IEC 62271-110

Edition 4.0 2017-10
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

High-voltage switchgear and controlgear –
Part 110: Inductive load switching

IEC 62271-110:2017-10 RLV(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.130.10

ISBN 978-2-8322-4923-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 110: Inductive load switching

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 62271-110 has been prepared by subcommittee 17A: Switching devices, of IEC technical committee 17: High-voltage switchgear and controlgear.

This fourth edition cancels and replaces the third edition published in 2012 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– all switching devices are now covered, not only circuit-breakers;
– a limited number of T10 tests no longer covers shunt-reactor switching tests below 52 kV;
– evaluation and reporting of a re-ignition-free arcing time window has been added.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
17A/1151/FDIS	17A/1155/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62271 series can be found, under the general title *High-voltage switchgear and controlgear*, 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 "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The contents of the corrigenda of December 2017 and February 2018 have been included in this copy.

IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 110: Inductive load switching

~~1 General~~

1 Scope

This part of IEC 62271 is applicable to AC ~~circuit-breakers~~ switching devices designed for indoor or outdoor installation, for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V and applied for inductive current switching ~~with or without additional short-circuit current breaking duties~~. It is applicable to switching devices (including circuit-breakers in accordance with IEC 62271-100) that are used to switch high-voltage motor currents and shunt reactor currents and also to high-voltage contactors used to switch high-voltage motor currents as covered by IEC 62271-106. ~~For circuit-breakers applied to switch shunt reactor currents at rated voltages according to IEC 62271-1:2007 Tables 2a and 2b, combined voltage tests across the isolating distance are not required (refer to 4.2).~~

Switching unloaded transformers, i.e. breaking transformer magnetizing current, is not considered in this document. The reasons for this are as follows:

a) Owing to the non-linearity of the transformer core, it is not possible to correctly model the switching of transformer magnetizing current using linear components in a test laboratory. Tests conducted using an available transformer, such as a test transformer, will only be valid for the transformer tested and cannot be representative for other transformers.

b) As detailed in IEC TR 62271-306~~[1]~~, the characteristics of this duty are usually less severe than any other inductive current switching duty. ~~It should be noted that~~ Such a duty may produce severe overvoltages within the transformer winding(s) depending on the ~~circuit-breaker~~ re-ignition behaviour of the switching device and transformer winding resonance frequencies.

~~Short-line faults, out-of-phase current making and breaking and capacitive current switching are not applicable to circuit-breakers applied to switch shunt reactors or motors. These duties are therefore not included in this standard.~~

~~Subclause 1.1 of IEC 62271-100:2008 is otherwise applicable.~~

NOTE 1 The switching of tertiary reactors from the high-voltage side of the transformer is not covered by this document.

NOTE 2 The switching of shunt reactors earthed through neutral reactors is not covered by this document. However, the application of test results according to this document, on the switching of neutral reactor earthed reactors (4-leg reactor scheme), is discussed in IEC TR 62271-306.

2 Normative references

~~Subclause 1.2 of IEC 62271-100:2008 is applicable with the following addition:~~

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.

~~[1] To be published.~~

IEC 60050-441, *International Electrotechnical Vocabulary – Chapter 441: Switchgear, controlgear and fuses* (available at www.electropedia.org)

IEC 62271-1:2017, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

IEC 62271-100:2008, *High-voltage switchgear and controlgear – Part 100: Alternating current circuit-breakers*
IEC 62271-100:2008/AMD1:2012

IEC 62271-106:2011, *High-voltage switchgear and controlgear – Part 106: Alternating current contactors, contactor-based controllers and motor-starters*

~~2 Normal and special service conditions~~

~~Clause 2 of IEC 62271-1:2007 is applicable.~~

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-441, IEC 62271-1 and the following ~~specific to inductive load switching~~ apply.

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

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

3.1
inductive current
power-frequency current ~~through a circuit-breaker~~ drawn by an inductive circuit having a power factor 0,5 or less

~~**3.102**~~
~~**small inductive current**~~
~~inductive current having a steady state value considerably less than the rated short-circuit breaking current~~

3.2
current chopping
abrupt current interruption in ~~the circuit-breaker~~ a switching device at a point-on-wave other than the natural power-frequency current zero ~~of the circuit connected to the circuit-breaker~~

3.3
virtual current chopping
current chopping in one of the three phases in a three-phase circuit originated by transients in ~~(parts of) the circuit~~ another phase of the circuit

~~**3.105**~~
~~**chopping current**~~
~~current interruption prior to the natural power-frequency current zero of the circuit connected to the switching device~~

~~3.106~~
~~**chopping level**~~
~~maximum recorded value of the chopping current due to true current chopping in a specific circuit under rated voltage and normal operating conditions~~

~~3.107~~
~~**load side oscillation**~~
~~oscillation of the interrupted load side network after current chopping or natural current zero~~

3.4
suppression peak
first peak of the transient voltage to earth on the load side of the ~~circuit-breaker~~ switching device following current interruption

Note 1 to entry: Suppression peak is not necessarily the absolute maximum of the transient recovery voltage. Previous breakdowns may have appeared at higher voltage values.

3.5
recovery peak
maximum value of the voltage across the ~~circuit-breaker~~ switching device occurring ~~after definite polarity change of~~ when the polarity of the recovery voltage is equal to the polarity of the power-frequency voltage

Note 1 to entry: ~~Suppression peak and~~ Recovery peak ~~are~~ is not necessarily the absolute ~~maxima in~~ maximum of the transient recovery voltage. Previous breakdowns may have appeared at higher voltage values.

~~3.110~~
~~**voltage escalation**~~
~~increase in the amplitude of the prospective recovery voltage of the load circuit, produced by the accumulation of energy due to repeated re-ignitions~~

3.6
re-ignition
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of less than a quarter cycle of power frequency

Note 1 to entry: In the case of inductive load switching the initiation of the re-ignition is a high-frequency event, which can be of a single or multiple nature and may in some cases be interrupted without power frequency follow current.

~~[SOURCE: IEC 60050-441:1998, 441-17-45]~~

3.7
re-ignition-free arcing time window
period of arc duration during a breaking operation during which the contacts of a mechanical switching device reach sufficient distance to exclude re-ignition

~~4 Ratings~~

~~Clause 4 of IEC 62271-100:2008 is applicable except for the references to short-line faults, out-of-phase making and breaking, capacitive current switching and as noted in specific subclauses below. Circuit-breakers do not normally have inductive load switching ratings. However, circuit-breakers applied for this purpose should meet the requirement of this standard part.~~

~~4.2 Rated insulation level~~

~~Subclause 4.2 of IEC 62271-1:2007 is applicable with the following addition:~~

The rated values stated in Tables 1a and 1b and Tables 2a and 2b of IEC 62271-1:2007 are applicable with the exception of columns (6) and (8) in Table 2a and column (7) in Table 2b.

5 Design and construction

Clause 5 of IEC 62271-100:2008 is applicable.

4 Type tests

4.1 General

Subclause 6.1 of IEC 62271-100:2008 is applicable with the following addition:

Circuit-breakers according to IEC 62271-100 and contactors according to IEC 62271-106 do not have dedicated inductive switching ratings. However, switching devices applied for this purpose shall meet the requirements of this document.

For shunt reactor switching test of circuit-breakers, the rated insulation level values stated in Tables 1a, 1b, 3 and 4 of IEC 62271-1:2017 are applicable with the exception of combined voltage tests across the isolating distance (columns (6) and (8) in Table 3 and column (7) in Table 4).

The type tests are in addition to those specified in the relevant product standard, with the exception of short-line faults, out-of-phase switching and capacitive current switching.

NOTE 1 The reason for this exception is the source-less nature of the shunt reactor load circuit.

NOTE 2 In some cases (high chopping overvoltage levels, or where a neutral reactor is present or in cases of shunt reactors with isolated neutral), it can be necessary to specify an appropriate insulation level which is higher than the rated values stated above.

Inductive current switching tests performed for a given current rating level and type of application may be considered valid for another current rating and same type of application as detailed below:

a) for high-voltage shunt reactor switching at rated voltages of 52 kV and above, tests at a particular current rating level are to be considered valid for applications with a higher current level up to 150 % of the tested current value;

b) for shunt reactor switching at rated voltages below 52 kV, type testing is required but short circuit test duties T30 and T10 will cover the requirements provided that the TRV values of T30 and T10 are equal to or higher than the reactor switching TRV values;

c) for high-voltage motor switching, type testing for stalled motor currents at 100 A and 300 A is considered to cover stalled motor currents in the range 100 A to 300 A and up to the current associated with the short-circuit current of test duty T10 according to 6.106.1 of IEC 62271-100:2008 for circuit-breakers and up to the rated operational current for contactors.

With respect to a) the purpose of type testing is also to determine a re-ignition-free zones arcing time window for controlled switching purposes (refer to IEC TR 62271-302) and caution should be exercised when considering applications at higher currents than the tested values since the re-ignition-free arcing window can increase at higher current.

Annex B of IEC 62271-100:2008 is applicable can be used with respect to tolerances on test quantities.

6.2 Dielectric tests

Subclause 6.2 of IEC 62271-100:2008 is applicable with the following addition:

~~Refer to 4.2.~~

~~6.3 Radio interference voltage (r.i.v.) test~~

~~Subclause 6.3 of IEC 62271-1:2007 is applicable.~~

~~6.4 Measurement of the resistance of circuits~~

~~Subclause 6.4 of IEC 62271-1:2007 is applicable.~~

~~6.5 Temperature-rise tests~~

~~Subclause 6.5 of IEC 62271-1:2007 is applicable.~~

~~6.6 Short-time withstand current and peak withstand current tests~~

~~Subclause 6.6 of IEC 62271-1:2007 is applicable.~~

~~6.7 Verification of protection~~

~~Subclause 6.7 of IEC 62271-1:2007 is applicable.~~

~~6.8 Tightness tests~~

~~Subclause 6.8 of IEC 62271-1:2007 is applicable.~~

~~6.9 Electromagnetic compatibility tests (EMC)~~

~~Subclause 6.9 of IEC 62271-1:2007 is applicable.~~

~~6.101 Mechanical and environmental tests~~

~~Subclause 6.101 of IEC 62271-100:2008 is applicable.~~

4.2 Miscellaneous provisions for ~~making and breaking~~ inductive load switching tests

Subclause 6.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012 is applicable with the following addition:

High-voltage motor current and shunt reactor switching tests shall be performed at rated auxiliary and control voltage or, where necessary, at maximum auxiliary and control voltage to facilitate consistent control of the opening and closing operation according to 6.102.3.1 of IEC 62271-100:2008 ~~and at rated functional pressure for interruption and insulation~~.

~~For gas circuit-breakers, a shunt reactor switching test shall also be performed at the minimum functional pressure for interruption and insulation. This requirement applies for test duty 4 only (see 6.114.9).~~

For gas filled switching devices (including vacuum switching devices using gaseous media for insulation), tests shall be performed at the rated functional pressure for interruption and insulation, except for test-duty 4, where the pressure shall be the minimum functional pressure for interruption and insulation.

~~6.103 Test circuits for short-circuit making and breaking tests~~

~~Subclause 6.103 of IEC 62271-100:2008 is applicable.~~

~~6.104 Short-circuit test quantities~~

~~Subclause 6.104 of IEC 62271-100:2008 is applicable.~~

~~6.105 Short-circuit test procedure~~

~~Subclause 6.105 of IEC 62271-100:2008 is applicable.~~

~~6.106 Basic short-circuit test-duties~~

~~Subclause 6.106 of IEC 62271-100:2008 is applicable.~~

~~6.107 Critical current tests~~

~~Subclause 6.107 of IEC 62271-100:2008 is applicable.~~

~~6.108 Single-phase and double-earth fault tests~~

~~Subclause 6.108 of IEC 62271-100:2008 is applicable.~~

~~Subclauses 6.109 to 6.112 of IEC 62271-100:2008 are not applicable to this part of IEC 62271 series.~~

4.3 High-voltage motor current switching tests

4.3.1 Applicability

Subclause 4.3 is applicable to three-phase alternating current ~~circuit-breakers~~ switching devices having rated voltages above 1 kV and up to 17,5 kV, which are used for switching high-voltage motors. Tests may be carried out at 50 Hz with a relative tolerance of ±10 % or 60 Hz with a relative tolerance of ±10 %, both frequencies being considered equivalent.

Motor switching tests are applicable to all three-pole ~~circuit-breakers~~ switching devices having rated voltages equal to or less than 17,5 kV, which may be used for the switching of three-phase asynchronous squirrel-cage or slip-ring motors. The ~~circuit-breaker~~ switching device may be of a higher rated voltage than the motor when connected to the motor through a stepdown transformer. However, the ~~more~~ usual application is a direct cable connection between ~~circuit-breaker~~ switching device and motor. When tests are required, they shall be made in accordance with 4.3.2 to 4.3.9.

When overvoltage limitation devices are mandatory for the tested equipment, the voltage limiting devices may be included in the test circuit provided that the devices are an intrinsic part of the equipment under test.

No limits to the overvoltages are given as the overvoltages are only relevant to the specific application. Overvoltages between phases may be as significant as phase-to-earth overvoltages.

4.3.2 General

The switching tests can be either field tests or laboratory tests. As regards overvoltages, the switching of the current of a starting or stalled motor is usually the more severe operation.

Due to the non-linear behaviour of the motor iron core, it is not possible to exactly model the switching of motor current using linear components in a test station. Tests using linear components to simulate the motors can be considered to be more conservative than switching actual motors.

For laboratory tests a standardized circuit simulating the stalled condition of a motor is specified (refer to Figure 1). The parameters of this test circuit have been chosen to represent a relatively severe case with respect to overvoltages and will cover the majority of service applications.

The laboratory tests are performed to prove the ability of a ~~circuit-breaker~~ switching device to switch motors and to establish its behaviour with respect to switching overvoltages, re-ignitions and current chopping. These characteristics may serve as a basis for estimates of the ~~circuit-breaker~~ switching device's performance in other motor circuits. Tests performed with the test currents defined in 4.3.3 and 4.3.4 demonstrate the capability of the switching device to switch high-voltage motors up to its rated interrupting current.

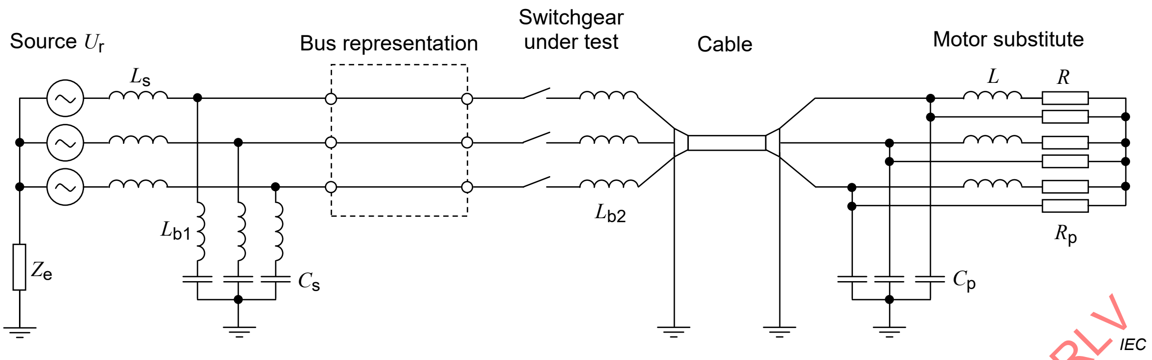
For field tests, actual circuits are used with a supply system on the source side and a cable and motor on the load side. There may be a transformer between the ~~circuit-breaker~~ switching device and motor. However, the results of such field tests are only valid for ~~circuit-breakers~~ switching devices working in circuits similar to those during the tests.

