ≤ 149,0	1,39	12,6	4,2	14,2	10,5
	149,0 < t ≤ 169,1	1,33	12,2	4,1	13,8	10,2

NOTE 1 Minimum close-open clearing times above these ranges have no practical use and are not included in the table.

NOTE 2 The symbols are defined in 7.104.1 of IEC 62271-100:2021.

Table 5 – Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test-duty T100a in non-effectively earthed neutral systems – Tests for 60 Hz operation

t ms	Minimum close-open clearing time ms	$\hat{I}$ p.u.	k_{pp} = 1,5 Δt_1 ms	 Δt_{a1} ms	 Δt_2 ms	 Δt_{a2} ms
45	8,3 < t ≤ 22,9	1,79	13,5	4,3	14,9	10,8
	22,9 < t ≤ 40,3	1,54	11,4	3,8	12,8	9,5
	40,3 < t ≤ 57,4	1,38	10,4	3,5	11,8	8,7
	57,4 < t ≤ 74,3	1,26	9,7	3,3	11,1	8,1
	74,3 < t ≤ 91,1	1,18	9,3	3,1	10,7	7,8
60	8,3 < t ≤ 22,7	No zero crossing between first two major loops				
	22,7 < t ≤ 40,0	1,68	12,4	4,1	13,8	10,2
	40,0 < t ≤ 57,1	1,52	11,2	3,8	12,6	9,4
	57,1 < t ≤ 74,0	1,39	10,5	3,5	11,9	8,8
	74,0 < t ≤ 90,9	1,30	9,9	3,3	11,3	8,3
	90,9 < t ≤ 107,7	1,22	9,5	3,2	10,9	8,0
	107,7 < t ≤ 124,5	1,17	9,2	3,1	10,6	7,7
75	8,3 < t ≤ 22,5	No zero crossing between first two major loops				
	22,5 < t ≤ 39,8	1,79	13,2	4,4	14,6	10,8
	39,8 < t ≤ 56,9	1,63	12,0	4,0	13,4	10,0
	56,9 < t ≤ 73,8	1,50	11,2	3,8	12,5	9,3
	73,8 < t ≤ 90,7	1,40	10,6	3,6	11,9	8,8
	90,7 < t ≤ 107,6	1,32	10,1	3,4	11,5	8,4
	107,6 < t ≤ 124,4	1,26	9,7	3,3	11,1	8,1
	124,4 < t ≤ 141,1	1,21	9,4	3,2	10,8	7,9
	141,1 < t ≤ 157,9	1,17	9,2	3,1	10,6	7,7
120	8,3 < t ≤ 22,2	No zero crossing between first three major loops				
	22,0 < t ≤ 39,4	No zero crossing between first three major loops				
	39,4 < t ≤ 56,4	1,84	13,7	4,7	15,1	11,2
	56,4 < t ≤ 73,4	1,73	12,7	4,3	14,1	10,6
	73,4 < t ≤ 90,2	1,64	12,0	4,1	13,4	10,0
	90,2 < t ≤ 107,1	1,56	11,4	3,9	12,8	9,6
	107,1 < t ≤ 123,9	1,48	11,0	3,7	12,4	9,2
	123,9 < t ≤ 140,7	1,42	10,6	3,6	12,0	8,9
	140,7 < t ≤ 157,5	1,37	10,3	3,5	11,7	8,6

NOTE 1 Minimum close-open clearing times above these ranges have no practical use and are not included in the table.

NOTE 2 The symbols are defined in 7.104.1 of IEC 62271-100:2021.

7.2.4 Short-circuit making current

7.2.4.1 General

Subclause 7.105.2 of IEC 62271-100:2021/AMD1:2024 is applicable with the following addition:

The short-circuit making current shall be that as defined in 5.2.

7.2.4.2 Three-phase tests

Subclause 7.105.2.2.1 of IEC 62271-100:2021 is applicable with the following addition:

For three-pole operated circuit-breakers intended for voltage zero closing in non-effectively earthed neutral systems a single making test with source voltages lower than nominal voltage may be performed to demonstrate the making and latching capability of the design. The peak making current shall be obtained by multiplying the rated short-circuit breaking current by the peak making factors specified in Table 1.

This test may be omitted if the enhanced short-circuit making performance has already been achieved as part of a previous test series on an equivalent, non-staggered design.

7.2.4.3 Single-phase tests

Subclause 7.105.2.2.2 of IEC 62271-100:2021 is applicable with the following addition:

For single-pole operated circuit-breakers intended for voltage zero closing in non-effectively earthed neutral systems a single making test with source voltages lower than nominal voltage may be performed to demonstrate the making and latching capability of the design. The peak making current shall be as defined according to the peak making factors in Table 1.

This test may be omitted if the enhanced short-circuit making performance has already been achieved as part of a previous test series for simultaneous operation.

7.3 Capacitive current making and breaking tests

7.3.1 General

Subclause 7.111 of IEC 62271-100:2021/AMD1:2024 is applicable unless otherwise specified in 7.3.2 to 7.3.4.

7.3.2 Test voltage to verify controlled opening in non-effectively earthed neutral systems

Subclause 7.111.7 of IEC 62271-100:2021 is applicable with the following addition:

For direct single-phase laboratory tests, the voltage measured at the circuit-breaker location immediately before opening shall be not less than the product of $U_r/\sqrt{3}$ and the following capacitive voltage factor k_c:

k_c = 1,5 for tests corresponding to:

- breaking during normal service conditions in non-effectively earthed neutral systems with a non-simultaneity at arcing contact separation at opening in the different poles exceeding one fourth of the cycle of the rated frequency;
- breaking of capacitor banks with non-effectively earthed neutral with a non-simultaneity at arcing contact separation at opening in the different poles exceeding one fourth of the cycle of the rated frequency.

Explanations relative to this voltage factor are given in Annex L.

7.3.3 Test-duty to verify controlled opening in non-effectively earthed neutral systems

Circuit-breakers intended for controlled opening of lines, cables and single capacitor banks will be exposed to significant dielectric stress in the event of inappropriate controller settings.

For this reason, circuit-breakers intended for controlled switching of lines, cables and single capacitor banks, an appropriate capacitive current switching class shall be chosen as per 6.107.4 of IEC 62271-100:2021 and tests shall be performed with the test voltage specified above as per the selected capacitive current switching class C1 or C2.

7.3.4 Test-duty to verify controlled switching of back-to-back capacitor banks

Circuit-breakers intended for controlled closing or opening of back-to-back capacitor banks will be exposed to significant inrush currents in the event of inappropriate controller settings.

For this reason, circuit-breakers intended for controlled switching of back-to-back capacitor banks, an appropriate capacitive current switching class shall be chosen as per 6.107.4 of IEC 62271-100:2021 and tests shall be performed with the test voltage specified above as per the selected capacitive current switching class C1 or C2.

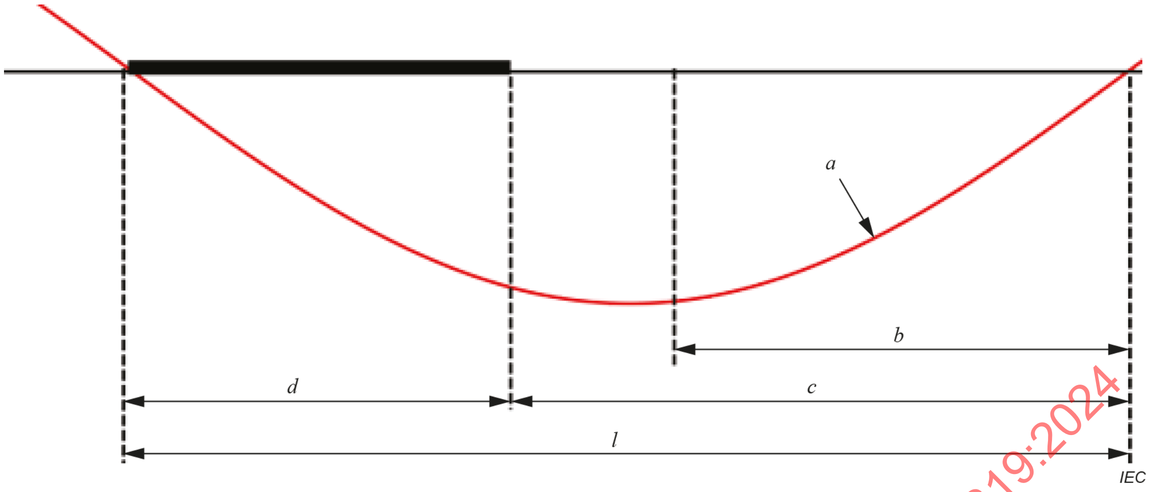
7.4 Determination of the chopping characteristics and RRDS for inductive load switching

Test results based on IEC 62271-110 for inductive load switching shall be used to determine the chopping characteristics of the circuit-breaker and the rate-of-rise of dielectric strength (RRDS). The evaluated data should be used to determine the suitability of the circuit-breaker for the specific shunt reactor application using the method described in IEC TR 62271-306.

NOTE 1 In service, the minimum arcing time and hence, the width of the re-ignition free arcing time window can be different from that obtained from inductive switching type test results depending on reactor characteristics and network configuration. The values can be dissimilar for each circuit-breaker pole based on type of grounding and magnetic core design of the reactor.

For each pole, the mechanical scatter of the circuit-breaker shall be within the re-ignition free arcing time window.

Figure 6 illustrates some key definitions for the determination of the minimal re-ignition free arcing time window for each pole needed for reactor switching. The minimum arcing time 'b' will be specific to the test currents and load circuit parameters used during inductive load testing as per IEC 62271-110 and cannot be directly applied for any reactor configuration.



Key

a – last half cycle current loop

b – minimum arcing time for an effectively earthed reactor obtained as per IEC 62271-110

c – re-evaluated minimum arcing time for specific reactor and system configuration

d – re-ignition free arcing time window

l – last half cycle loop duration

Figure 6 – Last half cycle current loop during reactor switching

NOTE 2 Controlled switching of inductive loads with a circuit-breaker with high current chopping can result in a suppression peak voltage which exceeds the voltage withstand of the circuit-breaker.

NOTE 3 As a general rule, re-ignitions are to be avoided as the re-ignition overvoltages can exceed the voltage withstand of the circuit-breaker and/or reactor, see also IEEE Std C57.21, Annex B. High du/dt can also result in damage to the reactor insulation material. Arcing times can be chosen to be longer than one half cycle so that interruption occurs with a greater distance between arcing contacts and re-ignition overvoltages remain within acceptable limits.

7.5 Controlled closing test

7.5.1 Applicability

This test procedure aims to demonstrate the ability of the circuit-breaker to consistently initiate current within a predefined making window. Independent of the application, testing at voltage zero target is the most onerous condition and is therefore sufficient to demonstrate the ability of a circuit-breaker for all target points.

This test is mandatory for all circuit-breakers intended for controlled closing, in case no other test can be used to reliably verify this characteristic. This test can be performed in combination with the RDDS test.

7.5.2 General requirements

A predefined making window shall be selected as per application requirements. Typical examples of predefined making windows are 1,0; 2,0; or 3,0 ms. A controller with a minimal precision of ±100 µs shall be used considering laboratory conditions demonstrates the best potential performance which may be expected of the circuit-breaker in an "ideal" controlled switching system.

NOTE Based on the test results, a different making window can be defined and indicated in the test report.

The predefined making window is chosen as a function of the desired maximum making voltage. Table K.2 and Table K.3 deliver some guidelines on how to determine the specified making window based on the desired maximum making voltage.

7.5.3 Specified target point for closing defined by the manufacturer

The laboratory controller shall be set at the specified target point for closing defined by manufacturer for the controlled closing test based on the RDDS and mechanical scatter characteristics of the circuit-breaker. Before commencing the controlled closing test, no-load operations shall be made and details of the operating characteristics of the circuit-breaker recorded.

As the RDDS characteristic of a circuit-breaker may vary from one voltage polarity to another, the circuit-breaker shall be tested in both voltage polarities.

The laboratory controller shall be set considering the circuit-breaker characteristics to reach effective making within the specified maximum making voltage.

7.5.4 Characteristics of the power frequency supply circuit

For single-phase testing, the test voltage shall be not less than $U_r/\sqrt{3}$ for circuit-breakers intended for application in effectively earthed neutral systems and not less than 1,5 times (depending on the application) $U_r/\sqrt{3}$ for circuit-breakers intended for application in non-effectively earthed neutral systems. For some applications, higher test voltages may be required such as for unearthed capacitor bank switching. For unit tests, the test voltage shall be chosen to correspond to the most stressed unit of the pole of the circuit-breaker. Three-phase testing is also acceptable.