The apparatus under test includes the ~~circuit-breaker~~ switching device with overvoltage protection devices if they are normally fitted.

NOTE 1 Overvoltages can be produced when switching running motors. This condition is not represented by the substitute circuit and is generally considered to be less severe than the stalled motor case.

NOTE 2 The starting period switching of a slip-ring motor is generally less severe due to the effect of the starting resistor.

~~NOTE 3 The rated voltage of the circuit-breaker can exceed that of the motor.~~



Key

U_r	rated voltage	
Z_e	earthing impedance	impedance high enough to limit the phase-to-earth fault current to less than the test current (can be infinite)
L_s	source side inductance	$\omega L_s \leq 0,1\ \omega L$, but prospective short-circuit current ≤ the rated short-circuit current of the tested ~~circuit-breaker~~ switching device
C_s	supply side capacitance	0,03 µF to 0,05 µF for supply circuit A
		1,5 µF to 2 µF for supply circuit B
L_{b1}	inductance of capacitors and connections	≤ 2 µH
Bus representation		5 m to 7 m in length spaced appropriate to the rated voltage
L_{b2}	inductance of connections	≤ 5 µH
Cable		100 m ± 10 m, screened,
		~~Z_0 =~~ surge impedance 30 Ω to 50 Ω
L	motor substitute inductance	load circuit 1: 100 A ± 10 A
		load circuit 2: 300 A ± 30 A
R	motor substitute resistance	cos $\varphi \leq 0,2$
C_p	motor substitute parallel capacitance	frequency 10 kHz to 15 kHz
R_p	motor substitute parallel resistance	amplitude factor 1,6 to 1,8

Figure 1 – Motor switching test circuit and summary of parameters

4.3.3 Characteristics of the supply circuits

4.3.3.1 General

A three-phase supply circuit shall be used. The tests shall be performed using two different supply circuits A and B as specified in 4.3.3.2 and 4.3.3.3, respectively. Supply circuit A represents the case of a motor connected directly to a transformer. Supply circuit B represents the case where parallel cables are applied on the supply side.

4.3.3.2 Supply circuit A

The three-phase supply may be earthed through a high ohmic impedance so that the supply voltage is defined with respect to earth. The impedance value shall be high enough to limit a prospective line-to-earth fault current to a value below the test current.

The source inductance L_s shall not be lower than that corresponding to the rated short-circuit breaking current of the tested ~~circuit-breaker~~ switching device. Its impedance shall also be not higher than 0,1 times the impedance of the inductance in the load circuit (see 4.3.4).

The supply side capacitance C_s is represented by three capacitors connected in earthed star. Their value, including the natural capacitance of the circuit shall be 0,04 μF ± 0,01 μF. The inductance L_{b1} of the capacitors and connections shall not exceed 2 μH.

The busbar inductance is represented by three bars forming a busbar each 6 m ± 1 m in length and spaced at a distance appropriate to the rated voltage.

4.3.3.3 Supply circuit B

As supply circuit A with the value of the supply side capacitance increased to 1,75 μF ± 0,25 μF.

4.3.4 Characteristics of the load circuit

4.3.4.1 General

A three-phase load circuit shall be used. The motor substitute circuit is connected to the ~~circuit-breaker~~ switching device under test by 100 m ± 10 m of screened cable. It is recommended that the cable be connected directly to the terminals of the motor or substitute circuit.

The inductance of any intermediate connection should not exceed 3 μH. The shield of the cable shall be earthed at both ends as shown in Figure 1. The tests shall be performed using two different motor substitute circuits as specified in 4.3.4.2 and 4.3.4.3. The inductance L_{b2} of the connections between the ~~circuit-breaker~~ switching device and cable shall not exceed 5 μH.

NOTE The use of a three-phase test circuit is necessary in order to allow the possibility of virtual current chopping.

4.3.4.2 Motor substitute circuit 1

Series-connected resistance and inductance shall be arranged to obtain a current of 100 A ± 10 A at a power factor less than 0,2 lagging. The star point shall not be connected to earth. Resistance R_p shall be connected in parallel with each phase impedance and capacitance C_p between each phase and earth so that the motor substitute circuit has a natural frequency of 12,5 kHz ± 2,5 kHz and an amplitude factor of 1,7 ± 0,1 measured in each phase with the other two phases connected to earth. The prospective transient recovery voltages values shall be determined in accordance with Annex F of IEC 62271-100:2008. A transformer may be introduced at the load end of the cable. This shall be considered as part of the motor substitute circuit.

4.3.4.3 Motor substitute circuit 2

As motor substitute circuit 1, but with the series resistance and inductance reduced to obtain a current of 300 A ± 30 A at a power factor less than 0,2 lagging. The prospective transient recovery voltage shall be as specified for motor substitute circuit 1.

4.3.5 Test voltage

a) The average value of the applied voltages shall be not less than the rated voltage U_r divided by √3 and shall not exceed this value by more than 10 % without the consent of the manufacturer.

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

The rated voltage U_r is that of the circuit-breaker switching device when using the substitute circuit, but is that of the motor when an actual motor is used.

b) The power-frequency recovery voltage of the test circuit may be stated as a percentage of the power-frequency recovery voltage specified below. It shall not be less than 95 % of the specified value and shall be maintained in accordance with 6.104.7 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

The average value of the power-frequency recovery voltages shall not be less than the rated voltage U_r of the circuit-breaker switching device divided by √3.

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

The power-frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its r.m.s. value shall be determined on the oscillogram within the time interval of one half cycle and one cycle of test frequency after final arc extinction, as indicated in Figure 44 of IEC 62271-100:2008. The vertical distance (V_1, V_2 and V_3 respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by 2√2 and multiplied by the appropriate calibration factor, gives the r.m.s. value of the recorded power-frequency recovery voltage.

4.3.6 Test-duties

The motor current switching tests shall consist of four test-duties as specified in Table 1.

Table 1 – Test-duties at motor current switching tests

Test-duty	Supply circuit	Motor substitute circuit
1	A	1
2	A	2
3	B	1
4	B	2

The number of tests for each test-duty shall be 20 tests with the initiation of the closing and tripping impulses distributed at intervals of approximately 9 electrical degrees.

The above tests shall be make–breaks tests or separate makes and breaks making and breaking tests except that when using an actual motor they shall only be make–breaks tests. When tests are made using the motor substitute circuit, the contacts of the circuit-breaker switching device shall not be separated until any DC component has become less than 20 %. When switching an actual motor, a make-break time of 200 ms is recommended.

4.3.7 Test measurements

At least the following quantities shall be recorded by oscillograph or other suitable recording techniques with bandwidth and time resolution high enough to measure the following:

– power-frequency voltage;

– power-frequency current;

– phase-to-earth voltage, at the motor or motor substitute circuit terminals, in all three phases.

4.3.8 Behaviour and condition of circuit-breaker switching device

The criteria for successful testing of a circuit-breaker are as follows:

a) the behaviour of the circuit-breaker during the motor switching tests fulfils the conditions given in 6.102.8 of IEC 62271-100:2008 as applicable;

b) voltage tests shall be performed in accordance with 6.2.11 of IEC 62271-100:2008 +IEC 62271-100:2008/AMD1:2012;

c) all re-ignitions shall take place between the arcing contacts.

The criteria for successful testing of contactors are listed in 6.102.9 of IEC 62271-106:2011.

4.3.9 Test report

In addition to the requirements of Annex C of IEC 62271-100:2008, the test report shall include a thorough description of the circuit, including the following details:

a) main dimensions and characteristics of the bus and connections to the ~~circuit-breaker~~ switching device;

b) the characteristics of the cable:
   1) length;
   2) rated values;
   3) type;
   4) main insulation dielectric – cross-linked polyethylene (XLPE), paper/oil, etc.;
   5) earthing;
   6) capacitances;
   7) surge impedance.

c) the parameters of the substitute motor circuit:
   1) natural frequency;
   2) amplitude factor;
   3) current;
   4) power factor.

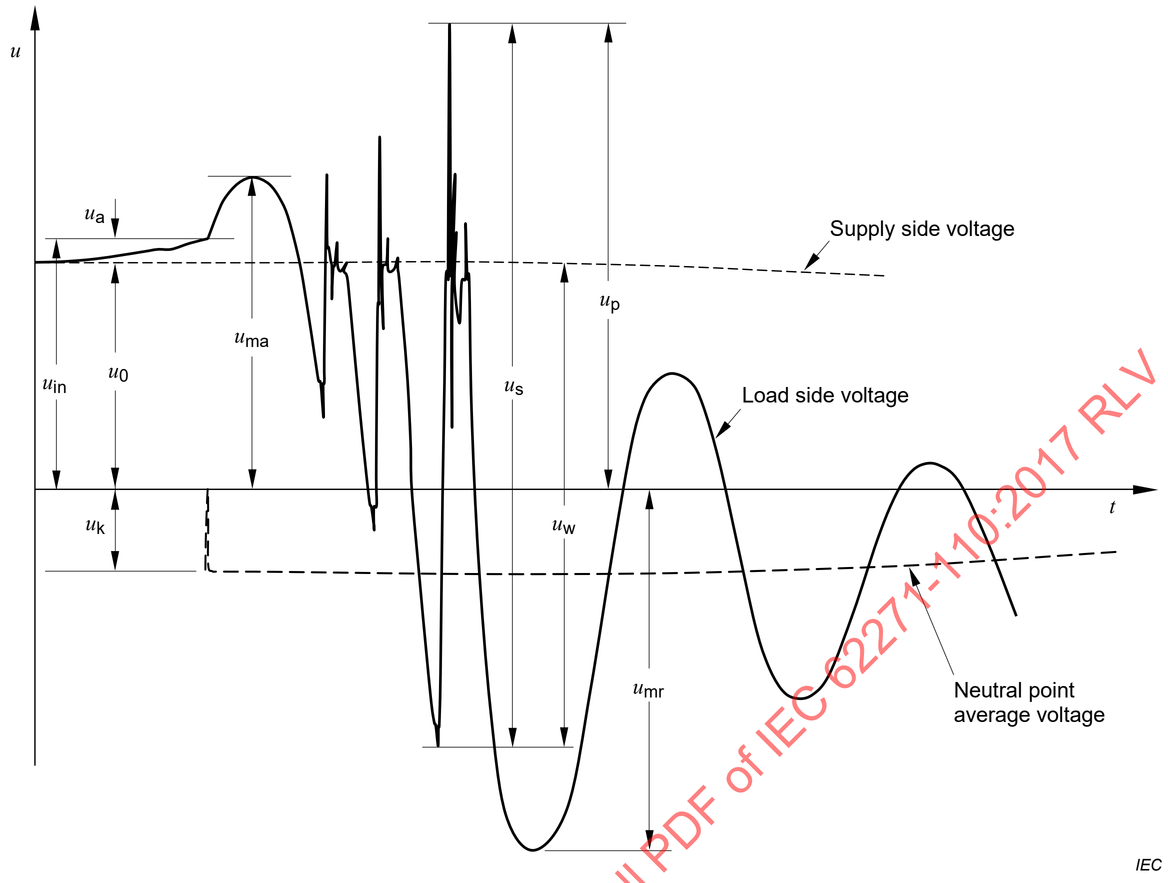
d) or details of the actual motor:
   1) type and rating;
   2) rated voltage;
   3) winding connection;
   4) rated motor current;
   5) starting current and power factor.

e) overvoltage characteristics.

The following characteristics of the voltages at the motor or motor substitute circuit terminals at each test (Figure 2) shall be evaluated:

– u_p: maximum overvoltage;
– u_{ma}: suppression peak overvoltage;
– u_{mr}: load side voltage peak to earth;
– u_s: maximum peak-to-peak voltage excursion at re-ignition and/or ~~prestrike~~ restrike.

When overvoltages occur which may be hazardous for a specific application, or where ~~circuit-breaker~~ switching device characteristics are required, a more comprehensive test programme will be required which is beyond the scope of this document.



Key

u_0	power-frequency voltage crest value to earth
u_k	neutral voltage shift at first-pole interruption
u_a	~~circuit-breaker~~ switching device arc voltage ~~drop~~
$u_{in} = u_0 + u_a$	initial voltage at the moment of current chopping
u_{ma}	suppression peak voltage to earth
u_{mr}	load side voltage peak to earth
u_w	voltage across the ~~circuit-breaker~~ switching device at re-ignition
u_p	maximum overvoltage to earth (could be equal to u_{ma} or u_{mr} if no re-ignitions occur)
u_s	maximum peak-to-peak overvoltage excursion at re-ignition

Figure 2 – Illustration of voltage transients at interruption of inductive current for first phase clearing in a three-phase non-effectively earthed circuit

4.4 Shunt reactor current switching tests

4.4.1 Applicability

These tests are applicable to three-phase alternating current switching devices (mainly circuit-breakers) which are used for steady-state switching of shunt reactors that are directly connected to the ~~circuit-breaker~~ switching device without interposing transformer. Tests may be carried out at 50 Hz ~~with a relative tolerance of ±10 %~~ or 60 Hz with a relative tolerance of ±10 %. Tests performed at ~~either 50 Hz or~~ 60 Hz shall be considered as valid for ~~both frequencies~~ 50 Hz. Tests at 50 Hz are valid for 60 Hz provided that the minimum arcing time without re-ignition is shorter than 8,3 ms.

~~NOTE 1 The switching of tertiary reactors from the high-voltage side of the transformer is not covered in this standard.~~

~~NOTE 2 Shunt reactors earthed through neutral reactors are not covered by this standard. However, the application of test results according to this subclause, on neutral reactor earthed reactors (4-leg reactor scheme), is discussed in IEC 62271-306.~~

NOTE If the re-ignition-free arcing window is shorter than 8,3 ms, there is no possibility of re-ignition at a second current zero at 60 Hz test even if only 50 Hz tests have been carried out. Most switching devices have a re-ignition-free arcing window shorter than 8,3 ms.

4.4.2 General

Reactor switching is an operation where small differences in circuit parameters can produce large differences in the severity of the duty. The results from any one series of tests cannot simply be applied to a different set of conditions.

NOTE Further guidance is given in IEC TR 62271-306.

The switching tests can be either field tests or laboratory tests. Results from field tests are only valid for ~~circuit-breakers~~ switching devices applied in circuits similar to those in the tests.

Standard circuits are specified in order to demonstrate the ability of the ~~circuit-breaker~~ switching device to interrupt reactor currents and to determine chopping characteristics (suppression peak overvoltages) and re-ignition behaviour. The parameters of these test circuits represent typical cases of application with relatively severe transient recovery voltage (TRV) and are regarded as covering the majority of service applications.