The test circuit shall fulfil the following criteria:

a) the power frequency voltage amplitude variation of the source shall be less than 2 %;
b) the test current shall not exceed the preferred value of rated capacitive current and a value in excess of 10 A is preferred;
c) test shall be performed at rated frequency.

Tests performed at 60 Hz cover 50 Hz applications.

7.5.5 Test procedure – general requirements

7.5.5.1 General

The controlled closing test consists of a series of making operations at rated operating conditions with the circuit-breaker in new condition and a series of making operations on a pre-conditioned circuit-breaker at minimum functional pressure for insulation and/or switching (if applicable). Tests on a pre-conditioned circuit-breaker only apply to class C2 circuit-breakers.

Tests shall be performed with both voltage polarities. The pre-conditioning tests shall comply with 7.111.9.4.1 of IEC 62271-100:2021.

The test arrangement shall be such as to avoid depressurisation of the circuit-breaker between the pre-conditioning tests and making operations. If local safety rules require depressurisation prior to access to the vicinity of the circuit-breaker it is permissible to decrease the pressure providing that the gas is reused when refilling the circuit-breaker. All the used gas may not be available for refilling of the test object. In this case, it is permitted to top up the test object with new gas to the specified pressure. Proper gas handling shall be used to avoid unnecessary refilling with new gas. At least 50 % of the used gas shall be reused.

Separate poles may be used for the new and pre-conditioned test series.

The circuit-breaker shall pass the tests in 7.5.5.2 and 7.5.5.3.

7.5.5.2 Test procedure for circuit-breaker in new condition

20 making operations shall be performed at the target point for closing specified by the manufacturer (see 7.5.3). All 20 making operations are to be performed with the same controller setting.

The circuit-breaker has passed the test if all 20 operations result in current initiation within the declared making window of the circuit-breaker. In the event of a single making operation within the 20 operations falling outside the making window a further 20 making operations shall be performed. The circuit-breaker has passed the test providing that current initiation occurs within the making window in not less than 19 of the second series of 20 operations.

7.5.5.3 Test procedure for pre-conditioned circuit-breaker

20 making operations shall be performed at the target point for closing specified by the manufacturer (see 7.5.3). All 20 making operations are to be performed with the same controller setting.

The circuit-breaker has passed the test if not less than 18 of the 20 operations result in current initiation within the declared making window of the circuit-breaker. In the event of a third making operation within the 20 operations falling outside the making window, a further 20 making operations shall be performed. The circuit-breaker has passed the test providing that current initiation occurs within the making window in not less than 18 of the second series of 20 operations.

8 Routine tests

8.1 General

Clause 8 of IEC 62271-100:2021/AMD1:2024 is applicable with the following additions:

A minimum of 30 operations at rated conditions shall be performed and recorded to confirm mechanical scatter as described in Annex B. If the circuit-breaker consists of more than one breaking unit per pole, the time difference shall not exceed requirements as specified in 6.7.3.

Opening and closing times shall be specified on a per pole basis.

Routine tests may be performed on site as per IEC 62271-100.

9 Guide to the selection of switchgear and controlgear for service (informative)

9.1 General

Clause 9 of IEC 62271-100:2021/AMD1:2024 is applicable with the following additions:

9.2 Voltage factors based on system configuration

When selecting a circuit-breaker for non-simultaneous closing, the suitability shall be evaluated based on the system voltage across the open arcing contacts. Other critical parameters such as RDDS and mechanical scatter also need to be considered. Refer to Annex K for more details.

Table 6 defines voltage across individual poles due to the shift in neutral voltage for non-simultaneous controlled closing.

Table 6 – Voltage factors depending on earthing conditions

Earthing conditions	Voltage factor (p.u.) [a]		
	First pole-to-close	Second pole-to-close	Third pole-to-close
Non-effectively earthed neutral systems	1,0	1,0/1,73[b]	1,5
Effectively earthed neutral systems[c]	1,0	1,0	1,0

[a] The values given do not consider trapped charges or oscillations on the load side.

[b] When the first two poles are closed simultaneously, each pole will be subjected to a voltage factor of 1,0 p.u. When the first and second poles are closed non-simultaneously the second pole-to-close will be subjected to a voltage factor of 1,73 p.u.

[c] When the supplying transformer and load to be switched are electrically close together, for example in the same substation (i.e. when $X_0/X_1 \leq 1$) a voltage factor 1,0 applies to all three poles. For rare cases when the load to be switched are remote from the supplying transformer (i.e. when $X_0/X_1 \leq 3$) voltage factors of 1,26 and 1,3 apply to the second and third pole-to-close respectively.

9.3 Mechanical and electrical characteristics of the circuit-breaker

9.3.1 Reference mechanical travel characteristics

For mechanically staggered circuit-breakers the reference mechanical travel characteristic of the individual poles may vary. In such cases the reference mechanical travel characteristic shall be measured on a per pole basis.

9.3.2 Mechanical characteristics of the circuit-breaker as a function of environmental and operating conditions

The closing and opening times and their variation as a function of ambient air temperature, idle time, control voltage, pressure for operation may be needed for controlled switching and shall be provided by the manufacturer by means of the parameter definition summary test report (Annex A).

Recommended test procedures are given in Annex D, Annex E, Annex F, Annex G, Annex H, Annex I and Annex J to determine the impact of these parameters on the operating times of the circuit-breaker.

To limit testing to a minimum, a combined test procedure which incorporates the requirements of IEC 62271-100 is given in Annex N.

9.4 Effect of RDDS and mechanical scatter on target determination

RDDS and mechanical scatter are two important circuit-breaker characteristics to be considered for controlled switching. A guide to determining the target point for making, depending on RDDS and mechanical scatter and for different applications is presented in Annex K.

10 Information to be given with enquiries, tenders and orders (informative)

10.1 General

Clause 10 of IEC 62271-100:2021 is applicable with the following addition.

A parameter definition summary test report as detailed (see Annex A) should be provided.

11 Transport, storage, installation, operation instructions and maintenance

11.1 General

Clause 11 of IEC 62271-100:2021/AMD1:2024 is applicable with the following additions:

11.2 Commissioning of circuit-breakers for controlled switching

To minimize system disturbances and limit the number of operations after circuit-breaker energization the following recommendations need be considered during on-site testing:

- perform no-load operations on the complete control switching system;
- establish a clear test procedure based on the system application (before and after energization);
- perform live tests to confirm that the correct targeting is achieved;
- use the controller data or other external recordings to make the necessary adjustments to the controller settings as needed.

11.3 Maintaining controlled switching accuracy

Recommendations are to be given regarding minimum maintenance requirements to ensure that the specified accuracy is maintained throughout the life of the installation.

The user needs to be informed of any possible effects of aging including special maintenance requirements to maintain circuit-breaker required performance.

Adaptive control can be used to compensate for both electrical and mechanical deviations assuming the measurement system has sufficient accuracy. When current measurement is needed, possible core saturation effects shall be considered. For mechanical adaptation control using auxiliary contacts, deviations in timing with respect to the arcing contacts need to be considered. Correlation between timing of the arcing contacts and auxiliary contacts, Δc_{aux} shall be measured and recorded as per Annex J.

It is recommended to set controller alarms that can detect improper operation. This will allow the user to make the necessary adjustments to the controller settings or to perform circuit-breaker maintenance.

12 Safety

Clause 12 of IEC 62271-100:2021 is applicable.

13 Influence of the product on the environment

Clause 13 of IEC 62271-100:2021 is applicable.

Annex A
(informative)

Parameter definition summary test report

A.1 General

The purpose of the parameter definition summary test report, typically provided by the circuit-breaker manufacturer, is to present a single document summarizing all the circuit-breaker characteristics which might be required for controlled switching for a given application.

The purpose of parameter definition tests is to determine the parameters which affect circuit-breaker timing response. These tests are design specific verifications which do not have pass/fail criteria but result in data that can be used to characterise the circuit-breaker. Recommended test procedures are presented in Annex B, Annex C, Annex D, Annex E, Annex F, Annex G, Annex H, Annex I and Annex J. All parameter definition tests (except for the impact of controlled voltage and mechanical scatter are performed at rated control voltage.

Applicable test results should be presented in the parameter definition summary test report, to be supplied to the user upon request and be preferably in a table format or in such a way as to facilitate transfer into any given controller.

It is not the intention of this technical specification to require repeated testing for parameter definition purposes. Therefore, parameter definition tests may be omitted if the required information can be reliably derived from alternative methods (i.e. type test reports already performed, well documented empirical observation or routine testing).

A.2 Information to be included in the parameter definition summary test report

A.2.1 General information

The following information shall be included in the parameter definition summary test report:

a) type of apparatus;
b) general layout drawing;
c) rated voltage (kV);
d) rated current (A);
e) rated frequency (Hz);
f) filling pressure for operation (MPa) (if applicable);
g) filling pressure for insulation and/or switching (MPa) (if applicable);
h) applicable standard(s);
i) manufacturer name.

A.2.2 Parameter definition tests

A.2.2.1 Determination of mechanical scatter

The following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) maximum, minimum and mean operating timing characteristics of the arcing contacts, auxiliary contacts, Δc_{aux} with respective ±3σ confidence interval for an opening and closing operations for rated supply voltage of auxiliary circuits, each pressure for operation (if applicable) and each control voltage (if applicable).

A.2.2.2 Determination of RDDS

The following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) RDDS in new condition in kV/ms in each polarity and for each pressure (if applicable);
c) when relevant, RDDS in worn condition in kV/ms in each polarity and for each pressure (if applicable).

A.2.2.3 Impact of control voltage

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) maximum, minimum and mean operating times for each voltage level defined in Table D.1.

A.2.2.4 Impact of low temperature

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) maximum, minimum and mean operating timing characteristics for each tested temperature.

A.2.2.5 Impact of high temperature

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) maximum, minimum and mean operating timing characteristics for each tested temperature.

A.2.2.6 Impact of pressure for operation

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) maximum, minimum and mean operating timing characteristics for each tested pressure for operation.

A.2.2.7 Impact of pressure for insulation and/or switching

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;
b) maximum, minimum and mean operating timing characteristics for each tested pressure for insulation and/or switching.

A.2.2.8 Impact of idle time

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;

b) maximum, minimum and mean operating timing characteristics for each tested idle time.

A.2.2.9 Impact of electrical wear

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;

b) time difference between the main and auxiliary contacts before and after preconditioning.

A.2.2.10 Determination of the characteristics of the circuit-breaker needed for reactor switching (if applicable)

When applicable, the following information shall be included in the parameter definition summary test report:

a) reference number of the test report;

b) chopping characteristics;

c) test voltage and k_{pp} of the test circuit and earthing conditions;

d) RRDS in kV/ms in each polarity.

Annex B
(informative)

Determination of mechanical scatter

B.1 Applicability

These are optional tests and should be performed only if the impact of mechanical scatter and electrical wear cannot be obtained from type tests already performed according to IEC 62271-100.

B.2 Test procedure

The measurement of mechanical scatter of the circuit-breaker arcing contacts, auxiliary contacts could be combined with the normal mechanical operation test sequence described in 7.101.2 of IEC 62271-100:2021. If insufficient data is available from a previously performed mechanical operation test, then the following test should be performed.

Operating times should be recorded with a minimal precision of 0,1 ms. Dynamic effects such as contact bounce may be important and it is recommended that there is no "filtering" of the measured signal. Such signal filtering may eliminate the earliest point of arcing contact touch/separation and as such create a false opening/closing time characteristic. In order to obtain more precise standard deviation results, all operations during the mechanical operation test should be recorded.

Circuit-breaker arcing contacts, auxiliary contacts which are intended to be used for position feedback in a controlled switching scheme, should be tested to prove their accuracy and repeatability. Testing could be performed on auxiliary contacts selected to represent the beginning, the end and intermediate position of the contact array.

The mechanical scatter is a random function of the circuit-breaker alone and cannot be compensated by a controller.

NOTE 1 In the event when the controller is an integral part of the circuit-breaker and cannot be disabled these tests can be undertaken with the controller in service.

Measurement of the mechanical scatter should be undertaken under stable conditions of all influencing variables such as temperature, control voltage, pressure for operation, pressure for insulation and/or switching.

Where relevant, the control voltage should be regulated within ±3 % of the specified value measured at the control circuits terminals and the voltage drop should not exceed 15 % of the rated value.

NOTE 2 The impact of control voltage is not relevant for circuit-breakers which are controlled by dry contacts.

Where relevant, tests should be conducted at the filling pressure for insulation and/or switching. For circuit-breakers with more than one filling pressure for insulation and/or switching, testing at one value is sufficient to cover all cases.