If the switching device is used to switch reactor currents smaller than the standardized values, the test current should be adjusted to give the lower limit of the actual current range. The lower the current the more severe the switching duty is for the switching device.

Laboratory tests may be made using an actual reactor but the re-ignitions and overvoltage magnitudes during switching will not necessarily be valid for other cases of installation.

4.4.3 Test circuits

Four in-service load circuit configurations are possible as shown in Table 2.

Table 2 – In-service load circuit configurations

In-service configuration	~~Circuit-breaker~~ Switching device location	Reactor neutral earthing	TRV values	Test circuit
1	Source side of reactor	Isolated	Table 3	Figure 3 or Figure 4
2		Earthed	Table 4	Figure 3 or Figure 4
3	Neutral side of reactor	Isolated	Table 5	Figure 5
4		Earthed	Table 6	Figure 4 or Figure 5

The in-service load circuit configurations are covered by three test circuits detailed in Tables 3, 4, 5 and 6 and Figures 3, 4 and 5, respectively.

NOTE 1 Applying a ~~circuit-breaker~~ switching device on the neutral side of the reactor is only a consideration at rated voltages of 52 kV and below and the TRV values shown in Tables 5 and 6 are limited to this range.

NOTE 2 The test circuit shown in Figure 4 is applicable for in-service configuration 4 even though the ~~circuit-breaker~~ switching device location is on the source side of the reactor.

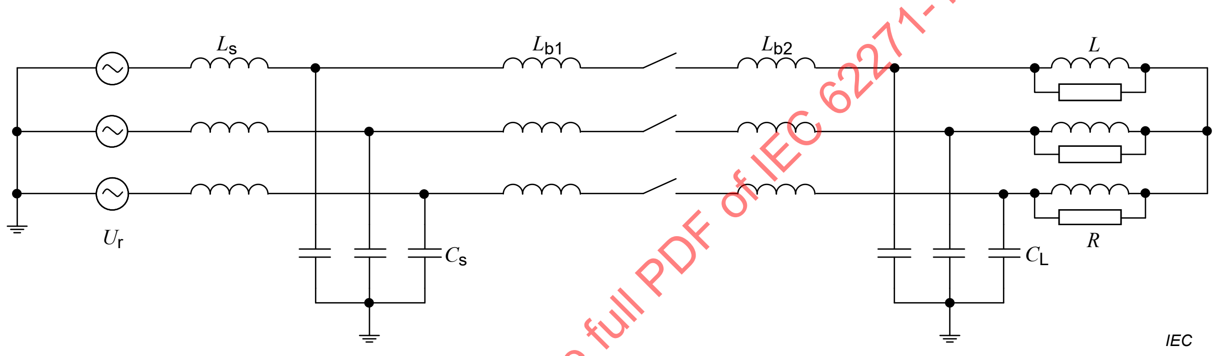
For circuit-breakers the requirements of 6.102.1 and 6.102.2 of IEC 62271-100:2008 +IEC 62271-100:2008/AMD1:2012 shall be fulfilled.

For three-pole in one enclosure type ~~circuit-breakers~~ switching devices, single pole testing is permissible provided that the correct transient recovery voltages to earth (enclosure) are achieved.

For non-earthed reactors on solidly earthed systems, three-pole testing is impractical at higher rated voltages. Single-pole testing is permissible on the basis that the neutral point is earthed prior to in-service switching ~~or that the methodology described in IEC 62271-306 is used to determine the suitability of the circuit-breaker for the application~~.

For switchgear under test that includes a ~~circuit-breaker~~ switching device with overvoltage protection devices, the devices may be included in the test circuit provided that the devices are an intrinsic part of the ~~circuit-breaker~~ switching device.

When overvoltage limiting devices are added in the test circuit for its protection against possible excessive overvoltages, it shall be proven that these devices have not limited the overvoltages recorded during the tests, for instance by recording the current through these devices.

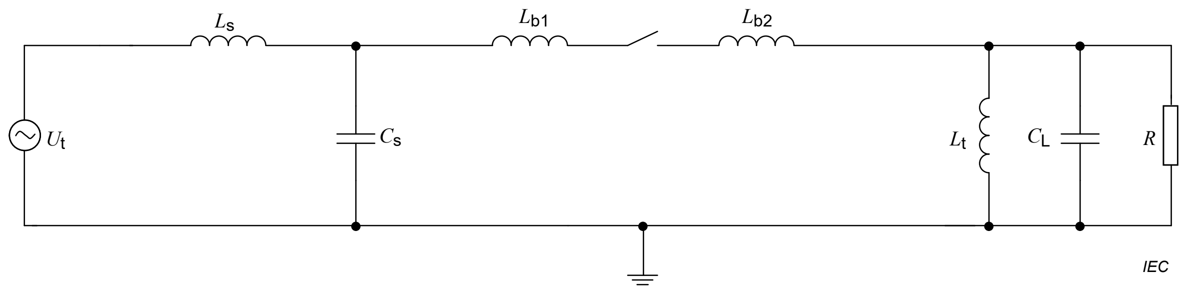


Key

U_r	rated voltage
L_s	inductance of the source
L_{b1}, L_{b2}	inductance of the connections
L	inductance of the reactor
C_s	capacitance of the source
C_L	capacitance of the load
R	representation of load losses (to obtain 1,9 amplitude factor)

NOTE The reactor neutral can be isolated or earthed.

Figure 3 – Reactor switching test circuit – Three-phase test circuit for in-service load circuit configurations 1 and 2 (Table 2)



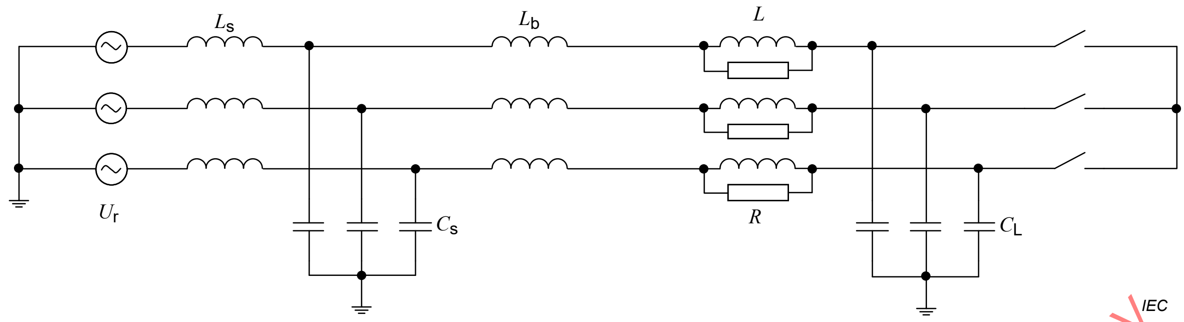
Key

U_t	test voltage
L_s	inductance of the source
L_{b1}, L_{b2}	inductance of the connections
L_t	inductance of the test-circuit reactor
C_s	capacitance of the source
C_L	capacitance of the load
R	representation of load losses (to obtain 1,9 amplitude factor)

~~NOTE~~ For in-service load circuit configurations 2 and 4 (Table 2) $U_t = U_r/\sqrt{3}$ and $L_t = L$ where L is the inductance of the reactor in service.

~~NOTE~~ For in-service load circuit configuration 1 (Table 2) $U_t = 1{,}5 \times U_r/\sqrt{3}$ and $L_t = 1{,}5 \times L$ where L is the inductance of the reactor in service.

Figure 4 – Reactor switching test circuit – Single-phase test circuit for in-service load circuit configurations 1, 2 and 4 (Table 2)



Key

U_r	rated voltage
L_s	inductance of the source
L_b	inductance of the connection
L	inductance of the reactor
C_s	capacitance of the source
C_L	capacitance of the load
R	representation of load losses (to obtain 1,9 amplitude factor)

NOTE This is the only test circuit that can be used for this case. No single-phase test circuit will give the correct test current and TRV and t_3 values.

Figure 5 – Reactor switching test circuit – Three-phase test circuit for in-service load circuit configuration 3 (Table 2)

4.4.4 Characteristics of the supply circuit

The source inductance L_s shall not be smaller than that corresponding to the rated short-circuit current of the circuit-breaker, nor larger than 10 % of the inductance of the load circuit L.

NOTE A higher value of L_s is acceptable if the resulting voltage drop is compensated by tuning the frequency of the TRV to that of the load side.

The source capacitance C_s shall be at least 10 times the load capacitance C_L.

The TRV of the supply circuit has a negligible influence on that of the complete circuit and is therefore not specified.

4.4.5 Characteristics of the connecting leads

The total inductance $L_b = L_{b1} + L_{b2}$ of the leads may be shared between the supply and the load side. The value of L_b is not specified but should be as small as possible.

4.4.6 Characteristics of the load circuits

4.4.6.1 General

The load circuits shall consist of a reactor, or alternatively, an air-cored or iron-cored reactance with appropriate shunt capacitance and resistance so as to produce a prospective transient voltage not less severe than the values specified in Tables 3, 4, 5 and 6.

Table 3 – Standard Values of prospective transient recovery voltages – Rated voltages 12 kV to 170 kV for effectively and non-effectively earthed systems – Switching shunt reactors with isolated neutrals (Table 2: In-service load circuit configuration 1)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter t_3 $_{-20}^{0}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
12	28	9	16
17,5	41	11	19
24	56	13	22
36	84	15	27
52	121	55	97
72,5	169	64	115
100	233	107	190
123	286	120	210
145	337	130	230
170	395	140	248

u_c and t_3 are as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

NOTE The first-pole-to-clear factor k_{pp} is 1,5 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r\sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of

– 500 pF for voltages below 52 kV;

– 1 750 pF for voltages at or above 52 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the circuit-breaker switching device. In the case that a re-ignition-free window is demonstrated for controlled switching application purposes, the t_3 time parameter can be adjusted to actual service conditions.

Table 4 – ~~Standard~~ Values of prospective transient recovery voltages – Rated voltages 100 kV to 1 200 kV for effectively earthed systems – Switching shunt reactors with earthed neutrals (See Table 2: In-service load circuit configuration 2)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter t_3 ${}_{-20}^{\ 0}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
100	155	87	155
123	191	97	172
145	225	105	187
170	264	114	203
245	380	167	297
300	465	185	328
362	562	203	360
420	652	220	388
550	853	250	444
800	1 240	300	536
1 100	1 700	–	1 170
1 200	1 860	–	1 220

u_c and t_3 as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

~~NOTE~~ The first-pole-to-clear factor k_{pp} is 1,0 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r \sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of

- 1 750 pF for voltages at or above 100 kV and below 245 kV;
- 2 600 pF for voltages of 245 kV up to and including 800 kV;
- 9 000 pF for voltages above 800 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the ~~circuit-breaker~~ switching device. ~~In the case that a re-ignition-free window is demonstrated for controlled switching application purposes, the t_3 time parameter can be adjusted to actual service conditions.~~

Table 5 – ~~Standard~~ Values of prospective transient recovery voltages – Rated voltages 12 kV to 52 kV for effectively and non-effectively earthed systems – Switching shunt reactors with isolated neutrals (See Table 2: In-service load circuit configuration 3)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter t_3 ${}^{0}_{-20}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
12	28	7	13
17,5	41	9	16
24	56	10	18
36	84	12	22
52	121	45	79

u_c and t_3 as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

~~NOTE~~ The first-pole-to-clear factor k_{pp} is 1,5 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r \sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of 500 pF for voltages below 52 kV and 1 750 pF for voltages of 52 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the ~~circuit-breaker~~ switching device. ~~In the case that a re-ignition-free window is demonstrated for controlled switching application purposes, the t_3 time parameter can be adjusted to actual service conditions.~~

Table 6 – ~~Standard~~ Values of prospective transient recovery voltages – Rated voltages 12 kV to 52 kV for effectively and non-effectively earthed systems – Switching shunt reactors with earthed neutrals (See Table 2: In-service load circuit configuration 4)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter t_3 ${}^{0}_{-20}$ %	
		Load circuit 1	Load circuit 2
		μs	μs
12	19	7	13
17,5	27	9	16
24	37	10	18
36	56	12	22
52	81	45	79

u_c and t_3 as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

~~NOTE~~ The first-pole-to-clear factor k_{pp} is 1,0 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r \sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of 500 pF for voltages below 52 kV and 1 750 pF for voltages of 52 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the ~~circuit-breaker~~ switching device. ~~In the case that a re-ignition-free window is demonstrated for controlled switching application purposes, the t_3 time parameter can be adjusted to actual service conditions.~~

The values of t_3 are based on a calculation at 50 Hz. There is no need to differentiate between 50 Hz and 60 Hz since the stress of the tests with both frequencies is equivalent. This is taken into account by the overlapping tolerances for the frequency of the test current.

The test current shall be symmetrical (DC component lower than 20 %).

4.4.6.2 Load circuit 1

The inductance L of the load circuit shall be adjusted to give the breaking currents in Table 7.

Table 7 – Load circuit 1 test currents

Rated voltage kV	Test current A (± 20 %)
< 52	1 600
52 to 72,5	630
100 to 800	315

NOTE A test at 315 A is not required for rated voltages of 1 100 kV and 1 200 kV since such a current value represents an unrealistic shunt reactor rating.

4.4.6.3 Load circuit 2

The inductance L of the load shall be adjusted to give the breaking currents in Table 8.

Table 8 – Load circuit 2 test currents

Rated voltage kV	Test current A (± 20 %)
< 52	500
52 to 72,5	200
100 to 1 200	100

However, if the ~~circuit-breaker~~ switching device is used to switch reactor currents smaller than these values, the load circuit 2 should be adjusted to give the lower limit of the actual current range. The lower the current the more ~~onerous~~ severe the switching duty is for the ~~circuit-breaker~~ switching device.

4.4.7 Earthing of the test circuit

Earthing of the test circuit shall be as indicated in Figures 3 to 5.

4.4.8 Test voltage

For three-phase tests, the test voltage measured between the phases at the ~~circuit-breaker~~ switching device location immediately prior to the opening shall, ~~as near as possible,~~ with a tolerance of ±5 %, be equal to the rated voltage U_r of the ~~circuit-breaker~~ switching device (Tables 3, 4, 5 and 6).

For single-phase laboratory tests, the ~~test~~ voltage measured at the ~~circuit-breaker~~ switching device location immediately before the opening shall, ~~as nearly as possible,~~ with a tolerance of ±5 %, be equal to ~~those~~ the test voltage as stated in Figure 4.

~~For unit tests, the test voltage shall be that of the most stressed unit of the pole of the circuit-breaker. If applicable, the tested unit shall include its grading capacitor.~~

4.4.9 Test-duties

4.4.9.1 General

The reactor switching tests shall consist of three three-phase test-duties or four single-phase test-duties using the supply circuit detailed in 4.4.4 and the load circuits detailed in 4.4.6.2 and 4.4.6.3.

Test-duties 1 and 2 shall be made at rated filling pressure for interruption, insulation and operation and shall consist of twenty breaking operations. They shall be made with each load circuit with the initiation of the tripping impulse distributed at intervals of ~~approximately~~ 9 electrical degrees for three-phase tests or 18 electrical degrees for single-phase tests.

Test-duty 3 ~~is~~ shall be performed at rated filling pressure for interruption, insulation and operation for single-phase tests only and shall consist of 18 breaking operations. It shall be performed with load circuit 2 around the arc duration at which the re-ignitions occurred in the previous test series with load circuit 2. Six breaking operations shall be made with the initiation of the tripping impulse at the point that gave the highest breakdown voltage u_w, 6 breaking operations with the initiation of the tripping impulse retarded by 9 electrical degrees and 6 breaking operations with the initiation of the tripping impulse advanced by 9 electrical degrees. If no re-ignition occurs in the test-duty with load circuit 2, test-duty 3 shall consist of 6 breaking operations with the initiation of the tripping impulse at the point that gave the shortest arcing time, 6 break tests with the initiation of the tripping impulse retarded by 9 electrical degrees and 6 break tests with the initiation of the tripping impulse retarded by a further 9 electrical degrees.

Test-duty 4 shall be performed at the minimum pressure for interruption, insulation and operation using load circuit 2 only. For three-phase tests, 20 breaking operations shall be made with the initiation of the tripping impulse distributed at intervals of 9 electrical degrees. For single-phase tests, 20 breaking operations shall be made with the initiation of the tripping impulse distributed at intervals of 18 electrical degrees.

The test-duties are summarized in Table 9.

Table 9 – Test-duties for reactor current switching tests

Test-duty	Number of breaking operations		Test current determined by
	Three-phase	Single-phase	
1	20	20	Load circuit 1 (4.4.6.2)
2	20	20	Load circuit 2 (4.4.6.3)
3	–	18	Load circuit 2 (4.4.6.3)
4	20	20	Load circuit 2 (4.4.6.3)

The current value used in test-duty 2, 3 and 4 is the minimum shunt reactor switching current. However, if the ~~circuit-breaker~~ switching device is to be used to switch reactor currents smaller than these values, the current for test-duty 2, 3 and 4 shall be adjusted to the lower limit of the actual current range or as close as possible to this current value. Calculation of the applicable t_3 value for such a case is described in Annex A.

4.4.9.2 Test measurements

At least the following quantities should be recorded by oscillograph or other suitable recording techniques with sufficient bandwidth and time resolution ~~high enough to measure~~:

- supply side voltage, phase-to-earth;
- voltage across ~~circuit-breaker~~ switching device terminals;
- load side voltage, phase-to-earth, at the terminal of the load reactor;
- load side neutral point voltage to earth (in three-phase tests);
- current through the ~~circuit-breaker~~ switching device.

4.4.9.3 Behaviour and condition of ~~circuit-breaker~~ switching device

The criteria for successful testing are as follows.

a) The ~~circuit-breaker~~ switching device shall interrupt the current with at most one re-ignition leading to conduction of another loop of power-frequency current. This criterion applies to all three ~~circuit-breaker~~ switching device poles in three-phase tests.

NOTE Multiple high-frequency re-ignitions in any one current zero crossing can be counted as one such re-ignition.

b) A visual inspection shall be performed to demonstrate that the re-ignitions occurred between the arcing contacts only. There shall be no evidence of puncture, flashover or permanent tracking of the internal ~~insulating materials~~ parts that contribute to the insulation. Wear of the parts of the arc control devices exposed to the arc is permissible provided that it does not impair breaking capability.

NOTE In many designs of circuit-breakers "auxiliary" nozzles are included that do not contribute to the insulation but assist the short-circuit current breaking process by the release of ablated vapour, leading to material loss and deformation.

Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a re-ignition.

For ~~circuit-breakers~~ switching devices with sealed-for-life interrupter units, no visual inspection is required but the dielectric condition test according to 6.2.11 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012 shall be performed.

4.4.9.4 Test report

In addition to the requirements of Annex C of IEC 62271-100:2008, the test report shall include a thorough description of the circuit including the following details (Figure 3, Figure 4 and Figure 5):

– L_s: inductance of the source;
– L_{b1}, L_{b2}: inductance of connections;
– L: inductance of reactor;
– C_s: capacitance of source;
– C_L: capacitance of load;
– R: representation of load losses.

The following quantities shall be measured and evaluated at each test (Figure 2 and Figure 6):

- u_{ma}: suppression peak voltage to earth;
- u_{in}: initial voltage (at the instant of chopping);
- u_{mr}: load side voltage peak to earth ~~(if more than u_{ma})~~;
- u_w: voltage across the switching device at re-ignition (if applicable);
- arcing time;
- breaking current;
- test voltage.

In three-phase tests, the above quantities shall be reported for all three ~~circuit-breaker~~ switching device poles.

NOTE The application of the test results to predict overvoltages in actual installations is treated in IEC TR 62271-306.

In addition, the re-ignition-free arcing window resulting from all tests shall be evaluated and included in the report. This is the period of shortest arc duration during which no re-ignition is observed. In a three-phase test, this period refers to absence of re-ignition in all three poles of the switching device.

If a re-ignition-free arcing window has been specified, the re-ignition-free arcing window measured during the tests should be equal to or greater than the specified value. Evaluation in this regard should consider the actual system frequency.

~~7 Routine tests~~

~~Clause 7 of IEC 62271-100:2008 is applicable.~~

~~8 Guide to selection of switchgear and controlgear~~

~~Clause 8 of IEC 62271-100:2008 is applicable and for further reference see IEC 62271-306.~~

If maximum overvoltage values have been specified, the overvoltage values calculated using the data obtained from the test results should be compared to the values specified.

If an arcing window without re-ignition has been specified, the arcing window without re-ignition measured during the tests should be equal to or greater than the specified value. Evaluation in this regard should consider the actual system frequency.

9 Information to be given with enquiries, tenders and orders

Clause 9 of IEC 62271-100:2008 is applicable.

10 Transport, storage, installation, operation and maintenance

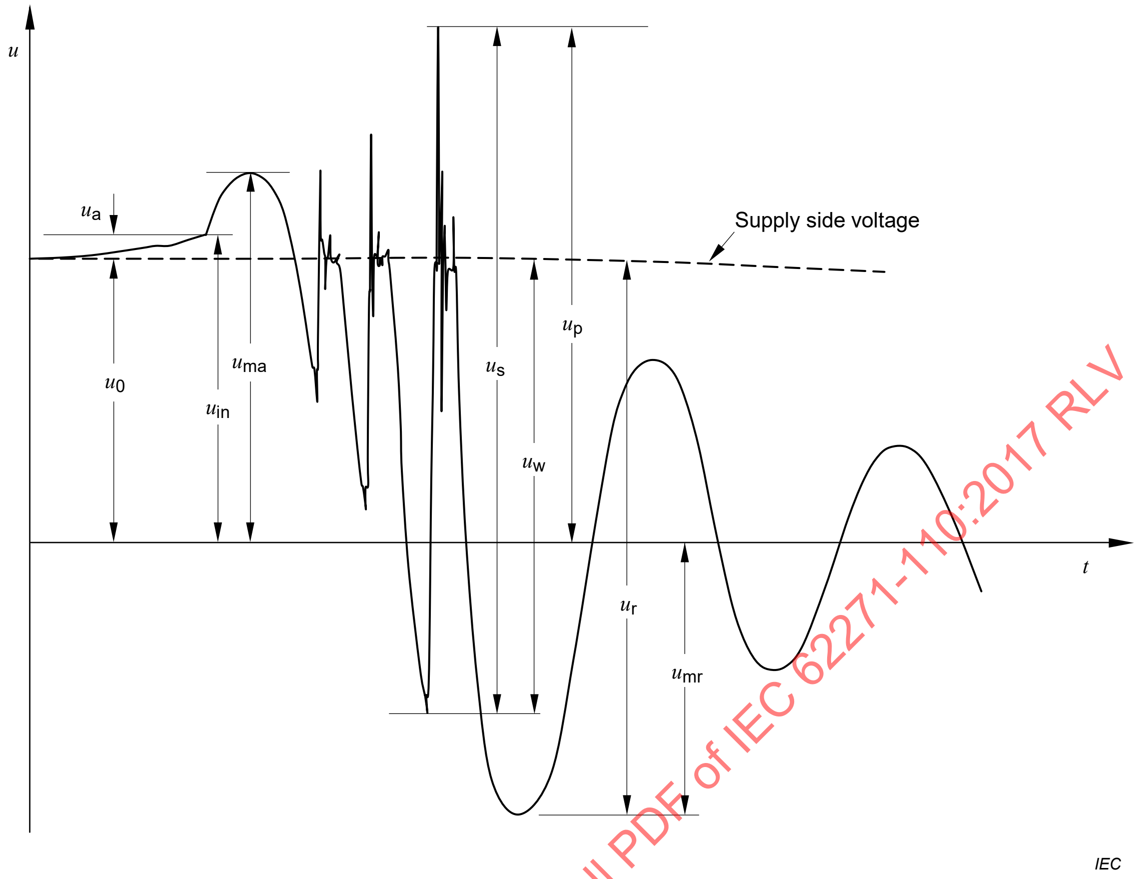
Clause 10 of IEC 62271-100:2008 is applicable.

11 Safety

Clause 11 of IEC 62271-100:2008 is applicable.

12 Influence of the product on the environment

Clause 12 of IEC 62271-100:2008 is applicable.



Key

u_0	power frequency voltage crest value to earth
u_a	arc voltage drop of ~~circuit-breaker~~ switching device
$u_{in} = u_0 + u_a$	initial voltage to earth at the moment of current chopping
u_{ma}	suppression peak voltage to earth
u_{mr}	load side voltage peak ~~voltage~~ to earth
~~u_p~~ u_s	maximum overvoltage to earth (could be equal to u_{ma} or u_{mr})
~~u_s~~ u_p	maximum peak-to-peak voltage excursion at re-ignition
u_w	voltage across the ~~circuit-breaker~~ switching device at re-ignition
u_r	voltage across the ~~circuit-breaker~~ switching device at the recovery ~~voltage~~ peak

Figure 6 – Illustration of voltage transients at interruption of inductive current for a single-phase test

Annex A
(normative)

Calculation of t_3 values

For the following cases, the required test circuit t_3 values shall be calculated as described in Annex A:

a) for ~~circuit-breakers~~ switching devices rated at less than 52 kV, where the required test current is less than the 500 A value stated in Table 8;

b) for ~~circuit-breakers~~ switching devices rated 52 kV to 72,5 kV, where the required test current is less than the 200 A value stated in Table 8;

c) for ~~circuit-breakers~~ switching devices rated at 100 kV to 1 200 kV, where the required test current is less than the 100 A value stated in Table 8.

Step 1: Calculate the required inductance (L)

$$L = \frac{U_r}{\sqrt{3}\,\omega I}$$

where U_r is the rated voltage, I is the required test current and $\omega = 314$ rad/s at 50 Hz.

$L = \frac{1{,}84\,U_r}{I}$, with U_r in kilovolt (kV), I in ampere (A) and L in henry (H), all at 50 Hz.

Step 2: Calculate the required t_3 value

Case 1: Reactor neutral earthed

Time to peak T for (1 − cosine) function is given by:

$$T = \pi\sqrt{LC}$$

Ratio t_3/T for an amplitude factor of 1,9 is 0,873:

$$t_3 = 0{,}873 \times \pi \times \sqrt{LC} = 2{,}74 \times \sqrt{LC} \times 10^6 \text{ µs}$$

where the value of C in farad (F) is taken from NOTE 2 in Tables 3, 4, 5 and 6 (default value if actual value is not known).

Case 2: Reactor neutral isolated

$$t_3 = 0{,}873 \times \pi \times \sqrt{1{,}5\,LC} = 3{,}36 \times \sqrt{LC} \times 10^6 \text{ µs}$$

EXAMPLE 1 U_r = 245 kV, 50 Hz and required test current 75 A, reactor neutral earthed:

$$L = \frac{1{,}84 \times 245}{75} = 6 \text{ H}$$

$$t_3 = 2{,}74\sqrt{6 \times 2\,600 \times 10^{-12}} \times 10^6 = 342\ \mu s$$

EXAMPLE 2 U_r = 36 kV, 50 Hz and required test current 350 A, reactor neutral isolated:

$$L = \frac{1{,}84 \times 36}{350} = 0{,}19\ H$$

$$t_3 = 3{,}36\sqrt{0{,}19 \times 500 \times 10^{-12}} \times 10^6 = 32{,}7\ \mu s$$

Bibliography

~~IEC 62271-106, *High-voltage switchgear and controlgear – Part 106: Alternating current contactors, contactor-based controllers and motor-starters*~~

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*~~[2]~~

~~2 To be published.~~

IEC 62271-110

Edition 4.0 2017-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

**Appareillage à haute tension –
Partie 110: Manœuvre de charges inductives**

IEC 62271-110:2017-10(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 110: Inductive load switching

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62271-110 has been prepared by subcommittee 17A: Switching devices, of IEC technical committee 17: High-voltage switchgear and controlgear.

This fourth edition cancels and replaces the third edition published in 2012 and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– all switching devices are now covered, not only circuit-breakers;
– a limited number of T10 tests no longer covers shunt-reactor switching tests below 52 kV;
– evaluation and reporting of a re-ignition-free arcing time window has been added.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
17A/1151/FDIS	17A/1155/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62271 series can be found, under the general title *High-voltage switchgear and controlgear*, 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 "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The contents of the corrigenda of December 2017 and February 2018 have been included in this copy.

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 110: Inductive load switching

1 Scope

This part of IEC 62271 is applicable to AC switching devices designed for indoor or outdoor installation, for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V and applied for inductive current switching. It is applicable to switching devices (including circuit-breakers in accordance with IEC 62271-100) that are used to switch high-voltage motor currents and shunt reactor currents and also to high-voltage contactors used to switch high-voltage motor currents as covered by IEC 62271-106.

Switching unloaded transformers, i.e. breaking transformer magnetizing current, is not considered in this document. The reasons for this are as follows:

a) Owing to the non-linearity of the transformer core, it is not possible to correctly model the switching of transformer magnetizing current using linear components in a test laboratory. Tests conducted using an available transformer, such as a test transformer, will only be valid for the transformer tested and cannot be representative for other transformers.

b) As detailed in IEC TR 62271-306, the characteristics of this duty are usually less severe than any other inductive current switching duty. Such a duty may produce severe overvoltages within the transformer winding(s) depending on the re-ignition behaviour of the switching device and transformer winding resonance frequencies.

NOTE 1 The switching of tertiary reactors from the high-voltage side of the transformer is not covered by this document.

NOTE 2 The switching of shunt reactors earthed through neutral reactors is not covered by this document. However, the application of test results according to this document, on the switching of neutral reactor earthed reactors (4-leg reactor scheme), is discussed in IEC TR 62271-306.

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, *International Electrotechnical Vocabulary – Chapter 441: Switchgear, controlgear and fuses* (available at www.electropedia.org)

IEC 62271-1:2017, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

IEC 62271-100:2008, *High-voltage switchgear and controlgear – Part 100: Alternating current circuit-breakers*
IEC 62271-100:2008/AMD1:2012

IEC 62271-106:2011, *High-voltage switchgear and controlgear – Part 106: Alternating current contactors, contactor-based controllers and motor-starters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-441, IEC 62271-1 and the following apply.