Test sequence:

a) the circuit-breaker should be operated sequentially 100 times with a test sequence C-t_a-O-t_a (t_a is defined in Table D.1) at rated supply voltage of auxiliary circuits, rated control voltage (if applicable) and the filling pressure for operation (if applicable);
b) where relevant, sequence a) should be repeated at the minimum control voltage;
c) where relevant, sequence a) should be repeated at the minimum functional pressure for operation (NOTE 3).

NOTE 3 For hydraulic operating mechanisms the test can be carried out at the "pump start" pressure for operation.

B.3 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.1.

Annex C
(informative)

Determination of the rate of decrease of dielectric strength (RDDS)

C.1 Applicability

This is an optional test and should be performed if the RDDS characteristic of the circuit-breaker is unknown. This test procedure is applicable when the circuit-breaker is used for controlled closing applications. Typical applications are energisation of capacitor banks, shunt reactors and transformers.

NOTE 1 The suitability of a measured RDDS in conjunction with the mechanical scatter for a given application is determined by the user with the help of the manufacturer. Annex K and CIGRE Technical Brochure 757 [1][1] give some guidance on how to select the appropriate circuit-breaker.

NOTE 2 The suitability of this procedure has not been verified for vacuum circuit-breakers although successful implementation of controlled switching for vacuum in medium voltage is well documented.

NOTE 3 A more suitable test method or calculation could be used depending on the circuit-breaker technology.

C.2 General

The amplitude of the test voltage should be not less than the phase-to-earth rated voltage for circuit-breakers intended for application in effectively earthed neutral systems and not less than 1,5 times the phase-to-earth rated voltage for circuit-breakers intended for application in non-effectively earthed neutral systems. For some applications, higher test voltages may be required and agreed with the end user, for example a test voltage of 1,73 times the phase-to-earth rated voltage when the first two poles are closed non-simultaneously for non-effectively earthed capacitor bank applications (see Table 6).

The test current should not exceed the value of rated capacitive current, preferred value 10 A.

The test may be performed at 50 Hz or 60 Hz subject to the normal tolerances detailed in IEC 62271-100.

NOTE 1 It is recognised that the frequency at which the test is undertaken could affect the results and that test procedures based on the use of DC voltage do not correlate exactly with results of AC tests. Whilst care should be taken when using tests at one frequency for application at another frequency it is believed that the differences between 50 Hz and 60 Hz results are sufficiently small to be of no practical consequence.

The RDDS measurement tests should be performed with the circuit-breaker in new condition, at the rated supply voltage of the auxiliary and control circuits, at filling pressure for operation (if applicable) and the minimum functional pressure for insulation and/or switching (if applicable).

As far as practicable, the test arrangement should be such that no interference with the circuit-breaker between the test series is necessary. If this is not possible the interference should be minimised.

NOTE 2 Additional RDDS tests after preconditioning as per IEC 62271-100:2021, 7.111.9.4.1 could be necessary for special applications such as for controlled switching of transmission lines where faults have a higher probability of occurrence.

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[1] Numbers in square brackets refer to the Bibliography.

The following characteristics should be determined during the RDDS tests:

- pre-arcing time = contact touch time – making time,
- making voltage,
- RDDS is the making voltage versus pre-arcing time.

The instant of contact touch in each test is derived from measurements of no-load closing operations prior to the RDDS measurement tests and from the travel curve obtained during each test.

NOTE Alternative methods can be used to determine the pre-arcing time.

C.3 Test procedure

C.3.1 Preferred test procedure

The RDDS measurement tests should consist of a series of operations "around the clock", which can be performed according to the procedure described below:

a) perform 4 making operations preferably as close as possible to voltage peak (other making angles are also acceptable);
b) delay the close impulse by 15° and perform a further 4 making operations;
c) repeat step b) until the entire voltage cycle (360°) is tested;
d) repeat step a) to confirm that the characteristics of the circuit-breaker remain unchanged from the starting conditions.

C.3.2 Alternative test procedure

When no laboratory controller is available, random closing operations could be carried out to determine RDDS. It can require more making operations to obtain the equivalent results as per C.3.1.

NOTE Other test procedures could be suitable to determine RDDS.

C.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.2.

Annex D
(informative)

Impact of control voltage

D.1 Applicability

This is an optional test and should be performed only if the impact of control voltage is applicable and cannot be assessed from the results obtained from the mechanical operating tests described in 7.101.2 of IEC 62271-100:2021.

NOTE For example, the test is not applicable for circuit breakers controlled by dry contacts.

D.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

It is recommended to carry out this test in conjunction with the mechanical operation test of the circuit-breaker as per IEC 62271-100:2021, 7.101.2.

D.3 Test procedure

The control voltage should be as per Table D.1.

Table D.1 – Tests to assess the impact of control voltage

Operating sequence	Control voltage		Number of tests
C-t_a-O-t_a	Minimum	85 %	30
	Rated	100 %	30
	Maximum	110 %	30
C	Additional	93 %	30
O[a]		70 %	30

C Closing operation.

O 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).

[a] Applicable only for DC control circuits.

The control voltage should be set within ±3 % of the specified value and should be measured directly at the terminals of the control circuits.

D.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.3.

Annex E
(informative)

Impact of low temperature

E.1 Applicability

This is an optional test and should be performed only if the impact of low temperature cannot be assessed from the results obtained from the low temperature tests described in 7.101.3.4 of IEC 62271-100:2021.

E.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

For circuit-breakers having staggered poles to achieve the intended non-simultaneity, the tests may be performed on a circuit-breaker having a similar non-staggered design.

E.3 Test procedure

The test procedure as per IEC 62271-100:2021, 7.101.3.4 is applied with the following additions to clauses b) and c).

b) The opening and closing times should be recorded for 10 opening and 10 closing operations at an ambient air temperature of 20°C ± 5°C (T_A).

c) With the circuit-breaker in the closed position, the ambient air temperature should be decreased with at least two intermediate steps, which are equally distributed within the initial and final temperatures until the appropriate, minimum air temperature (T_L) is reached. At each step the circuit-breaker should be kept in the closed position until the circuit-breaker has thermally stabilised. It is considered that thermal stability is reached after three times the thermal time constant of the circuit-breaker. For measurements at the minimum temperature the heater (if any) should remain energised. At each temperature level 10 opening and 10 closing operations should be carried out and the operating times should be recorded. The first operation at each temperature level should be excluded from the calculation of the characteristic operating time to eliminate idle time effects from the calculation. The circuit-breaker should be kept in the closed position for 24 h after the ambient air temperature stabilises at (T_L).

NOTE 1 Mentioned above is a combined test procedure of this document and IEC 62271-100:2021, 7.101.3.4. If tests per IEC 62271-100:2021, 7.101.3.4 are already done, the above steps b) and c) can be carried out separately excluding the last sentence in c).

NOTE 2 The use of only 10 operations to establish the operating characteristics has limited statistical validity however it is sufficiently accurate to determine the relationship between operating time and ambient temperature. In case of doubt larger numbers of operations can be undertaken to improve the statistical validity.

E.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.4.

Annex F
(informative)

Impact of high temperature

F.1 Applicability

This is an optional test and should be performed only if the impact of high temperature cannot be assessed from the results obtained from the high temperature tests described in 7.101.3.5 of IEC 62271-100:2021.

F.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

For circuit-breakers having staggered poles to achieve the intended non-simultaneity, the tests may be performed on a circuit-breaker having a similar non-staggered design.

F.3 Test procedure

The test procedure as per IEC 62271-100:2021, 7.101.3.5 is applied with the following additions to clauses m) and n).

m) The opening and closing times should be recorded for 10 opening and 10 closing operations at an ambient air temperature of 20°C ± 5°C (T_A).

n) With the circuit-breaker in the closed position, the ambient air temperature should be increased with at least one intermediate step, which is half way between the initial and final temperatures until the appropriate maximum air temperature (T_H) is reached. At each step the circuit-breaker should be kept in the closed position until the circuit-breaker has thermally stabilised. It is considered that thermal stability is reached after three times the thermal time constant of the circuit-breaker. At each temperature level 10 opening and 10 closing operations should be carried out and the operating times should be recorded. The first operation at each temperature level should be excluded from the calculation of the characteristic operating time to eliminate idle time effects from the calculation. The circuit-breaker should be kept in the closed position for 24 h after the ambient air temperature stabilises at (T_H).

NOTE 1 Mentioned above is a combined test procedure of this document and IEC 62271-100:2021, 7.101.3.5. If tests per IEC 62271-100:2021, 7.101.3.5 are already done, the above steps m) and n) can be carried out separately excluding the last sentence in n).

NOTE 2 The use of only 10 operations to establish the operating characteristics has limited statistical validity however it is sufficiently accurate to determine the relationship between operating time and ambient temperature. In case of doubt larger numbers of operations can be undertaken to improve the statistical validity.

F.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.5.

Annex G
(informative)

Impact of pressure for operation

G.1 Applicability

This is an optional test applicable for mechanisms which can operate over a range of pressures for operation, for example pressurised fluid-based mechanisms, and should be performed only if the impact of pressure for operation cannot be assessed from the results obtained from the mechanical operating tests described in 7.101.2 of IEC 62271-100:2021.

G.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

The test sample should represent the smallest indivisible operational unit of the circuit-breaker e.g. a single pole of an independent pole operated circuit-breaker or a three-pole operated circuit-breaker.

G.3 Test procedure

30 C-t_a-O-t_a sequences should be performed at the following pressures for operation:

a) minimum functional pressure,
b) at least three intermediate pressures,
c) filling pressure.

G.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.6.

Annex H
(informative)

Impact of pressure for insulation and/or switching

H.1 Applicability

This is an optional test and should be performed only if the impact of pressure for insulation and/or switching cannot be derived from other type tests performed according to IEC 62271-110 or IEC 62271-100 where tests are performed at different pressures for insulation and/or switching.

H.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

The test sample should represent the smallest indivisible operational unit of the circuit-breaker e.g. a single pole of an independent pole operated circuit-breaker or a three-pole operated circuit-breaker.

The gas should be thermally stabilized after each filling.

H.3 Test procedure

30 C-t_a-O-t_a sequences should be performed at the following pressures for insulation and/or switching:

a) minimum functional pressure,
b) at least one intermediate pressure,
c) filling pressure.

H.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.7.

Annex I
(informative)

Impact of idle time

I.1 Applicability

This is an optional test and should be performed only if the impact of idle time cannot be assessed from the results obtained from the mechanical operating tests described in 7.101.2 of IEC 62271-100:2021 or if no specific procedure exists to mitigate idle time effect during field operation.

I.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

Auxiliary conditioning equipment such as heaters should be energised as per normal service.

The test sample should represent the smallest, indivisible, operational unit of the circuit-breaker, for example a single pole of an independent pole operated circuit-breaker or a three-pole operated circuit-breaker. The use of alternative arrangements of the circuit-breaker is acceptable provided that the relevant conditions of 7.101.3.1 of IEC 62271-100:2021/AMD1:2024 are met.

The following idle times should be tested: 168 h (1 week); 64 h; 32 h; 16 h; 8 h; 4 h; 2 h; 1 h; and 0,5 h. An idle time of 168 h is the longest time for which a "regularly operated" circuit-breaker might be left idle during normal service. To limit the number of tests to a minimum, it is recommended to start the test with the longest idle time of 168 h. If idle time has no effect, then it is not necessary to test for shorter idle times.

NOTE 1 Some types of mechanisms and circuit-breakers are not affected by the idle time depending on mechanism design and choice of lubricants. Most of the ones that are affected will often reach a point of saturation level where operating times remain constant for longer idle times.

NOTE 2 Circuit-breakers which have not reached a saturated value at an idle time of 168 h can require an extended test procedure agreed between manufacturer and user or a specific procedure to mitigate idle time effect during field operation.

At least two different poles should be used in the case of an independent pole operated circuit-breaker or a three-pole operated circuit-breaker.

NOTE 3 It is recognised that it is difficult to distinguish between small idle time effects and normal mechanical scatter. However, the proposed test procedure is regarded as being sufficient to identify major idle time effects which can be of importance for satisfactory controlled switching.

I.3 Test procedure

The following procedure should be executed for both closing and opening operations.

a) The circuit-breaker should be operated with time intervals of one minute until the operating times of the last three operations are stable or stop decreasing. The averages of the last three operations are considered as the operating time references denoted as t_{ref} in ms.

NOTE 1 The interval of one minute can be extended based on the time required to recharge the operating mechanism to the nominal energy level.

NOTE 2 Stability is obtained when operating time variations are within the mechanical scatter of the circuit-breaker.

b) Before each open or close idle time test, the circuit-breaker should be exercised as per a). The breaker is then operated after each idle time listed above. The idle time is defined as per Figure I.1.