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

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

3.1
inductive current
power-frequency current drawn by an inductive circuit having a power factor 0,5 or less

3.2
current chopping
abrupt current interruption in a switching device at a point-on-wave other than the natural power-frequency current zero

3.3
virtual current chopping
current chopping in one of the three phases in a three-phase circuit originated by transients in another phase of the circuit

3.4
suppression peak
first peak of the transient voltage to earth on the load side of the switching device following current interruption

Note 1 to entry: Suppression peak is not necessarily the absolute maximum of the transient recovery voltage. Previous breakdowns may have appeared at higher voltage values.

3.5
recovery peak
maximum value of the voltage across the switching device occurring when the polarity of the recovery voltage is equal to the polarity of the power-frequency voltage

Note 1 to entry: Recovery peak is not necessarily the absolute maximum of the transient recovery voltage. Previous breakdowns may have appeared at higher voltage values.

3.6
re-ignition
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of less than a quarter cycle of power frequency

Note 1 to entry: In the case of inductive load switching the initiation of the re-ignition is a high-frequency event, which can be of a single or multiple nature and may in some cases be interrupted without power-frequency follow current.

3.7
re-ignition-free arcing time window
period of arc duration during a breaking operation during which the contacts of a mechanical switching device reach sufficient distance to exclude re-ignition

4 Type tests

4.1 General

Circuit-breakers according to IEC 62271-100 and contactors according to IEC 62271-106 do not have dedicated inductive switching ratings. However, switching devices applied for this purpose shall meet the requirements of this document.

For shunt reactor switching test of circuit-breakers, the rated insulation level values stated in Tables 1a, 1b, 3 and 4 of IEC 62271-1:2017 are applicable with the exception of combined voltage tests across the isolating distance (columns (6) and (8) in Table 3 and column (7) in Table 4).

The type tests are in addition to those specified in the relevant product standard, with the exception of short-line faults, out-of-phase switching and capacitive current switching.

NOTE 1 The reason for this exception is the source-less nature of the shunt reactor load circuit.

NOTE 2 In some cases (high chopping overvoltage levels, or where a neutral reactor is present or in cases of shunt reactors with isolated neutral), it can be necessary to specify an appropriate insulation level which is higher than the rated values stated above.

Inductive current switching tests performed for a given current level and type of application may be considered valid for another current rating and same type of application as detailed below:

a) for shunt reactor switching at rated voltages of 52 kV and above, tests at a particular current level are to be considered valid for applications with a higher current level up to 150 % of the tested current value;
b) for shunt reactor switching at rated voltages below 52 kV, type testing is required;
c) for high-voltage motor switching, type testing for stalled motor currents at 100 A and 300 A is considered to cover stalled motor currents in the range 100 A to 300 A and up to the current associated with the short-circuit current of test-duty T10 according to 6.106.1 of IEC 62271-100:2008 for circuit-breakers and up to the rated operational current for contactors.

With respect to a) the purpose of type testing is also to determine a re-ignition-free arcing time window for controlled switching purposes (refer to IEC TR 62271-302) and caution should be exercised when considering applications at higher currents than the tested values since the re-ignition-free arcing window can increase at higher current.

Annex B of IEC 62271-100:2008 can be used with respect to tolerances on test quantities.

4.2 Miscellaneous provisions for inductive load switching tests

Subclause 6.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012 is applicable with the following addition:

High-voltage motor current and shunt reactor switching tests shall be performed at rated auxiliary and control voltage or, where necessary, at maximum auxiliary and control voltage to facilitate consistent control of the opening and closing operation according to 6.102.3.1 of IEC 62271-100:2008.

For gas filled switching devices (including vacuum switching devices using gaseous media for insulation), tests shall be performed at the rated functional pressure for interruption and insulation, except for test-duty 4, where the pressure shall be the minimum functional pressure for interruption and insulation.

4.3 High-voltage motor current switching tests

4.3.1 Applicability

Subclause 4.3 is applicable to three-phase alternating current switching devices having rated voltages above 1 kV and up to 17,5 kV, which are used for switching high-voltage motors. Tests may be carried out at 50 Hz with a relative tolerance of ±10 % or 60 Hz with a relative tolerance of ±10 %, both frequencies being considered equivalent.

Motor switching tests are applicable to all three-pole switching devices having rated voltages equal to or less than 17,5 kV, which may be used for the switching of three-phase asynchronous squirrel-cage or slip-ring motors. The switching device may be of a higher rated voltage than the motor when connected to the motor through a stepdown transformer. However, the usual application is a direct cable connection between switching device and motor. When tests are required, they shall be made in accordance with 4.3.2 to 4.3.9.

When overvoltage limitation devices are mandatory for the tested equipment, the voltage limiting devices may be included in the test circuit provided that the devices are an intrinsic part of the equipment under test.

No limits to the overvoltages are given as the overvoltages are only relevant to the specific application. Overvoltages between phases may be as significant as phase-to-earth overvoltages.

4.3.2 General

The switching tests can be either field tests or laboratory tests. As regards overvoltages, the switching of the current of a starting or stalled motor is usually the more severe operation.

Due to the non-linear behaviour of the motor iron core, it is not possible to exactly model the switching of motor current using linear components in a test station. Tests using linear components to simulate the motors can be considered to be more conservative than switching actual motors.

For laboratory tests a standardized circuit simulating the stalled condition of a motor is specified (refer to Figure 1). The parameters of this test circuit have been chosen to represent a relatively severe case with respect to overvoltages and will cover the majority of service applications.

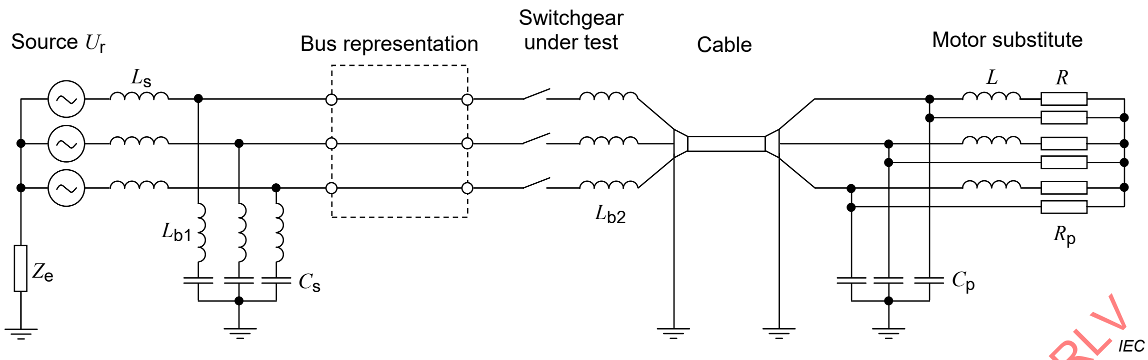
The laboratory tests are performed to prove the ability of a switching device to switch motors and to establish its behaviour with respect to switching overvoltages, re-ignitions and current chopping. These characteristics may serve as a basis for estimates of the switching device's performance in other motor circuits. Tests performed with the test currents defined in 4.3.3 and 4.3.4 demonstrate the capability of the switching device to switch high-voltage motors up to its rated interrupting current.

For field tests, actual circuits are used with a supply system on the source side and a cable and motor on the load side. There may be a transformer between the switching device and motor. However, the results of such field tests are only valid for switching devices working in circuits similar to those during the tests.

The apparatus under test includes the switching device with overvoltage protection devices if they are normally fitted.

NOTE 1 Overvoltages can be produced when switching running motors. This condition is not represented by the substitute circuit and is generally considered to be less severe than the stalled motor case.

NOTE 2 The starting period switching of a slip-ring motor is generally less severe due to the effect of the starting resistor.



Key

U_r	rated voltage	
Z_e	earthing impedance	impedance high enough to limit the phase-to-earth fault current to less than the test current (can be infinite)
L_s	source side inductance	$\omega L_s \leq 0{,}1\ \omega L$, but prospective short-circuit current ≤ the rated short-circuit current of the tested switching device
C_s	supply side capacitance	0,03 µF to 0,05 µF for supply circuit A
		1,5 µF to 2 µF for supply circuit B
L_{b1}	inductance of capacitors and connections	≤ 2 µH
Bus representation		5 m to 7 m in length spaced appropriate to the rated voltage
L_{b2}	inductance of connections	≤ 5 µH
Cable		100 m ± 10 m, screened, surge impedance 30 Ω to 50 Ω
L	motor substitute inductance	load circuit 1: 100 A ± 10 A
		load circuit 2: 300 A ± 30 A
R	motor substitute resistance	cos $\varphi \leq 0{,}2$
C_p	motor substitute parallel capacitance	frequency 10 kHz to 15 kHz
R_p	motor substitute parallel resistance	amplitude factor 1,6 to 1,8

Figure 1 – Motor switching test circuit and summary of parameters

4.3.3 Characteristics of the supply circuits

4.3.3.1 General

A three-phase supply circuit shall be used. The tests shall be performed using two different supply circuits A and B as specified in 4.3.3.2 and 4.3.3.3, respectively. Supply circuit A represents the case of a motor connected directly to a transformer. Supply circuit B represents the case where parallel cables are applied on the supply side.

4.3.3.2 Supply circuit A

The three-phase supply may be earthed through a high ohmic impedance so that the supply voltage is defined with respect to earth. The impedance value shall be high enough to limit a prospective line-to-earth fault current to a value below the test current.

The source inductance L_s shall not be lower than that corresponding to the rated short-circuit breaking current of the tested switching device. Its impedance shall also be not higher than 0,1 times the impedance of the inductance in the load circuit (see 4.3.4).

The supply side capacitance C_s is represented by three capacitors connected in earthed star. Their value, including the natural capacitance of the circuit shall be 0,04 μF ± 0,01 μF. The inductance L_{b1} of the capacitors and connections shall not exceed 2 μH.

The busbar inductance is represented by three bars forming a busbar each 6 m ± 1 m in length and spaced at a distance appropriate to the rated voltage.

4.3.3.3 Supply circuit B

As supply circuit A with the value of the supply side capacitance increased to 1,75 μF ± 0,25 μF.

4.3.4 Characteristics of the load circuit

4.3.4.1 General

A three-phase load circuit shall be used. The motor substitute circuit is connected to the switching device under test by 100 m ± 10 m of screened cable. It is recommended that the cable be connected directly to the terminals of the motor or substitute circuit.

The inductance of any intermediate connection should not exceed 3 μH. The shield of the cable shall be earthed at both ends as shown in Figure 1. The tests shall be performed using two different motor substitute circuits as specified in 4.3.4.2 and 4.3.4.3. The inductance L_{b2} of the connections between the switching device and cable shall not exceed 5 μH.

NOTE The use of a three-phase test circuit is necessary in order to allow the possibility of virtual current chopping.

4.3.4.2 Motor substitute circuit 1

Series-connected resistance and inductance shall be arranged to obtain a current of 100 A ± 10 A at a power factor less than 0,2 lagging. The star point shall not be connected to earth. Resistance R_p shall be connected in parallel with each phase impedance and capacitance C_p between each phase and earth so that the motor substitute circuit has a natural frequency of 12,5 kHz ± 2,5 kHz and an amplitude factor of 1,7 ± 0,1 measured in each phase with the other two phases connected to earth. The prospective transient recovery voltages values shall be determined in accordance with Annex F of IEC 62271-100:2008. A transformer may be introduced at the load end of the cable. This shall be considered as part of the motor substitute circuit.

4.3.4.3 Motor substitute circuit 2

As motor substitute circuit 1, but with the series resistance and inductance reduced to obtain a current of 300 A ± 30 A at a power factor less than 0,2 lagging. The prospective transient recovery voltage shall be as specified for motor substitute circuit 1.

4.3.5 Test voltage

a) The average value of the applied voltages shall be not less than the rated voltage U_r divided by √3 and shall not exceed this value by more than 10 % without the consent of the manufacturer.

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

   The rated voltage U_r is that of the switching device when using the substitute circuit, but is that of the motor when an actual motor is used.

b) The power-frequency recovery voltage of the test circuit may be stated as a percentage of the power-frequency recovery voltage specified below. It shall not be less than 95 % of the specified value and shall be maintained in accordance with 6.104.7 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

   The average value of the power-frequency recovery voltages shall not be less than the rated voltage U_r of the switching device divided by √3.

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

   The power-frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its r.m.s. value shall be determined on the oscillogram within the time interval of one half cycle and one cycle of test frequency after final arc extinction, as indicated in Figure 44 of IEC 62271-100:2008. The vertical distance (V_1, V_2 and V_3 respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by 2√2 and multiplied by the appropriate calibration factor, gives the r.m.s. value of the recorded power-frequency recovery voltage.

4.3.6 Test-duties

The motor current switching tests shall consist of four test-duties as specified in Table 1.

Table 1 – Test-duties at motor current switching tests

Test-duty	Supply circuit	Motor substitute circuit
1	A	1
2	A	2
3	B	1
4	B	2

The number of tests for each test-duty shall be 20 tests with the initiation of the closing and tripping impulses distributed at intervals of approximately 9 electrical degrees.

The above tests shall be make–break tests or separate making and breaking tests except that when using an actual motor they shall only be make–break tests. When tests are made using the motor substitute circuit, the contacts of the switching device shall not be separated until any DC component has become less than 20 %. When switching an actual motor, a make-break time of 200 ms is recommended.

4.3.7 Test measurements

At least the following quantities shall be recorded by oscillograph or other suitable recording techniques with bandwidth and time resolution high enough to measure the following:

– power-frequency voltage;
– power-frequency current;
– phase-to-earth voltage, at the motor or motor substitute circuit terminals, in all three phases.

4.3.8 Behaviour and condition of switching device

The criteria for successful testing of a circuit-breaker are as follows:

a) the behaviour of the circuit-breaker during the motor switching tests fulfils the conditions given in 6.102.8 of IEC 62271-100:2008 as applicable;

b) voltage tests shall be performed in accordance with 6.2.11 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012;

c) all re-ignitions shall take place between the arcing contacts.

The criteria for successful testing of contactors are listed in 6.102.9 of IEC 62271-106:2011.

4.3.9 Test report

In addition to the requirements of Annex C of IEC 62271-100:2008, the test report shall include a thorough description of the circuit, including the following details:

a) main dimensions and characteristics of the bus and connections to the switching device;

b) the characteristics of the cable:
   1) length;
   2) rated values;
   3) type;
   4) main insulation dielectric – cross-linked polyethylene (XLPE), paper/oil, etc.;
   5) earthing;
   6) capacitances;
   7) surge impedance.

c) the parameters of the substitute motor circuit:
   1) natural frequency;
   2) amplitude factor;
   3) current;
   4) power factor.

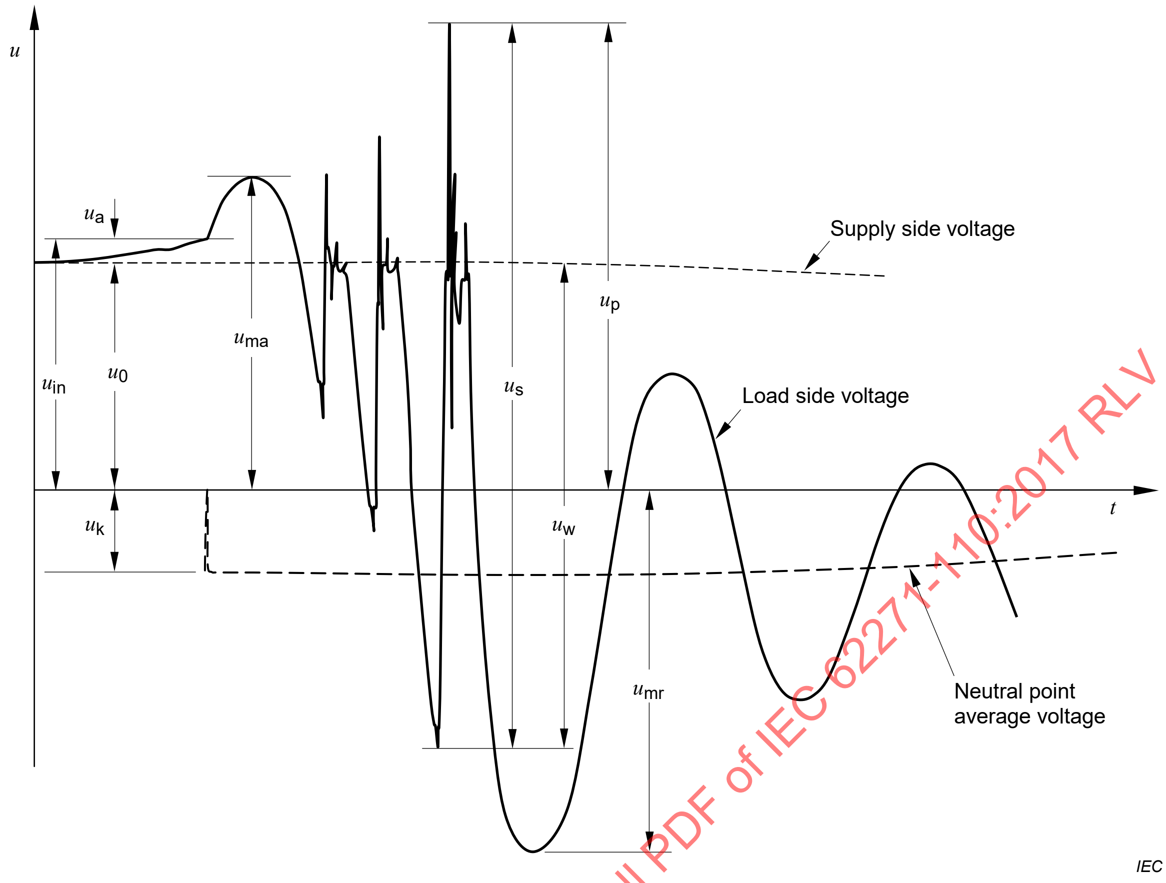
d) or details of the actual motor:
   1) type and rating;
   2) rated voltage;
   3) winding connection;
   4) rated motor current;
   5) starting current and power factor.

e) overvoltage characteristics.

The following characteristics of the voltages at the motor or motor substitute circuit terminals at each test (Figure 2) shall be evaluated:

– u_p: maximum overvoltage;
– u_{ma}: suppression peak overvoltage;
– u_{mr}: load side voltage peak to earth;
– u_s: maximum peak-to-peak voltage excursion at re-ignition and/or restrike.

When overvoltages occur which may be hazardous for a specific application, or where switching device characteristics are required, a more comprehensive test programme will be required which is beyond the scope of this document.



Key

u_0	power-frequency voltage crest value to earth
u_k	neutral voltage shift at first-pole interruption
u_a	switching device arc voltage
$u_{in} = u_0 + u_a$	initial voltage at the moment of current chopping
u_{ma}	suppression peak voltage to earth
u_{mr}	load side voltage peak to earth
u_w	voltage across the switching device at re-ignition
u_p	maximum overvoltage to earth (could be equal to u_{ma} or u_{mr} if no re-ignitions occur)
u_s	maximum peak-to-peak overvoltage excursion at re-ignition

Figure 2 – Illustration of voltage transients at interruption of inductive current for first phase clearing in a three-phase non-effectively earthed circuit

4.4 Shunt reactor current switching tests

4.4.1 Applicability

These tests are applicable to three-phase alternating current switching devices (mainly circuit-breakers) which are used for steady-state switching of shunt reactors that are directly connected to the switching device without interposing transformer. Tests may be carried out at 50 Hz or 60 Hz with a relative tolerance of ±10 %. Tests performed at 60 Hz shall be considered as valid for 50 Hz. Tests at 50 Hz are valid for 60 Hz provided that the minimum arcing time without re-ignition is shorter than 8,3 ms.

NOTE If the re-ignition-free arcing window is shorter than 8,3 ms, there is no possibility of re-ignition at a second current zero at 60 Hz test even if only 50 Hz tests have been carried out. Most switching devices have a re-ignition-free arcing window shorter than 8,3 ms.

4.4.2 General

Reactor switching is an operation where small differences in circuit parameters can produce large differences in the severity of the duty. The results from any one series of tests cannot simply be applied to a different set of conditions.

NOTE Further guidance is given in IEC TR 62271-306.

The switching tests can be either field tests or laboratory tests. Results from field tests are only valid for switching devices applied in circuits similar to those in the tests.

Standard circuits are specified in order to demonstrate the ability of the switching device to interrupt reactor currents and to determine chopping characteristics (suppression peak overvoltages) and re-ignition behaviour. The parameters of these test circuits represent typical cases of application with relatively severe transient recovery voltage (TRV) and are regarded as covering the majority of service applications.

If the switching device is used to switch reactor currents smaller than the standardized values, the test current should be adjusted to give the lower limit of the actual current range. The lower the current the more severe the switching duty is for the switching device.

Laboratory tests may be made using an actual reactor but the re-ignitions and overvoltage magnitudes during switching will not necessarily be valid for other cases of installation.

4.4.3 Test circuits

Four in-service load circuit configurations are possible as shown in Table 2.

Table 2 – In-service load circuit configurations

In-service configuration	Switching device location	Reactor neutral earthing	TRV values	Test circuit
1	Source side of reactor	Isolated	Table 3	Figure 3 or Figure 4
2		Earthed	Table 4	Figure 3 or Figure 4
3	Neutral side of reactor	Isolated	Table 5	Figure 5
4		Earthed	Table 6	Figure 4 or Figure 5

The in-service load circuit configurations are covered by three test circuits detailed in Tables 3, 4, 5 and 6 and Figures 3, 4 and 5, respectively.

NOTE 1 Applying a switching device on the neutral side of the reactor is only a consideration at rated voltages of 52 kV and below and the TRV values shown in Tables 5 and 6 are limited to this range.

NOTE 2 The test circuit shown in Figure 4 is applicable for in-service configuration 4 even though the switching device location is on the source side of the reactor.

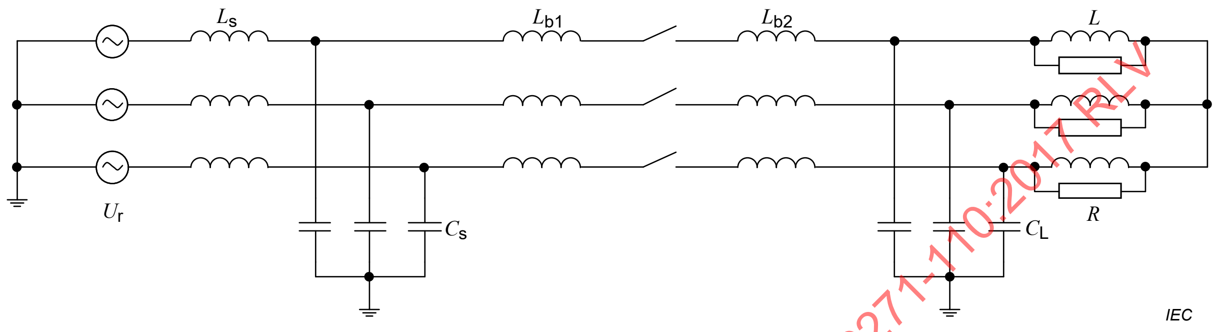
For circuit-breakers the requirements of 6.102.1 and 6.102.2 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012 shall be fulfilled.

For three-pole in one enclosure type switching devices, single pole testing is permissible provided that the correct transient recovery voltages to earth (enclosure) are achieved.

For non-earthed reactors on solidly earthed systems, three-pole testing is impractical at higher rated voltages. Single-pole testing is permissible on the basis that the neutral point is earthed prior to in-service switching.

For switchgear under test that includes a switching device with overvoltage protection devices, the devices may be included in the test circuit provided that the devices are an intrinsic part of the switching device.

When overvoltage limiting devices are added in the test circuit for its protection against possible excessive overvoltages, it shall be proven that these devices have not limited the overvoltages recorded during the tests, for instance by recording the current through these devices.

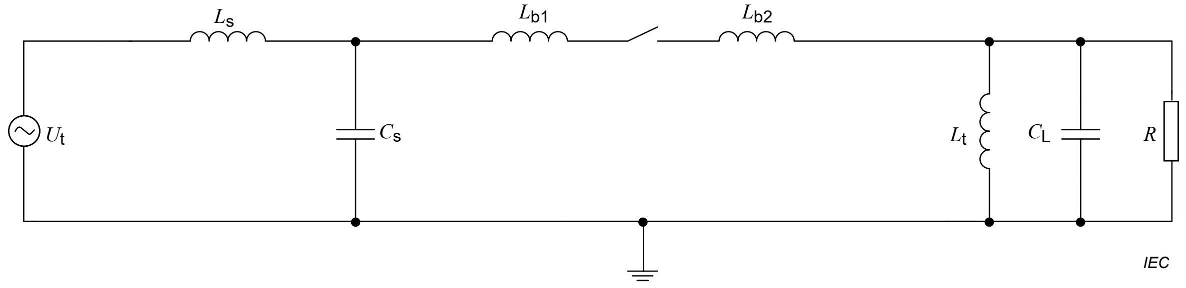


Key

U_r	rated voltage
L_s	inductance of the source
L_{b1}, L_{b2}	inductance of the connections
L	inductance of the reactor
C_s	capacitance of the source
C_L	capacitance of the load
R	representation of load losses (to obtain 1,9 amplitude factor)

NOTE The reactor neutral can be isolated or earthed.

Figure 3 – Reactor switching test circuit – Three-phase test circuit for in-service load circuit configurations 1 and 2 (Table 2)



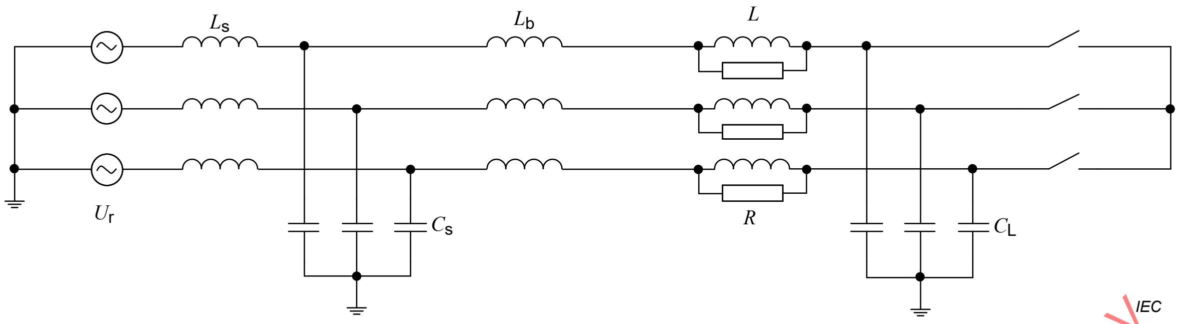
Key

U_t	test voltage
L_s	inductance of the source
L_{b1}, L_{b2}	inductance of the connections
L_t	inductance of the test-circuit reactor
C_s	capacitance of the source
C_L	capacitance of the load
R	representation of load losses (to obtain 1,9 amplitude factor)

For in-service load circuit configurations 2 and 4 (Table 2) $U_t = U_r/\sqrt{3}$ and $L_t = L$ where L is the inductance of the reactor in service.

For in-service load circuit configuration 1 (Table 2) $U_t = 1{,}5 \times U_r/\sqrt{3}$ and $L_t = 1{,}5 \times L$ where L is the inductance of the reactor in service.

Figure 4 – Reactor switching test circuit – Single-phase test circuit for in-service load circuit configurations 1, 2 and 4 (Table 2)



Key

U_r	rated voltage
L_s	inductance of the source
L_b	inductance of the connection
L	inductance of the reactor
C_s	capacitance of the source
C_L	capacitance of the load
R	representation of load losses (to obtain 1,9 amplitude factor)

NOTE This is the only test circuit that can be used for this case. No single-phase test circuit will give the correct test current and TRV and t_3 values.

Figure 5 – Reactor switching test circuit – Three-phase test circuit for in-service load circuit configuration 3 (Table 2)

4.4.4 Characteristics of the supply circuit

The source inductance L_s shall not be smaller than that corresponding to the rated short-circuit current of the circuit-breaker, nor larger than 10 % of the inductance of the load circuit L.

NOTE A higher value of L_s is acceptable if the resulting voltage drop is compensated by tuning the frequency of the TRV to that of the load side.

The source capacitance C_s shall be at least 10 times the load capacitance C_L.

The TRV of the supply circuit has a negligible influence on that of the complete circuit and is therefore not specified.

4.4.5 Characteristics of the connecting leads

The total inductance $L_b = L_{b1} + L_{b2}$ of the leads may be shared between the supply and the load side. The value of L_b is not specified but should be as small as possible.

4.4.6 Characteristics of the load circuits

4.4.6.1 General

The load circuits shall consist of a reactor, or alternatively, an air-cored or iron-cored reactance with appropriate shunt capacitance and resistance so as to produce a prospective transient voltage not less severe than the values specified in Tables 3, 4, 5 and 6.

Table 3 –Values of prospective transient recovery voltages – Rated voltages 12 kV to 170 kV for effectively and non-effectively earthed systems – Switching shunt reactors with isolated neutrals (Table 2: In-service load circuit configuration 1)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter $t_3\ {}^{0}_{-20}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
12	28	9	16
17,5	41	11	19
24	56	13	22
36	84	15	27
52	121	55	97
72,5	169	64	115
100	233	107	190
123	286	120	210
145	337	130	230
170	395	140	248

u_c and t_3 are as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

The first-pole-to-clear factor k_{pp} is 1,5 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r\sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of

- 500 pF for voltages below 52 kV;
- 1 750 pF for voltages at or above 52 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the switching device.