The operating time for each operation compared to t_{ref} should represent the impact of idle time. For a three-pole operated circuit-breaker, the impact of idle time can be evaluated for each pole of the circuit-breaker.

NOTE 3 Time interval 't' can be one minute or less or until the operating mechanism has finished charging.

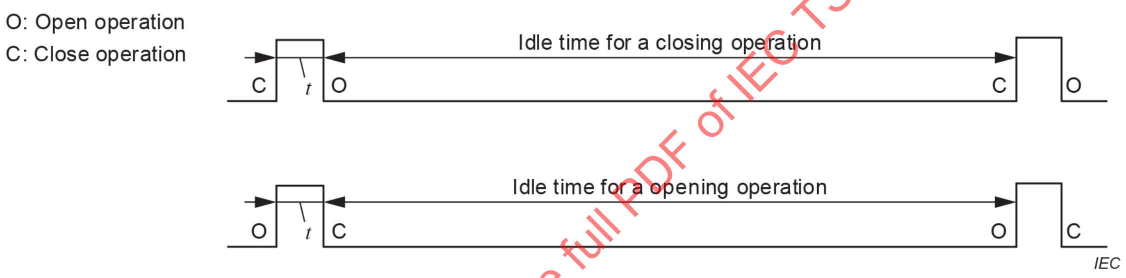

Figure I.1 – Illustration of idle time for a close and open operation

c) For single pole operated circuit-breakers, steps a) and b) are to be repeated on a second pole.

NOTE 4 Step b) can be repeated up to 6 times if the idle time characteristic shows a large scatter.

NOTE 5 It could be useful to measure the contact speed and the timing of auxiliary contacts to distinguish between latching effects at the start of travel and changes to the contact travel characteristic.

NOTE 6 If the influencing parameters have changed during the test, they could be compensated for before determining the impact of idle time.

Steps at shorter idle times could be omitted if it is shown that there is no impact at longer idle times. To limit the number of tests to a minimum, it is recommended to start the test with the longest idle time of 168 h.

I.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.8.

Annex J
(informative)

Impact of electrical wear on the accuracy of auxiliary contacts

J.1 Applicability

This is an optional test and should be performed only for special applications such as for controlled switching of transmission lines, where faults have a higher probability of occurrence, or if the impact of electrical wear on the accuracy of auxiliary contacts cannot be derived from other type tests performed according to IEC 62271-100 or IEC 62271-101.

J.2 General

The test should be carried out by varying the parameter being studied, all other parameters should be at rated and stable conditions.

J.3 Test procedure

The time difference between the main and auxiliary contacts should be measured before and after preconditioning as per IEC 62271-100:2021, 7.111.9.4.1.

J.4 Test results

Test results should be reported in the parameter definition summary test report as per A.2.2.9.

Annex K
(informative)

Effects of RDDS and mechanical scatter on voltage targeting

K.1 Introduction to controlled making

The objective of controlled closing of a circuit-breaker is to control the making instant with a targeted switching angle based on a reference synchronizing signal. Depending on the application, it consists of making at specific point on the sinusoidal voltage during a closing operation.

The closing and making sequence are described in Figure K.1 in 4 steps for a gas circuit-breaker.

Step 1: open position. In open position the distance between the circuit-breaker arcing contacts in open position is sufficient to withstand the voltage applied at its terminals.

Step 2: making instant. During closing a dielectric breakdown occurs when the distance between the circuit-breaker contacts becomes insufficient to withstand the voltage and the current starts to flow through the arc between the arcing contacts prior to the contacts touch. This is known as the making instant.

Step 3: arcing contact touch. When the arcing contacts touch the arc is no longer present and the current continues to flow through the arcing contacts. The time between the making instant and contact touch is defined as the pre-arcing time.

Step 4: main contact touch. At the end of the closing operation the main contacts touch and the current is commutated from the arcing to main contacts.

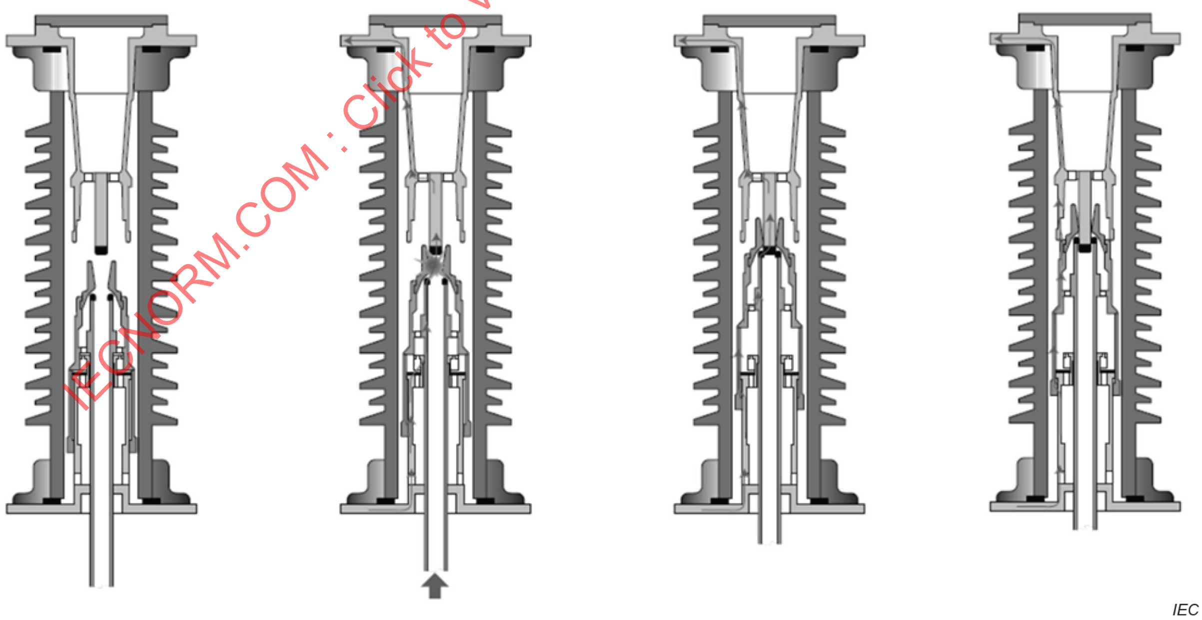

Figure K.1 – Closing and making sequence for a gas circuit-breaker

A circuit-breaker dedicated to perform controlled closing operations should have a sufficiently high RDDS to avoid premature pre-arcing phenomena. Theoretically, when targeting voltage zero, the corresponding RDDS should be higher than the voltage derivative at its zero crossing. High RDDS alone does not guarantee successful controlled switching. Closing time mechanical scatter is another important parameter for controlled switching. It should be small enough to allow a narrow making window. For example, a circuit-breaker with RDDS lower than 1 p.u. may still be suitable for some applications if the closing time mechanical scatter is small enough.

K.2 Abbreviations used in this annex

The following quantities are used along this annex:

- U_r : rated voltage [kV];
- U_{pe} : phase-to-earth peak voltage [kV or p.u.];
- f_r : rated frequency [Hz];
- $\omega = 2\pi \times f_r$: angular frequency corresponding to the power frequency [rad/s];
- U_{cb} : peak voltage applied across the circuit-breaker terminals [kV or p.u.];
- T_{prearc} : pre-arcing time [ms];
- 3σ : circuit-breaker closing time mechanical scatter ($\pm 3\sigma$) [ms];
- $RDDS$: rate of decrease of dielectric strength [kV/ms or p.u.];
- α : switching angle [°].

1 p.u. for U_{pe} is defined by the following formula.

$$\sqrt{\frac{2}{3}} \times U_r$$

Table K.1 – Examples of U_{pe} equal to 1 p.u.

U_r	U_{pe}
kV	kV
132	107,8
230	187,8
400	326,6
500	408,2

1 p.u. for RDDS is defined by the following formula.

$$\omega \times \sqrt{\frac{2}{3}} \times U_r$$

It corresponds to the derivative at zero crossing of the voltage having a peak of U_{pe} .

Table K.2 – Examples of RDDS equal to 1 p.u.

U_r kV	RDDS at 50 Hz kV/ms	RDDS at 60 Hz kV/ms
132	33,9	40,6
230	59,0	70,8
400	102,6	123,1
500	128,3	153,9

Voltage targeting, RDDS and closing time mechanical scatter should be considered together for successful controlled closing operation.

K.3 Controlled closing at voltage zero

Making at voltage zero is the most difficult to achieve because the derivative of the applied voltage across the circuit-breaker arcing contacts is maximum at that point. Hence, making at voltage zero is taken as reference for all other switching applications.

The controller is essential for synchronous switching. It should be able to integrate relevant circuit breaker characteristics such as the RDDS slope, the closing time standard deviation as well as other parameters such as the making window.

There are two methods: "balanced" and "tangent" to define a time shift (T_{shift}) related to voltage zero.

The "balanced" method is used when RDDS is greater or equal to one p.u. The aim is to balance the making voltage on both slopes as illustrated in Figure K.2. T_{shift} can be calculated using the following formula.

$$T_{shift} = \frac{U_{cb}}{RDDS} \times \sin(\omega \times 3\sigma)$$

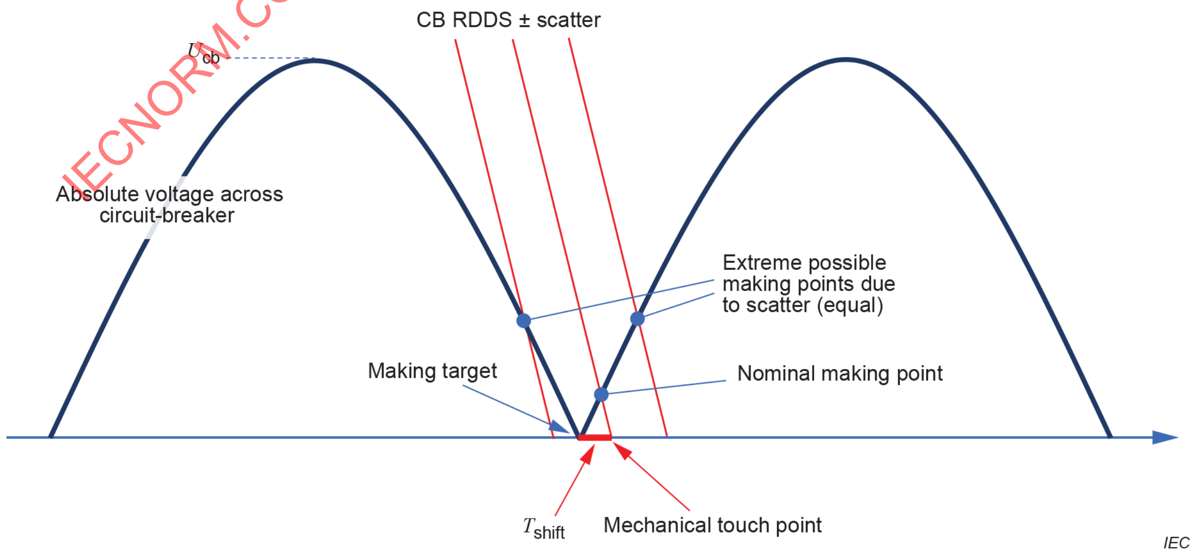

Figure K.2 – "Balanced" method for voltage zero making

The "tangent" method is used when RDDS is smaller than one p.u. The aim is to reduce the probability of interception the RDDS slope and the falling voltage loop as illustrated in Figure K.3. T_{shift} can be calculated using the following formula.

$$T_{\text{shift}} = \frac{U_{\text{cb}}}{RDDS} \times \sqrt{1 - \left(\frac{RDDS}{\omega \times U_{\text{cb}}}\right)^2} - \frac{1}{\omega} \times \cos^{-1}\left(-\frac{RDDS}{\omega \times U_{\text{cb}}}\right) + 3\sigma$$

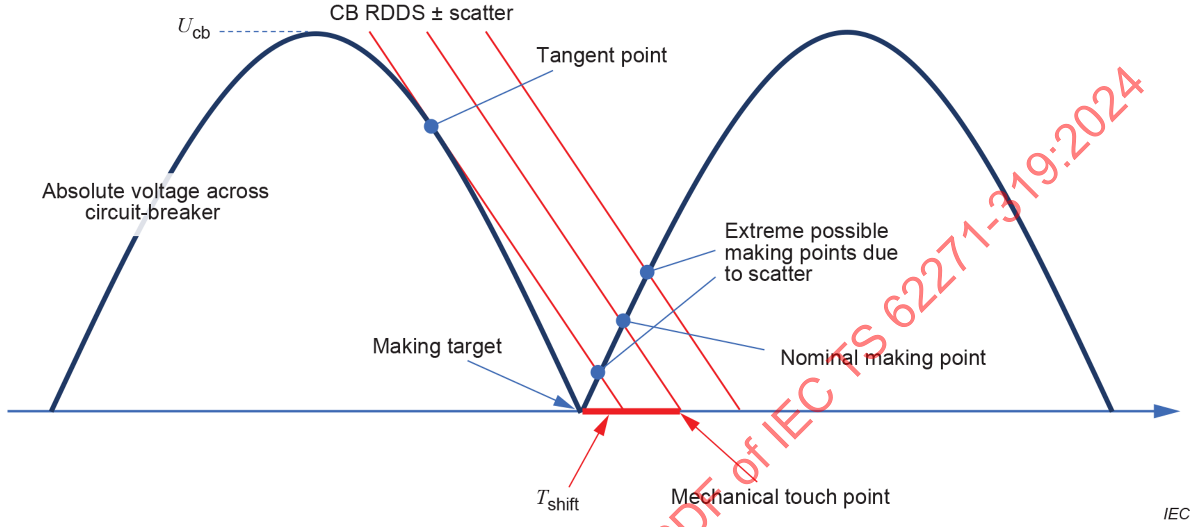

Figure K.3 – "Tangent" method for voltage zero making

Table K.3 and Table K.4 summarizes the expected performance in term of making voltage considering the circuit-breaker RDDS, closing time mechanical scatter and 1 p.u. voltage applied across circuit-breaker arcing contacts using both "balanced" and "tangent" methods described above. The "balance" method results are presented in the tables for RDDS 1 p.u. and above and the "tangent" method results are presented in the tables for RDDS less than 1 p.u.