Table 4 – Values of prospective transient recovery voltages – Rated voltages 100 kV to 1 200 kV for effectively earthed systems – Switching shunt reactors with earthed neutrals (See Table 2: In-service load circuit configuration 2)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter t_3 ${}_{-20}^{0}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
100	155	87	155
123	191	97	172
145	225	105	187
170	264	114	203
245	380	167	297
300	465	185	328
362	562	203	360
420	652	220	388
550	853	250	444
800	1 240	300	536
1 100	1 700	–	1 170
1 200	1 860	–	1 220

u_c and t_3 as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

The first-pole-to-clear factor k_{pp} is 1,0 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r \sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of

- 1 750 pF for voltages at or above 100 kV and below 245 kV;
- 2 600 pF for voltages of 245 kV up to and including 800 kV;
- 9 000 pF for voltages above 800 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the switching device.

Table 5 – Values of prospective transient recovery voltages – Rated voltages 12 kV to 52 kV for effectively and non-effectively earthed systems – Switching shunt reactors with isolated neutrals (See Table 2: In-service load circuit configuration 3)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter t_3 ${}^{0}_{-20}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
12	28	7	13
17,5	41	9	16
24	56	10	18
36	84	12	22
52	121	45	79

u_c and t_3 as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

The first-pole-to-clear factor k_{pp} is 1,5 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r \sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of 500 pF for voltages below 52 kV and 1 750 pF for voltages of 52 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the switching device.

Table 6 – Values of prospective transient recovery voltages – Rated voltages 12 kV to 52 kV for effectively and non-effectively earthed systems – Switching shunt reactors with earthed neutrals (See Table 2: In-service load circuit configuration 4)

Rated voltage U_r kV	Peak voltage u_c kV	Time parameter $t_3\ {}^{0}_{-20}$ %	
		Load circuit 1	Load circuit 2
		µs	µs
12	19	7	13
17,5	27	9	16
24	37	10	18
36	56	12	22
52	81	45	79

u_c and t_3 as defined in 4.102 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

The first-pole-to-clear factor k_{pp} is 1,0 for this case. The amplitude factor k_{af} is assumed to be 1,9.

$$u_c = U_r \sqrt{\frac{2}{3}} \times k_{pp} \times 1{,}9$$

NOTE 1 The transient voltage is of a damped (1-cos) form and the values are for the first pole to clear. Stated u_c values do not take arc voltage, current chopping or re-ignitions into account and actual measured u_c values can be higher than those stated in this table.

NOTE 2 The values of t_3 are based on a mean capacitance value of load side capacitance C_L of 500 pF for voltages below 52 kV and 1 750 pF for voltages of 52 kV.

If the actual values of C_L are known for a particular application, then the applicable t_3 values can be calculated as described in Annex A.

NOTE 3 The recovery voltages given in the table are not necessarily representative for all field applications, but are suitable to determine the current chopping behaviour of the switching device.

The values of t_3 are based on a calculation at 50 Hz. There is no need to differentiate between 50 Hz and 60 Hz since the stress of the tests with both frequencies is equivalent. This is taken into account by the overlapping tolerances for the frequency of the test current.

The test current shall be symmetrical (DC component lower than 20 %).

4.4.6.2 Load circuit 1

The inductance L of the load circuit shall be adjusted to give the breaking currents in Table 7.

Table 7 – Load circuit 1 test currents

Rated voltage kV	Test current A (± 20 %)
< 52	1 600
52 to 72,5	630
100 to 800	315

NOTE A test at 315 A is not required for rated voltages of 1 100 kV and 1 200 kV since such a current value represents an unrealistic shunt reactor rating.

4.4.6.3 Load circuit 2

The inductance L of the load shall be adjusted to give the breaking currents in Table 8.

Table 8 – Load circuit 2 test currents

Rated voltage kV	Test current A (± 20 %)
< 52	500
52 to 72,5	200
100 to 1 200	100

However, if the switching device is used to switch reactor currents smaller than these values, the load circuit 2 should be adjusted to give the lower limit of the actual current range. The lower the current the more severe the switching duty is for the switching device.

4.4.7 Earthing of the test circuit

Earthing of the test circuit shall be as indicated in Figures 3 to 5.

4.4.8 Test voltage

For three-phase tests, the test voltage measured between the phases at the switching device location immediately prior to the opening shall, with a tolerance of ±5 %, be equal to the rated voltage U_r of the switching device (Tables 3, 4, 5 and 6).

For single-phase laboratory tests, the voltage measured at the switching device location immediately before the opening shall, with a tolerance of ±5 %, be equal to the test voltage as stated in Figure 4.

4.4.9 Test-duties

4.4.9.1 General

The reactor switching tests shall consist of three three-phase test-duties or four single-phase test-duties using the supply circuit detailed in 4.4.4 and the load circuits detailed in 4.4.6.2 and 4.4.6.3.

Test-duties 1 and 2 shall be made at rated filling pressure for interruption, insulation and operation and shall consist of twenty breaking operations. They shall be made with each load circuit with the initiation of the tripping impulse distributed at intervals of 9 electrical degrees for three-phase tests or 18 electrical degrees for single-phase tests.

Test-duty 3 shall be performed at rated filling pressure for interruption, insulation and operation for single-phase tests only and shall consist of 18 breaking operations. It shall be performed with load circuit 2 around the arc duration at which the re-ignitions occurred in the previous test series with load circuit 2. Six breaking operations shall be made with the initiation of the tripping impulse at the point that gave the highest breakdown voltage u_w, 6 breaking operations with the initiation of the tripping impulse retarded by 9 electrical degrees and 6 breaking operations with the initiation of the tripping impulse advanced by 9 electrical degrees. If no re-ignition occurs in the test-duty with load circuit 2, test-duty 3 shall consist of 6 breaking operations with the initiation of the tripping impulse at the point that gave the shortest arcing time, 6 break tests with the initiation of the tripping impulse retarded by 9 electrical degrees and 6 break tests with the initiation of the tripping impulse retarded by a further 9 electrical degrees.

Test-duty 4 shall be performed at the minimum pressure for interruption, insulation and operation using load circuit 2 only. For three-phase tests, 20 breaking operations shall be made with the initiation of the tripping impulse distributed at intervals of 9 electrical degrees. For single-phase tests, 20 breaking operations shall be made with the initiation of the tripping impulse distributed at intervals of 18 electrical degrees.

The test-duties are summarized in Table 9.

Table 9 – Test-duties for reactor current switching tests

Test-duty	Number of breaking operations		Test current determined by
	Three-phase	Single-phase	
1	20	20	Load circuit 1 (4.4.6.2)
2	20	20	Load circuit 2 (4.4.6.3)
3	–	18	Load circuit 2 (4.4.6.3)
4	20	20	Load circuit 2 (4.4.6.3)

The current value used in test-duty 2, 3 and 4 is the minimum shunt reactor switching current. However, if the switching device is to be used to switch reactor currents smaller than these values, the current for test-duty 2, 3 and 4 shall be adjusted to the lower limit of the actual current range or as close as possible to this current value. Calculation of the applicable t_3 value for such a case is described in Annex A.

4.4.9.2 Test measurements

At least the following quantities should be recorded by oscillograph or other suitable recording techniques with sufficient bandwidth and time resolution:

– supply side voltage, phase-to-earth;
– voltage across switching device terminals;
– load side voltage, phase-to-earth, at the terminal of the load reactor;
– load side neutral point voltage to earth (in three-phase tests);
– current through the switching device.

4.4.9.3 Behaviour and condition of switching device

The criteria for successful testing are as follows.

a) The switching device shall interrupt the current with at most one re-ignition leading to conduction of another loop of power-frequency current. This criterion applies to all three switching device poles in three-phase tests.

   NOTE Multiple high-frequency re-ignitions in any one current zero crossing can be counted as one such re-ignition.

b) A visual inspection shall be performed to demonstrate that the re-ignitions occurred between the arcing contacts only. There shall be no evidence of puncture, flashover or permanent tracking of the internal parts that contribute to the insulation. Wear of the parts of the arc control devices exposed to the arc is permissible provided that it does not impair breaking capability.

   NOTE In many designs of circuit-breakers "auxiliary" nozzles are included that do not contribute to the insulation but assist the short-circuit current breaking process by the release of ablated vapour, leading to material loss and deformation.

   Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a re-ignition.

   For switching devices with sealed-for-life interrupter units, no visual inspection is required but the dielectric condition test according to 6.2.11 of IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012 shall be performed.

4.4.9.4 Test report

In addition to the requirements of Annex C of IEC 62271-100:2008, the test report shall include a thorough description of the circuit including the following details (Figure 3, Figure 4 and Figure 5):

– L_s: inductance of the source;
– L_{b1}, L_{b2}: inductance of connections;
– L: inductance of reactor;
– C_s: capacitance of source;
– C_L: capacitance of load;
– R: representation of load losses.

The following quantities shall be measured and evaluated at each test (Figure 2 and Figure 6):

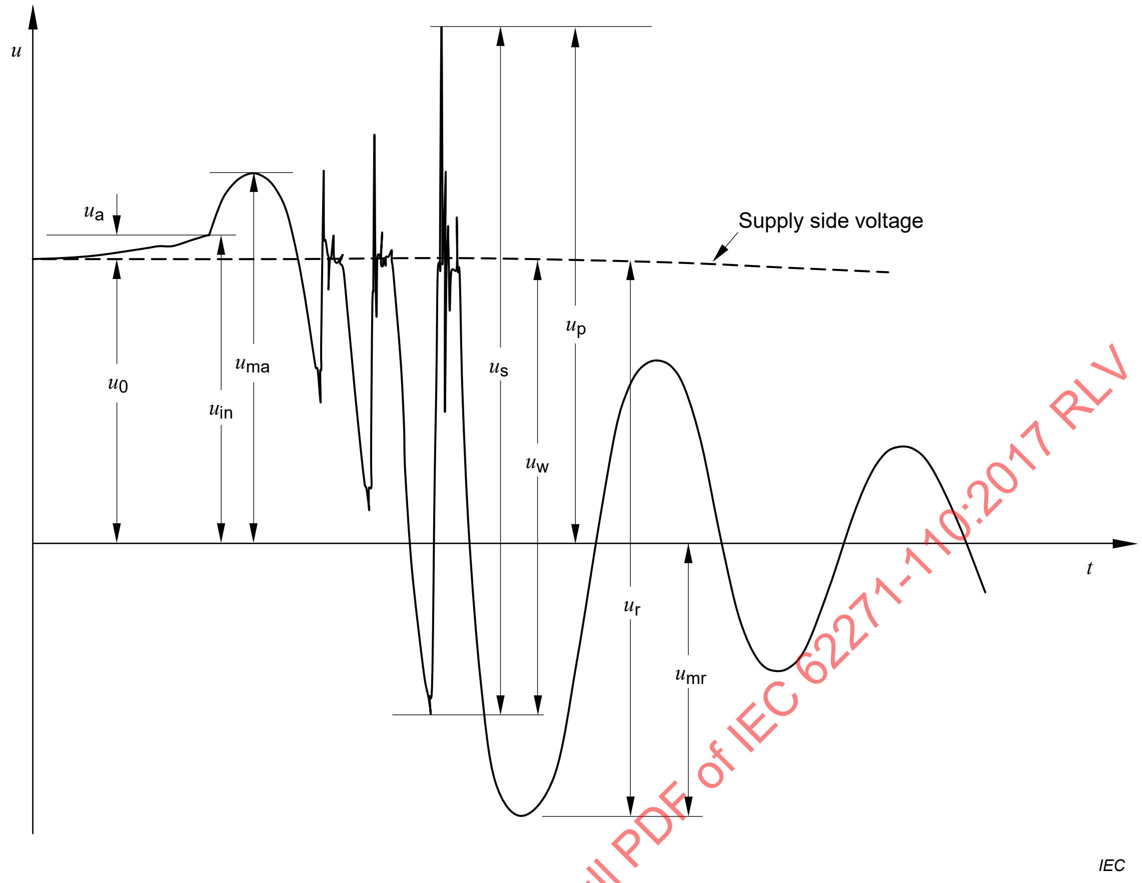
- u_{ma}: suppression peak voltage to earth;
- u_{in}: initial voltage (at the instant of chopping);
- u_{mr}: load side voltage peak to earth;
- u_w: voltage across the switching device at re-ignition (if applicable);
- arcing time;
- breaking current;
- test voltage.

In three-phase tests, the above quantities shall be reported for all three switching device poles.

NOTE The application of the test results to predict overvoltages in actual installations is treated in IEC TR 62271-306.

In addition, the re-ignition-free arcing window resulting from all tests shall be evaluated and included in the report. This is the period of shortest arc duration during which no re-ignition is observed. In a three-phase test, this period refers to absence of re-ignition in all three poles of the switching device.

If a re-ignition-free arcing window has been specified, the re-ignition-free arcing window measured during the tests should be equal to or greater than the specified value. Evaluation in this regard should consider the actual system frequency.



Key

u_0	power frequency voltage crest value to earth
u_a	arc voltage drop of switching device
$u_{in} = u_0 + u_a$	initial voltage to earth at the moment of current chopping
u_{ma}	suppression peak voltage to earth
u_{mr}	load side voltage peak to earth
u_s	maximum overvoltage to earth (could be equal to u_{ma} or u_{mr})
u_p	maximum peak-to-peak voltage excursion at re-ignition
u_w	voltage across the switching device at re-ignition
u_r	voltage across the switching device at the recovery peak

Figure 6 – Illustration of voltage transients at interruption of inductive current for a single-phase test

Annex A
(normative)

Calculation of t_3 values

For the following cases, the required test circuit t_3 values shall be calculated as described in Annex A:

a) for switching devices rated at less than 52 kV, where the required test current is less than the 500 A value stated in Table 8;

b) for switching devices rated 52 kV to 72,5 kV, where the required test current is less than the 200 A value stated in Table 8;

c) for switching devices rated at 100 kV to 1 200 kV, where the required test current is less than the 100 A value stated in Table 8.

Step 1: Calculate the required inductance (L)

$$L = \frac{U_r}{\sqrt{3}\,\omega I}$$

where U_r is the rated voltage, I is the required test current and $\omega = 314$ rad/s at 50 Hz.

$L = \frac{1{,}84\,U_r}{I}$, with U_r in kilovolt (kV), I in ampere (A) and L in henry (H), all at 50 Hz.

Step 2: Calculate the required t_3 value

Case 1: Reactor neutral earthed

Time to peak T for (1 − cosine) function is given by:

$$T = \pi\sqrt{LC}$$

Ratio t_3/T for an amplitude factor of 1,9 is 0,873:

$$t_3 = 0{,}873 \times \pi \times \sqrt{LC} = 2{,}74 \times \sqrt{LC} \times 10^6 \text{ µs}$$

where the value of C in farad (F) is taken from NOTE 2 in Tables 3, 4, 5 and 6 (default value if actual value is not known).