Table K.3 – Maximum making voltage as a function of RDDS and mechanical scatter at 50 Hz

Scatter ±3σ	RDDS							
	0,5 p.u.	0,6 p.u.	0,7 p.u.	0,8 p.u.	0,9 p.u.	1,0 p.u.	1,1 p.u.	1,2 p.u.
	Maximum making voltage limit							
ms	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
0,5	0,33	0,27	0,22	0,19	0,16	0,16	0,16	0,16
0,6	0,35	0,29	0,25	0,21	0,19	0,19	0,19	0,19
0,7	0,37	0,32	0,27	0,24	0,22	0,22	0,22	0,22
0,8	0,39	0,34	0,30	0,27	0,25	0,25	0,25	0,25
0,9	0,41	0,36	0,32	0,30	0,28	0,28	0,28	0,28
1,0	0,43	0,38	0,35	0,32	0,31	0,31	0,31	0,31
1,1	0,45	0,41	0,37	0,35	0,34	0,34	0,34	0,34
1,2	0,47	0,43	0,40	0,38	0,37	0,37	0,37	0,37
1,3	0,49	0,45	0,42	0,41	0,40	0,40	0,40	0,40
1,4	0,51	0,47	0,45	0,43	0,43	0,43	0,43	0,43
1,5	0,53	0,50	0,47	0,46	0,45	0,45	0,45	0,45

Table K.4 – Maximum making voltage as a function of RDDS and mechanical scatter at 60 Hz

Scatter ±3σ	RDDS							
	0,5 p.u.	**0,6 p.u.**	**0,7 p.u.**	**0,8 p.u.**	**0,9 p.u.**	**1,0 p.u.**	**1,1 p.u.**	**1,2 p.u.**
	Maximum making voltage limit							
ms	**p.u.**	**p.u.**	**p.u.**	**p.u.**	**p.u.**	**p.u.**	**p.u.**	**p.u.**
0,5	0,35	0,29	0,25	0,21	0,19	0,19	0,19	0,19
0,6	0,38	0,32	0,28	0,25	0,23	0,22	0,22	0,22
0,7	0,40	0,35	0,31	0,28	0,26	0,26	0,26	0,26
0,8	0,42	0,38	0,34	0,31	0,30	0,30	0,30	0,30
0,9	0,45	0,40	0,37	0,35	0,33	0,33	0,33	0,33
1,0	0,47	0,43	0,40	0,38	0,37	0,37	0,37	0,37
1,1	0,50	0,46	0,43	0,41	0,40	0,40	0,40	0,40
1,2	0,52	0,48	0,46	0,44	0,44	0,44	0,44	0,44
1,3	0,55	0,51	0,49	0,47	0,47	0,47	0,47	0,47
1,4	0,57	0,54	0,52	0,51	0,50	0,50	0,50	0,50
1,5	0,59	0,56	0,55	0,54	0,54	0,54	0,54	0,54

K.4 Controlled closing at voltage peak

There are two methods: "balanced" and "maximum angle" to define a time shift (T_{shift}) related to voltage peak.

The "balanced" method is generally used when RDDS is greater or equal to 0,7 p.u. The aim is to balance the making voltage on both slopes as illustrated in Figure K.4. T_{shift} can be calculated using the following formula.

$$T_{\text{shift}} = \frac{U_{\text{cb}}}{RDDS} \times \cos(\omega \times 3\sigma)$$

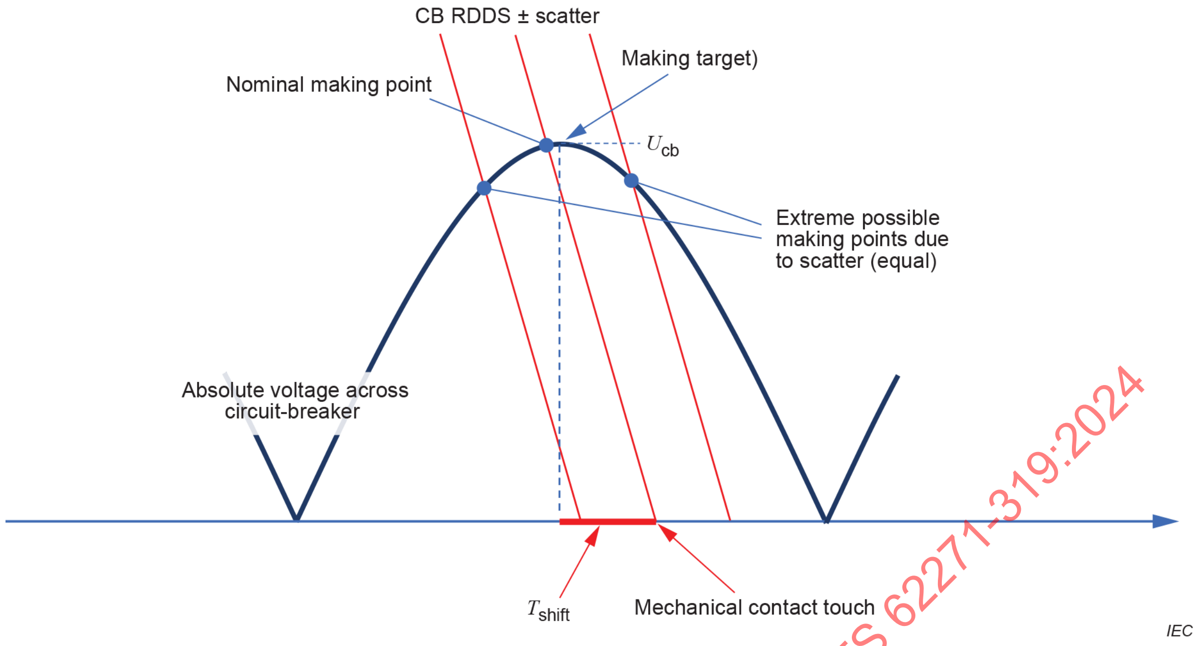

Figure K.4 – Controlled switching at peak voltage, balanced approach

The "maximum angle" method is generally used when RDDS is smaller than 0,7 p.u. The aim is to intercept the RDDS slope and the rising voltage loop as close as possible to the peak (maximum angle 90°) as illustrated in Figure K.5. T_{shift} can be calculated using the following formula.

$$T_{shift} = \frac{U_{cb}}{RDDS} - 3\sigma$$

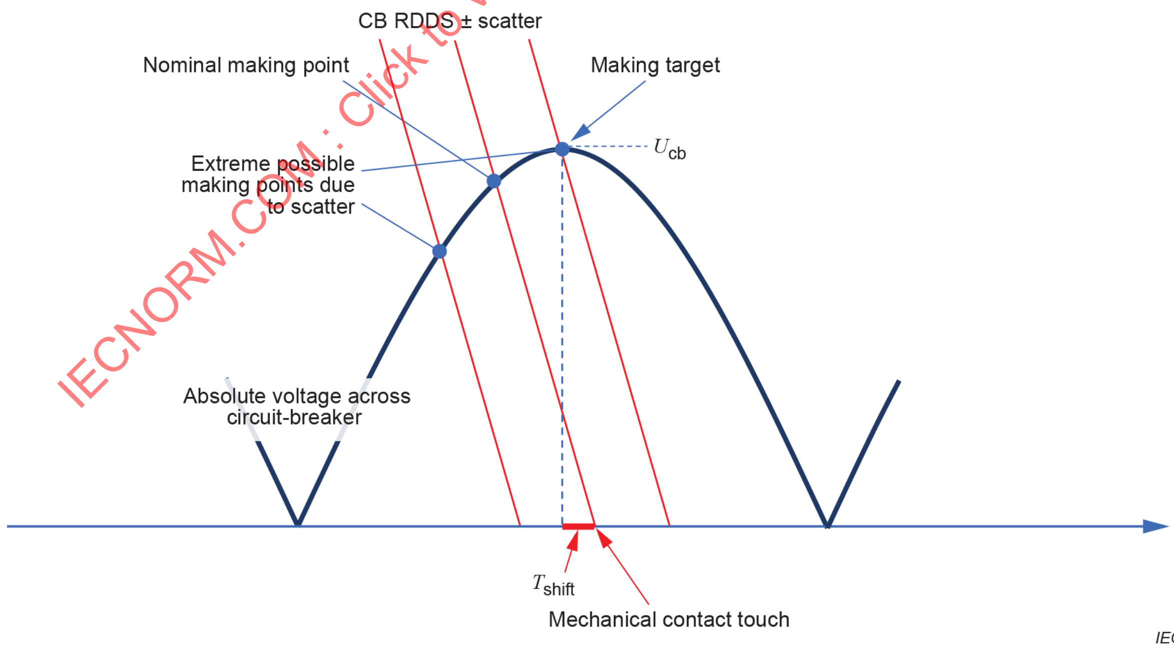

Figure K.5 – Controlled switching at peak voltage, maximum angle method

The minimum achievable angle, based on the circuit-breaker RDDS value and closing time scatter, can be determined from Table K.5 for 50 Hz and Table K.6 for 60 Hz.

Table K.5 – Minimum making angle as a function of RDDS and mechanical scatter when targeting voltage peak at 50 Hz

Scatter ±3σ	RDDS													
	0,5 p.u.		0,6 p.u.		0,7 p.u.		0,8 p.u.		0,9 p.u.		1 p.u.		2 p.u.	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
	Minimum making angle													
ms	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0,0	-	90,0	-	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0
0,5	-	75,6	-	75,2	81,0	74,9	81,0	74,6	81,0	74,4	81,0	74,2	81,0	73,2
1,0	-	64,9	-	63,8	72,0	63,0	72,0	62,2	72,0	61,6	72,0	61,1	72,0	58,3
1,5	-	55,8	-	54,1	63,0	52,7	63,0	51,5	63,0	50,5	63,0	49,6	63,0	44,6

[a] balanced method

[b] maximum angle method

Table K.6 – Minimum making angle as a function of RDDS and mechanical scatter when targeting voltage peak at 60 Hz

Scatter ±3σ	RDDS													
	0,5 p.u.		0,6 p.u.		0,7 p.u.		0,8 p.u.		0,9 p.u.		1 p.u.		2 p.u.	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
	Minimum making angle													
ms	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0,0	-	90,0	-	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0
0,5	-	73,3	-	72,7	79,2	72,3	79,2	71,9	79,2	71,6	79,2	43,2	79,2	36,7
1,0	-	61,1	-	59,8	68,4	58,7	68,4	57,8	68,4	57,0	68,4	56,4	68,4	52,7
1,5	-	50,9	-	48,8	57,6	47,1	57,6	45,6	57,6	44,4	57,6	43,2	57,6	36,7

[a] balanced method

[b] maximum angle method

K.5 Making at variable angles

Making at different angles could be required for certain applications such as transformer making. The upper and lower making voltage limits depend on the system configuration. T_{shift} can be calculated using the following formula.

$$T_{\text{shift}} = \frac{U_{\text{pe}}}{RDDS} \times \sin\left(\alpha \times \frac{\pi}{180}\right)$$

An example of making at angle α is shown in Figure K.6.

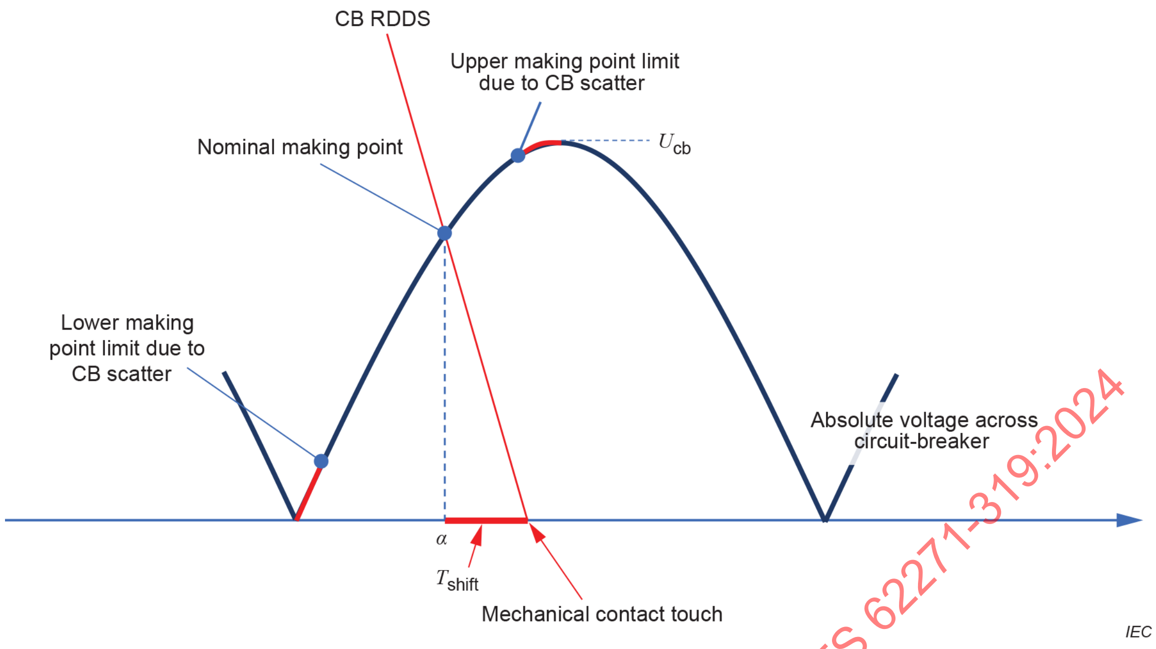

Figure K.6 – Making at variable angles

Figure K.7 shows the minimum RDDS as a function of minimum making angle.

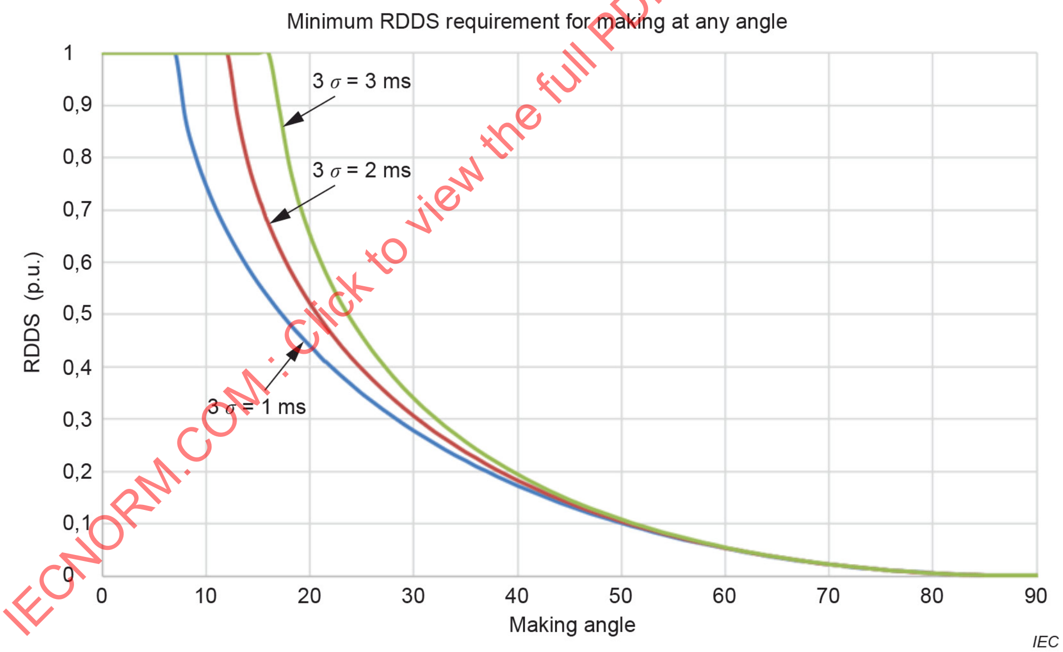

Figure K.7 – Minimum limits RDDS and making angle

RDDS limits are calculated using the tangent method (see Figure K.3).

K.6 Making on a DC trapped charge

When making on a DC trapped charge, the aim is to target a making instant when the voltage across the circuit-breaker arcing contacts is near zero. It occurs when the system voltage and DC trapped charge are equal.

For example, when the DC trapped charge equals 1 p.u., the making instant can be at the peak system voltage of the same polarity as the trapped charge as illustrated in Figure K.8. T_{shift} can be calculated using the following formula.

$$T_{\text{shift}} = \frac{U_{\text{cb}}}{RDDS} \times \left[1 - \cos(\omega \times 3\sigma)\right]$$

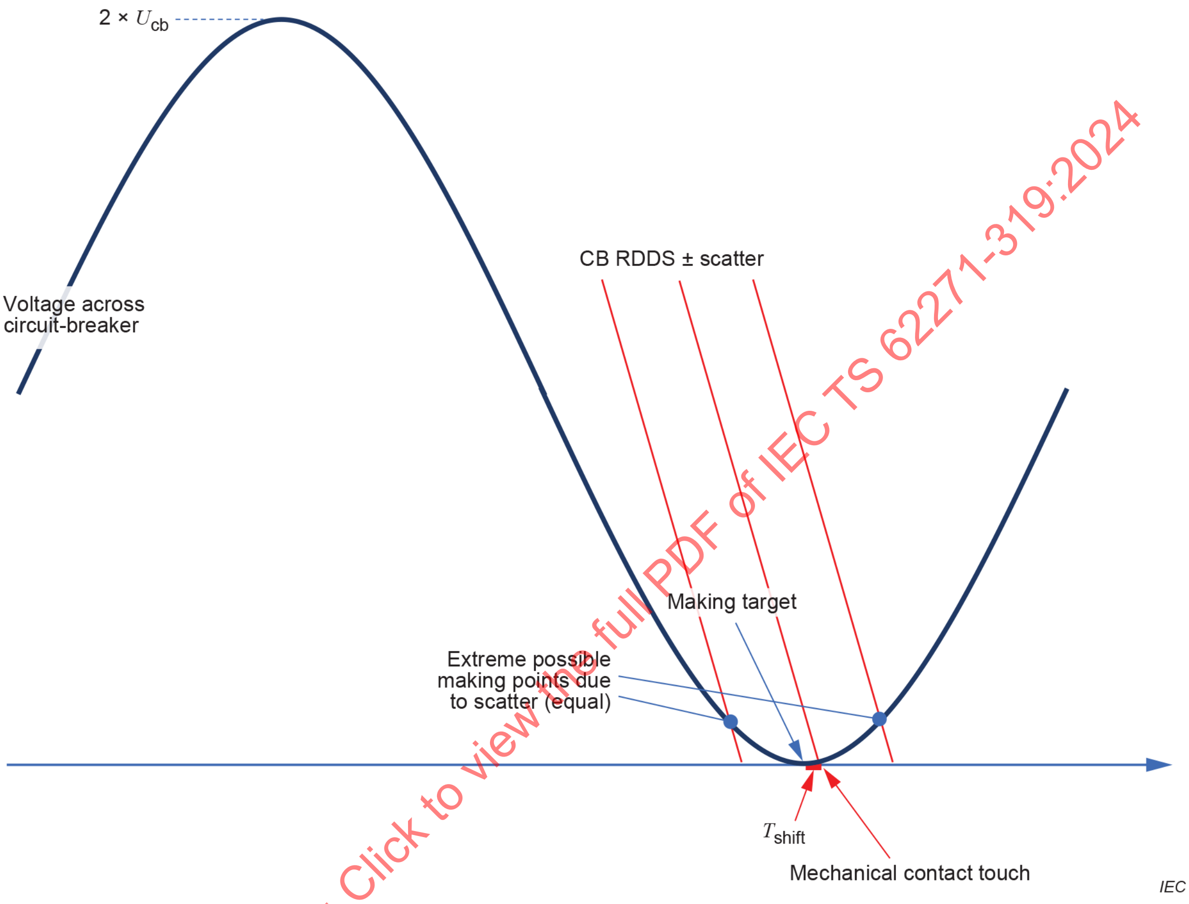

Figure K.8 – Making on a DC trapped charge of 1 p.u.

Expected making voltages are summarized in following tables:

Table K.7 – Making voltage when closing on a DC trapped charge of 1 p.u. at 50 Hz

Scatter ±3σ	RDDS					
	1 p.u.	0,9 p.u.	0,8 p.u.	0,7 p.u.	0,6 p.u.	0,5 p.u.
	Making voltage					
ms	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
0,0	0,00	0,00	0,03	0,00	0,07	0,22
0,5	0,01	0,01	0,03	0,05	0,15	0,31
1,0	0,05	0,05	0,06	0,13	0,25	0,40
1,5	0,11	0,11	0,15	0,23	0,35	0,50
2,0	0,19	0,19	0,25	0,34	0,46	0,60
2,5	0,29	0,31	0,37	0,46	0,57	0,71
3,0	0,41	0,44	0,50	0,58	0,68	0,81

Table K.8 – Making voltage when closing on a DC trapped charge at 60 Hz

Scatter ±3σ	RDDS					
	1 p.u.	0,9 p.u.	0,8 p.u.	0,7 p.u.	0,6 p.u.	0,5 p.u.
	Making voltage					
ms	p.u.	p.u.	p.u.	p.u.	p.u.	p.u.
0,0	0,00	0,00	0,00	0,00	0,07	0,22
0,5	0,02	0,02	0,03	0,07	0,17	0,33
1,0	0,07	0,07	0,09	0,17	0,29	0,44
1,5	0,16	0,16	0,21	0,30	0,41	0,56
2,0	0,27	0,28	0,35	0,43	0,55	0,69
2,5	0,41	0,44	0,50	0,58	0,68	0,81
3,0	0,57	0,60	0,66	0,73	0,82	0,94

NOTE For other DC trapped charges the formula for calculating T_{shift} and making voltage tables can be found in [1].

K.7 Making on an oscillatory trapped charge

An oscillatory trapped charge can occur, for example, after shunt reactor interruption on series compensated lines. When reclosing on the oscillatory trapped charge, the aim is to target a making instant when the voltage across the circuit-breaker arcing contacts is near zero. The oscillation depends on variety of parameters such as:

– line length,
– compensation level,
– X/R ratio,
– dead time for reclosing,
– parallel line voltage coupling.

As an example, Figure K.9 shows the case of 2 possible reclosing targets with a 1 p.u. RDDS circuit-breaker. In this example, the early target is more favourable due to a lower oscillation amplitude.

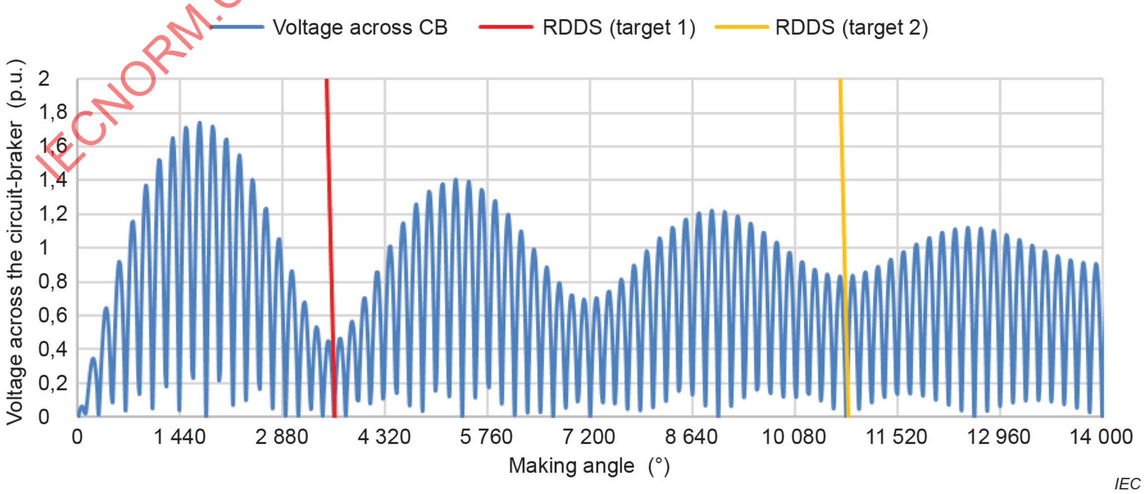

Figure K.9 – Reclosing on an oscillatory trapped charge

K.8 Synthesis

To achieve optimized controlled making, the following closing shift should be added to the making target.

Table K.9 – Controlled closing target

Making target			RDDS	T_{shift}	Method	Ref.
U	°	ms	p.u.	ms		
Zero	0	0	≥1	$\frac{U_{cb}}{RDDS} \times \sin(\omega \times 3\sigma)$	balanced	K.3
			<1	$T_{shift} = \frac{U_{cb}}{RDDS} \times \sqrt{1 - \left(\frac{RDDS}{\omega \times U_{cb}}\right)^2} - \frac{1}{\omega} \times \cos^{-1}\left(-\frac{RDDS}{\omega \times U_{cb}}\right) + 3\sigma$	tangent	K.3
Peak	90	$\frac{1}{4 \times f_r}$	≥0,7	$\frac{U_{cb}}{RDDS} \times \cos(\omega \times 3\sigma)$	balanced	K.4
			<0,7	$\frac{U_{cb}}{RDDS} - 3\sigma$	maximum angle	K.4
Rising slope	α	$\frac{\alpha}{360 \times f_r}$	>RDDSmin	$\frac{U_{cb}}{RDDS} \times \sin\left(\alpha \times \frac{\pi}{180}\right)$	Making at variable angles	K.5
Zero	90	$\frac{1}{4 \times f_r}$		$\frac{U_{cb}}{RDDS} \times [1 - \cos(\omega \times 3\sigma)]$	Making on a DC trapped charge of 1 p.u.	K.6
Zero	variable	depends on system configuration			Making on an oscillatory trapped charge	K.7

Annex L
(informative)

Capacitive switching voltage factor for single-phase testing in a non-effectively earthed neutral system

L.1 General

Annex L explains the rationale behind the capacitive voltage factor specified for single-phase testing in non-effectively earthed neutral systems with and without intended delay in the last-pole-to-clear.

L.2 Simultaneous opening simulation results

The three-phase current interruption occurs on subsequent current zeros after contact separation. The following sequence is considered (Figure L.1):

a) **at 180°:** the current in the first phase is interrupted at current zero (light blue), the voltage across the open contacts appears (blue); voltage of 1 p.u. is trapped on the load side capacitance;

b) **between 180° and 270°:** the neutral voltage (red) increases to −0,5 p.u.; the voltage across the arcing contacts of the first pole-to-clear (dark blue) increases to 1,5 p.u.;

c) **at 270°:** at this point interruption occurs simultaneously in the second and third poles (light yellow and light green); the neutral voltage remains at −0,5 p.u.; the voltage across the arcing contacts of the first pole-to-clear makes a knee point at 1,5 p.u.; the trapped charge voltages on the last poles-to-clear are −0,87 p.u. and +0,87 p.u. respectively;

d) **after 270°:** following the source side voltage of 1,0 p.u the voltage across the arcing contacts increases to 2,5 p.u. for the first pole-to-clear (dark blue) and 1,87 p.u. for the last poles-to-clear (dark yellow and dark green).

In single-phase tests to cover three-phase conditions only the voltage of the first pole-to-clear is considered for testing. To achieve the peak of this voltage of 2,5 p.u. a voltage factor of 1,4 is defined as explained in IEC TR 62271-306:2012, 9.6.

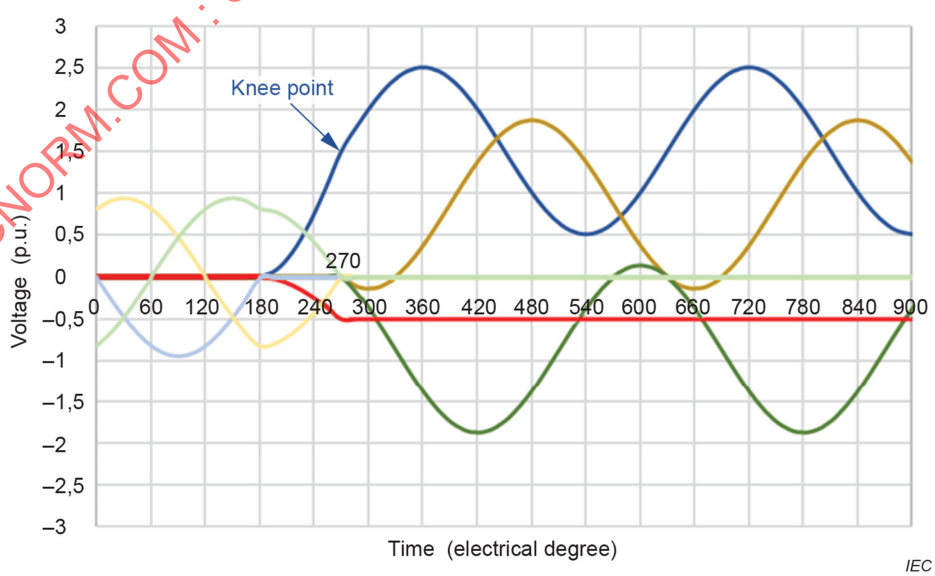

Figure L.1 – Three-phase interruption at subsequent current zeros

L.3 Non-simultaneous opening simulation results

For controlled opening, when the pole discrepancy between the first pole and the last poles is greater than 1/4 of a cycle, current interruption in the last poles can occur later than the subsequent current zeros. Figure L.2 illustrates the case of a delayed current interruption of the last two poles 270° after current interruption of the first pole.

a) **at 180°:** the current in the first phase is interrupted at current zero (light blue), the voltage across the open contacts appears (blue); voltage of 1 p.u. is trapped on the load side capacitance;

b) **between 180° and 360°:** the neutral voltage (red) increases to −1,0 p.u.; the voltage across the arcing contacts of the first pole-to-clear (dark blue) increases to 3,0 p.u;

c) **between 360° and 450°:** the neutral voltage (red) decreases to −0,5 p.u.; the voltage across the arcing contacts of the first pole-to-clear (dark blue) decreases to 1,5 p.u;

d) **at 450°:** at this point interruption occurs simultaneously in the second and third poles (light yellow and light green); the neutral voltage remains at −0,5 p.u.; the voltage across the arcing contacts of the first pole-to-clear makes a knee point at 1,5 p.u.; the trapped charge voltages on the last poles-to-clear are −0,87 p.u. and +0,87 p.u. respectively;

e) **after 450°:** following the source side voltage of 1,0 p.u the voltage across the arcing contacts increases to 2,5 p.u. for the first pole-to-clear (dark blue) and to 1,87 p.u. for the last poles-to-clear (dark yellow and dark green).

In single-phase tests to cover three-phase conditions only the voltage of the first pole-to-clear is considered for testing. To achieve the peak of this voltage of 3,0 p.u. a voltage factor of 1,5 is defined.

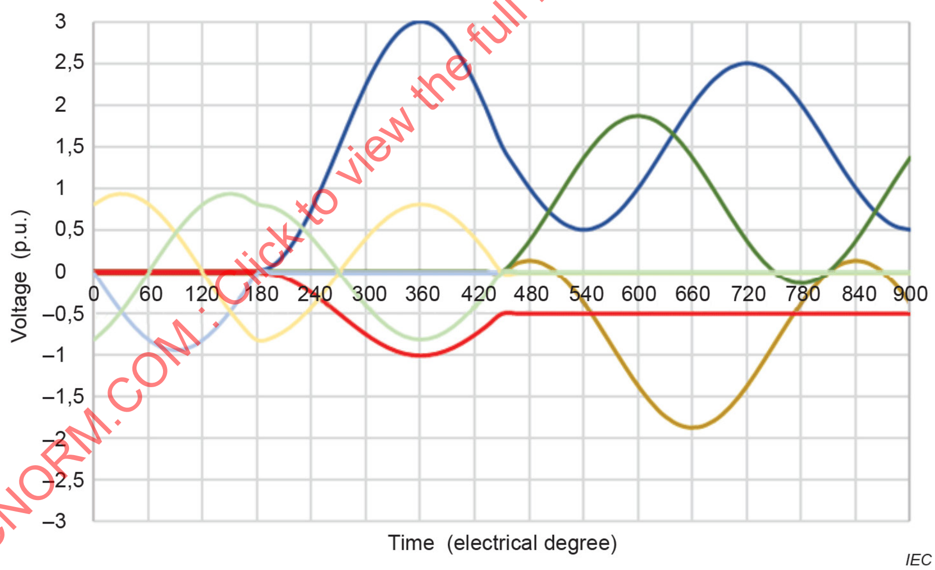

Figure L.2 – Three-phase interruption with last poles delayed

Annex M
(informative)

Requirements for simultaneity of poles that consists of more than one MBU connected in series

M.1 General

As per IEC 62271-100, if one pole consists of more than one MBU connected in series, the maximum difference between the instants of contacts touching within these series connected MBUs shall not exceed 1/6 of a cycle of rated frequency. Also, the maximum difference between the instants of contact separation within these series connected MBUs shall not exceed 1/8 of a cycle of rated frequency.

To ensure intended performance with controlled switching, it is essential that series connected MBUs of the same pole act mechanically simultaneously and with equal dynamic dielectric characteristics. The mechanical non-simultaneity should be considered by setting the targets but should generally be as small as possible for best results.

The closing time of a pole is the time from a close command to contacts touch of the last MBU to close.

The opening time of a pole is the time from a trip command to contacts separation of the first MBU to open.

Manufacturers generally provide a method to access series connected MBUs in an enclosure (e.g. GIS, dead tank CB, etc.) to record the operating characteristics of individual MBUs.

M.2 Simulations to evaluate the impact of non-simultaneity of MBUs of a same pole

The impact of the simultaneity of MBUs of a same pole is estimated based on statistical simulations considering:

- 2 MBUs per pole (MBU "A" and MBU "B") controlled independently;
- MBU "A" closes first at the targeted switching angle;
- MBU "B" closes after MBU "A";
- closing time scatter of individual MBUs of ±0,5 ms, ±1 ms and ±1,5 ms;
- total RDDS of 1 p.u. and 2 p.u.;
- non-simultaneity is defined as the difference between MBU "B" closing time mean value and MBU "A" closing time mean value; it is increased by steps of 1 ms in the range [0 to 5] ms.

The simulation results are compared with a single-break circuit-breaker as a reference having RDDS 1 p.u. and closing time scatter ±1 ms. The cases and simulations are presented in Table M.1 and Table M.2, Figure M.1, Figure M.2, Figure M.3, Figure M.4 and Figure M.5.

Table M.1 – Case studies based on statistical simulations

Case	Number of MBUs	Non-simultaneity range	Total RDDS	Scatter ±3σ	Voltage target	Angle target	fr
		ms	p.u.	ms		°	Hz
1	1	NA	1	1,0	Zero	0	50
2	1	NA	1	1,0	Zero	0	60
3	1	NA	1	1,0	Peak	90	50
4	1	NA	1	1,0	Peak	90	60
5	2	[0, 5]	1	1,0	Zero	0	50
6	2	[0, 5]	1	1,0	Zero	0	60
7	2	[0, 5]	1	1,0	Peak	90	50
8	2	[0, 5]	1	1,0	Peak	90	60
9	2	[0, 5]	2	1,0	Zero	0	50
10	2	[0, 5]	2	1,0	Zero	0	60
11	2	[0, 5]	2	1,0	Peak	90	50
12	2	[0, 5]	2	1,0	Peak	90	60
13	2	[0, 5]	1	0,5	Zero	0	50
14	2	[0, 5]	1	0,5	Zero	0	60
15	2	[0, 5]	1	0,5	Peak	90	50
16	2	[0, 5]	1	0,5	Peak	90	60
17	2	[0, 5]	1	1,5	Zero	0	50
18	2	[0, 5]	1	1,5	Zero	0	60
19	2	[0, 5]	1	1,5	Peak	90	50
20	2	[0, 5]	1	1,5	Peak	90	60

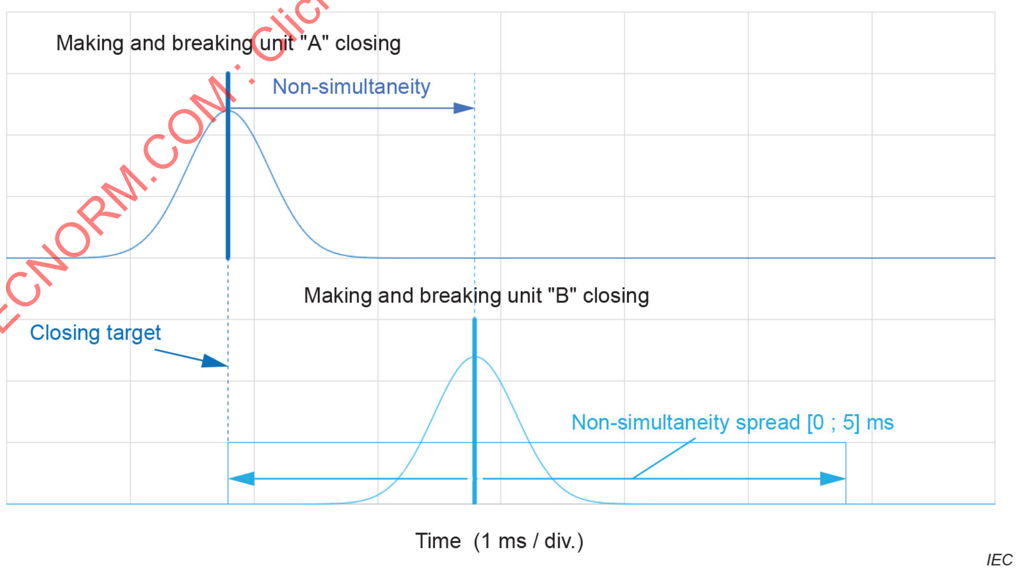

Figure M.1 – Closing time distribution and non-simultaneity between MBUs of one pole

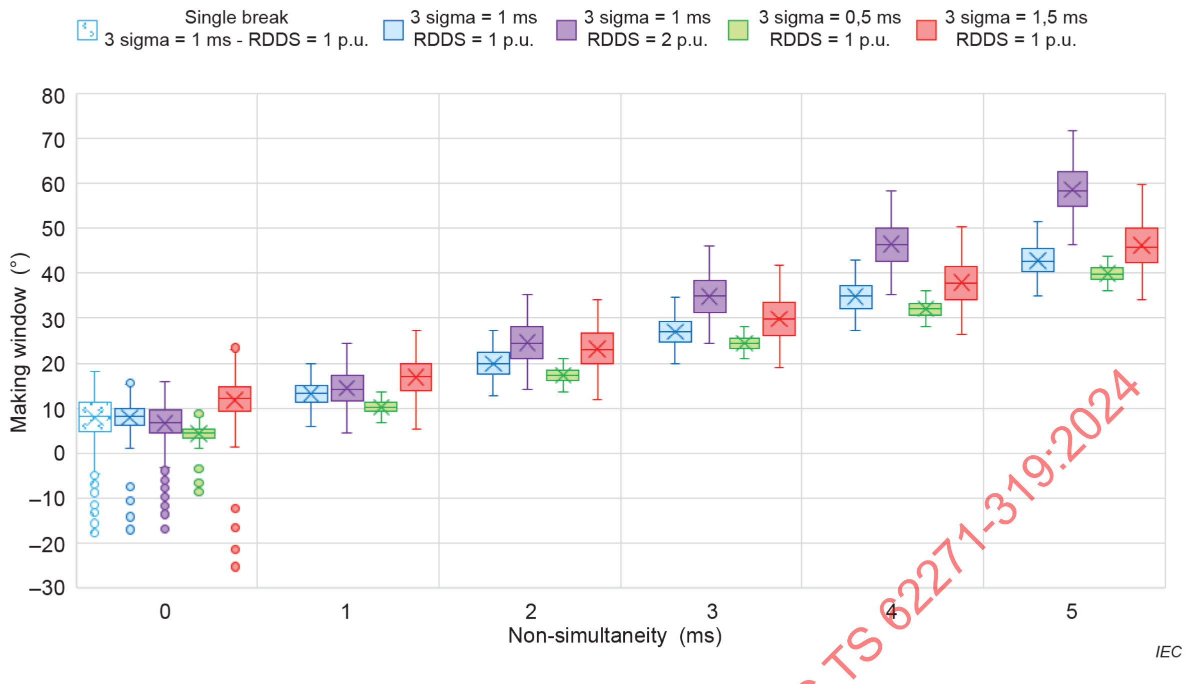

Figure M.2 – Simulation results when closing at voltage zero at 50 Hz

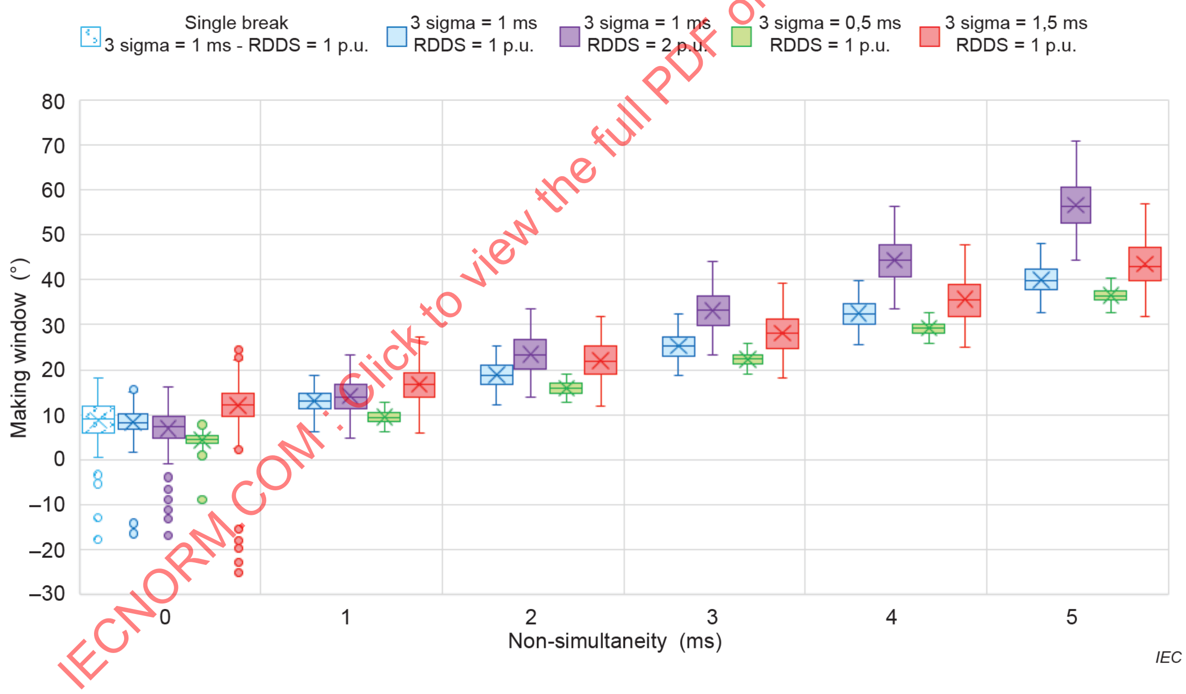

Figure M.3 – Simulation results when closing at voltage zero at 60 Hz

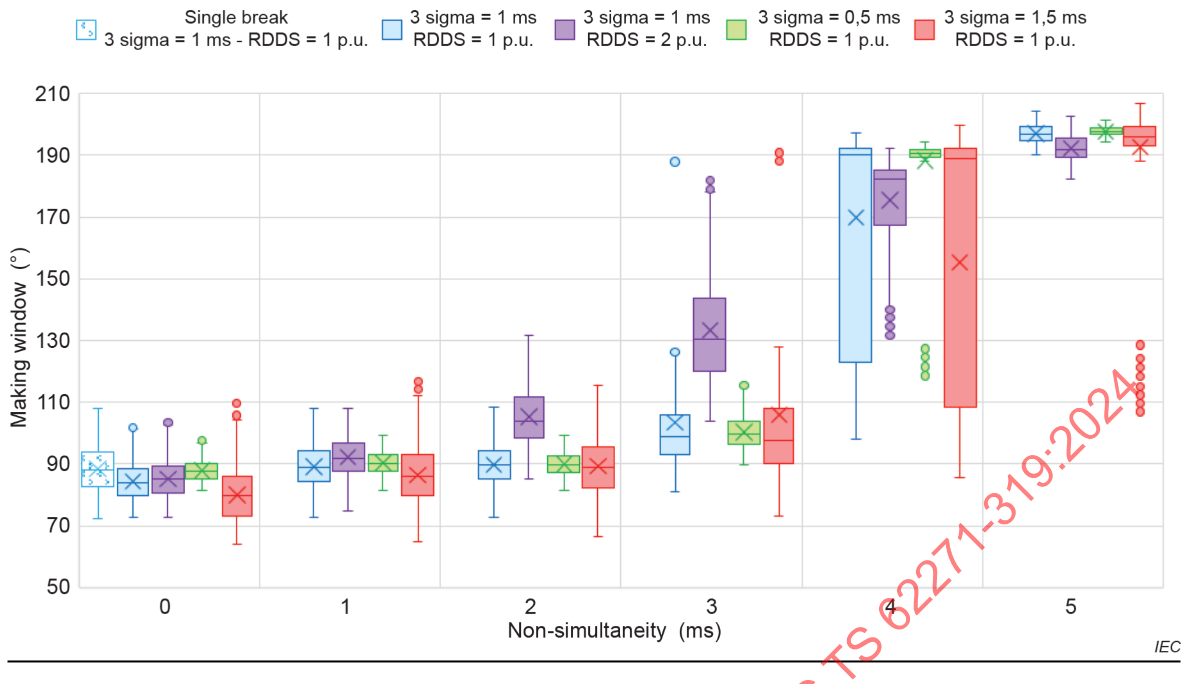

Figure M.4 – Simulation results when closing at voltage peak at 50 Hz

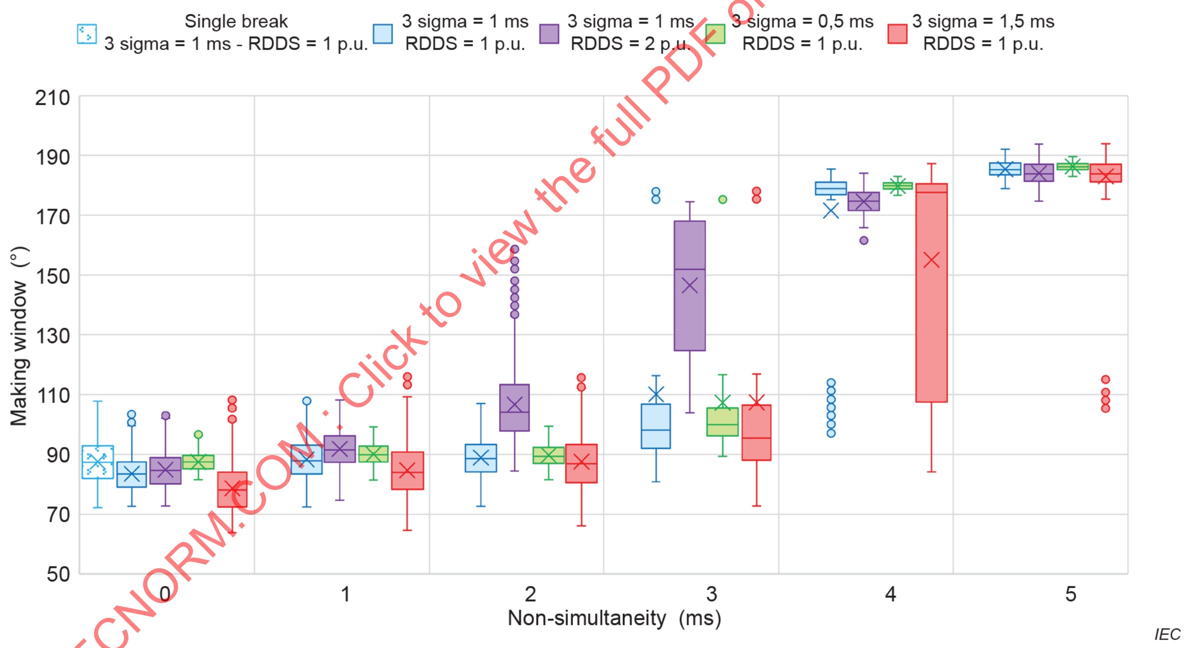

Figure M.5 – Simulation results when closing at voltage peak at 60 Hz