Case 2: Reactor neutral isolated

$$t_3 = 0{,}873 \times \pi \times \sqrt{1{,}5\,LC} = 3{,}36 \times \sqrt{LC} \times 10^6 \text{ µs}$$

EXAMPLE 1 U_r = 245 kV, 50 Hz and required test current 75 A, reactor neutral earthed:

$$L = \frac{1{,}84 \times 245}{75} = 6\text{ H}$$

$$t_3 = 2{,}74\sqrt{6 \times 2\,600 \times 10^{-12}} \times 10^6 = 342\ \mu s$$

EXAMPLE 2 U_r = 36 kV, 50 Hz and required test current 350 A, reactor neutral isolated:

$$L = \frac{1{,}84 \times 36}{350} = 0{,}19\ H$$

$$t_3 = 3{,}36\sqrt{0{,}19 \times 500 \times 10^{-12}} \times 10^6 = 32{,}7\ \mu s$$

Bibliography

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*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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APPAREILLAGE À HAUTE TENSION –

Partie 110: Manœuvre de charges inductives

AVANT-PROPOS

1) La Commission Electrotechnique Internationale (IEC) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de l'IEC). L'IEC a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. A cet effet, l'IEC – entre autres activités – publie des Normes internationales, des Spécifications techniques, des Rapports techniques, des Spécifications accessibles au public (PAS) et des Guides (ci-après dénommés "Publication(s) de l'IEC"). Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec l'IEC, participent également aux travaux. L'IEC collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.
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La Norme internationale IEC 62271-110 a été établie par le sous-comité 17A: Appareils de connexion, du comité d'études 17 de l'IEC: Appareillage haute tension.

Cette quatrième édition annule et remplace la troisième édition parue en 2012. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

– tous les appareils de connexion sont dorénavant couverts, et non uniquement les disjoncteurs;
– un nombre limité d'essais T10 ne couvrent plus les essais d'établissement et de coupure de courant de bobine d'inductance shunt en dessous de 52 kV;

– l'évaluation et la consignation d'une plage de coupure sans réallumage ont été ajoutées.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
17A/1151/FDIS	17A/1155/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 62271, publiées sous le titre général *Appareillage à haute tension*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. A cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

Le contenu des corrigenda de décembre 2017 et février 2018 a été pris en considération dans cet exemplaire.

APPAREILLAGE À HAUTE TENSION –

Partie 110: Manœuvre de charges inductives

1 Domaine d'application

La présente partie de l'IEC 62271 est applicable aux appareils de connexion à courant alternatif conçus pour une installation à l'intérieur ou à l'extérieur, et pour fonctionner à des fréquences de 50 Hz à 60 Hz, sur des réseaux de tensions supérieures à 1 000 V, et prévus pour l'établissement et la coupure de courants inductifs. Le présent document est applicable aux appareils de connexion (y compris les disjoncteurs selon l'IEC 62271-100) qui sont utilisés pour l'établissement et la coupure de courants de moteurs à haute tension et de courants de bobines d'inductance shunt, et aussi aux contacteurs à haute tension utilisés pour l'établissement et la coupure de courants de moteurs à haute tension, tels que couverts par l'IEC 62271-106.

La manœuvre de transformateurs à vide, c'est-à-dire la coupure de courants magnétisants de transformateurs, n'est pas prise en compte dans ce document. Les raisons pour cela sont les suivantes:

a) En raison du comportement non linéaire du circuit magnétique du transformateur, il n'est pas possible de modéliser correctement l'établissement et la coupure d'un courant magnétisant d'un transformateur en utilisant des composants linéaires dans un laboratoire d'essais. Les essais effectués en utilisant un transformateur à disposition, tel qu'un transformateur d'essai, sont valables seulement pour le transformateur soumis à l'essai et ne peuvent pas être représentatifs pour d'autres transformateurs.
b) Ainsi qu'il est détaillé dans l'IEC TR 62271-306, les caractéristiques de cette manœuvre sont habituellement moins sévères que les autres manœuvres d'établissement et de coupure de courants inductifs. Une telle manœuvre peut produire des surtensions sévères dans le ou les bobinages d'un transformateur en fonction de la caractéristique de réallumage de l'appareil de connexion et des fréquences de résonance du bobinage du transformateur.

NOTE 1 L'établissement et la coupure de bobines d'inductance tertiaire, du côté haute tension du transformateur, ne sont pas couverts par le présent document.

NOTE 2 L'établissement et la coupure de bobines d'inductance shunt mises à la terre à travers des bobines d'inductance de neutre ne sont pas couverts par le présent document. Cependant, l'application des résultats d'essai, effectués suivant le présent document, à l'établissement et à la coupure des bobines d'inductance mises à la terre par bobine d'inductance de neutre (schéma à quatre noyaux), est abordée dans l'IEC TR 62271-306.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60050-441, *Vocabulaire électrotechnique international – Chapitre 441: Appareillage et fusibles* (disponible à l'adresse www.electropedia.org)

IEC 62271-1:2017, *Appareillage à haute tension – Partie 1: Spécifications communes pour appareillage à courant alternatif*

IEC 62271-100:2008, *Appareillage à haute tension – Partie 100: Disjoncteurs à courant alternatif*
IEC 62271-100:2008/AMD1:2012

IEC 62271-106:2011, *Appareillage à haute tension – Partie 106: Contacteurs, combinés de démarrage à contacteurs et démarreurs de moteurs, pour courant alternatif*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC 60050-441, l'IEC 62271-1, ainsi que les suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
courant inductif
courant à fréquence industrielle fourni par un circuit inductif ayant un facteur de puissance inférieur ou égal à 0,5

3.2
arrachement du courant
interruption brusque du courant dans un appareil de connexion à un point de l'onde de courant autre que celle du passage à zéro du courant à fréquence industrielle

3.3
arrachement virtuel du courant
arrachement du courant dans l'une des trois phases d'un circuit triphasé provoqué par des transitoires dans une autre phase du circuit

3.4
crête d'extinction
première crête de la tension transitoire à la terre du côté charge de l'appareil de connexion après l'interruption du courant

Note 1 à l'article: La crête d'extinction n'est pas nécessairement la valeur maximale absolue de la tension transitoire de rétablissement. Des amorçages préalables peuvent être apparus à des valeurs de tension plus élevées.

3.5
crête de rétablissement
valeur maximale de la tension à travers l'appareil de connexion, se produisant lorsque la polarité de la tension de rétablissement est égale à la polarité de la tension à fréquence industrielle

Note 1 à l'article: La crête de rétablissement n'est pas nécessairement la valeur maximale absolue de la tension transitoire de rétablissement. Des amorçages préalables peuvent être apparus à des valeurs de tension plus élevées.

3.6
réallumage
rétablissement du courant entre les contacts d'un appareil mécanique de connexion au cours d'une manœuvre de coupure, l'intervalle de temps durant lequel le courant est resté nul étant inférieur à un quart de la période correspondant à la fréquence industrielle

Note 1 à l'article: Dans le cas de la manœuvre de charges inductives, l'établissement du réallumage est un événement à fréquence élevée, qui peut être de nature simple ou multiple et qui peut, dans certains cas, être interrompu sans courant de suite à fréquence industrielle.

3.7
plage de coupure sans réallumage
durée de l'arc au cours d'une manœuvre de coupure pendant laquelle les contacts d'un appareil mécanique de connexion atteignent une distance empêchant le réallumage

4 Essais de type

4.1 Généralités

Les disjoncteurs, selon l'IEC 62271-100, et les contacteurs, selon l'IEC 62271-106, ne disposent pas de caractéristiques assignées de manœuvres inductives dédiées. Toutefois, les appareils de connexion utilisés à cet effet doivent répondent aux exigences du présent document.

Pour les essais d'établissement et de coupure de courant de bobines d'inductance shunt des disjoncteurs, les valeurs des niveaux d'isolement assignés dans les Tableaux 1a, 1b, 3 et 4 de l'IEC 62271-1:2017 sont applicables, à l'exception des essais de tension combinée à travers la distance de sectionnement (colonnes (6) et (8) du Tableau 3 et colonne (7) du Tableau 4).

Les essais de type sont, en plus de ceux spécifiés dans la norme de produit applicable, à l'exception des défauts proches en ligne, l'établissement et la coupure de courants de discordance de phases et de courants capacitifs.

NOTE 1 Cette exception est due au fait que le circuit de charge par bobine d'inductance shunt ne comporte pas de source.

NOTE 2 Dans certains cas (niveaux élevés de surtension par arrachement de courant, ou lorsqu'une bobine d'inductance de neutre est présente ou dans le cas de bobines d'inductance shunt avec neutre isolé), il peut être nécessaire de spécifier un niveau d'isolement approprié qui est plus élevé que les valeurs assignées données ci-dessus.

Les essais d'établissement et de coupure de courants inductifs effectués pour un niveau de courant et un type d'application donnés peuvent être considérés comme valables pour un autre courant assigné et pour le même type d'application, tel que détaillé ci-après:

a) pour l'établissement et la coupure de bobines d'inductance shunt, de tensions assignées supérieures ou égales à 52 kV, les essais à un niveau de courant particulier doivent être considérés comme valables pour des applications avec un niveau de courant jusqu'à 150 % supérieur à la valeur du courant d'essai;
b) pour l'établissement et la coupure de bobines d'inductance shunt de tensions assignées inférieures à 52 kV, des essais de type sont exigés;
c) pour l'établissement et la coupure de moteurs à haute tension, des essais de type pour les courants de moteurs bloqués à 100 A et 300 A sont considérés comme couvrant les courants de moteurs bloqués dans la plage de 100 A à 300 A et le courant associé au courant de court-circuit de la séquence d'essais T10, conformément à 6.106.1 de l'IEC 62271-100:2008 pour les disjoncteurs et le courant d'emploi assigné pour les contacteurs.

Selon a), l'objet des essais de type est de déterminer également la plage de coupure sans réallumage pour des connexions contrôlées (se reporter à l'IEC TR 62271-302) et il convient de faire preuve de circonspection dans le cas des applications à des valeurs de courants supérieures aux valeurs en essai puisque la plage de coupure sans réallumage peut augmenter avec un courant plus élevé.

L'Annexe B de l'IEC 62271-100:2008 peut être utilisée en ce qui concerne les tolérances sur les grandeurs d'essai.

4.2 Dispositions diverses pour les essais de manœuvres de charges inductives

Le paragraphe 6.102 de l'IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012 est applicable, avec l'ajout suivant:

Les essais d'établissement et de coupure de courant de moteur à haute tension et de bobine d'inductance shunt doivent être effectués à la tension assignée d'alimentation des circuits auxiliaires et de commande ou, si nécessaire, à la tension maximale d'alimentation des circuits auxiliaires et de commande pour obtenir un fonctionnement stable des manœuvres d'ouverture et de fermeture, conformément à 6.102.3.1 de l'IEC 62271-100:2008.

Pour les appareils de connexion à remplissage de gaz (y compris les appareils de connexion à vide utilisant un support gazeux pour l'isolation), les essais doivent être effectués à la pression de fonctionnement assignée pour la coupure et l'isolement, excepté pour la séquence d'essais 4, pour laquelle la pression doit être la pression minimale de fonctionnement pour la coupure et l'isolement.

4.3 Essais d'établissement et de coupure de courants de moteurs à haute tension

4.3.1 Applicabilité

Le paragraphe 4.3 s'applique aux appareils de connexion triphasés à courant alternatif de tensions assignées supérieures à 1 kV et allant jusqu'à 17,5 kV, utilisés pour l'établissement et la coupure de moteurs à haute tension. Les essais peuvent être effectués à 50 Hz avec une tolérance relative de ±10 %, ou 60 Hz avec une tolérance relative de ±10 %, les deux fréquences étant considérées comme équivalentes.

Les essais d'établissement et de coupure de moteurs s'appliquent à tous les appareils de connexion tripolaires de tensions assignées inférieures ou égales à 17,5 kV, qui peuvent être utilisés pour l'établissement et la coupure de moteurs asynchrones triphasés à cage d'écureuil ou à bagues. L'appareil de connexion peut avoir une tension assignée plus élevée que celle du moteur lorsqu'il est raccordé au moteur par un transformateur abaisseur. Cependant, l'application courante est le raccordement direct par câble de l'appareil de connexion au moteur. Lorsque des essais sont exigés, ils doivent être effectués selon 4.3.2 à 4.3.9.

Lorsque des dispositifs limiteurs de surtension sont obligatoires pour les appareils soumis aux essais, des dispositifs limiteurs de tension peuvent être inclus dans le circuit d'essai, à condition que les dispositifs fassent partie intégrante de l'appareil en essai.

Aucune limite de surtension n'est donnée car les surtensions dépendent uniquement de l'application considérée. Les surtensions entre phases peuvent être aussi significatives que les surtensions entre phase et terre.

4.3.2 Généralités

Les essais de coupure et d'établissement peuvent être effectués soit sur site, soit en laboratoire. En ce qui concerne les surtensions, la coupure du courant d'un moteur de démarrage ou bloqué est normalement la manœuvre la plus sévère.

En raison du comportement non linéaire du circuit magnétique du moteur, il n'est pas possible de modéliser correctement l'établissement et la coupure d'un courant de moteur en utilisant des composants linéaires dans un laboratoire d'essais. Les essais effectués en utilisant des composants linéaires pour simuler des moteurs peuvent être considérés comme plus contraignants que l'établissement et la coupure de moteurs réels.

Un circuit normalisé simulant un moteur bloqué est spécifié pour les essais en laboratoire (voir la Figure 1). Les paramètres de ce circuit d'essai ont été choisis pour représenter un cas relativement sévère en ce qui concerne les surtensions, et couvrent la majorité des applications pratiques.

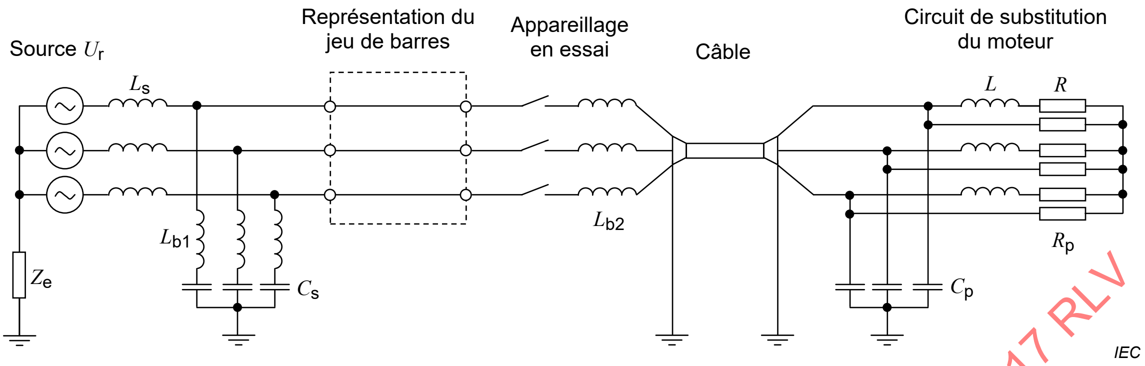
Les essais en laboratoire sont effectués pour prouver la capacité d'un appareil de connexion à établir et à couper les courants de moteurs, et pour déterminer son comportement en ce qui concerne les surtensions d'établissement et de coupure, les réallumages et l'arrachement de courant. Ces caractéristiques peuvent servir de base à l'estimation du fonctionnement de l'appareil de connexion avec d'autres circuits de moteurs. Les essais effectués avec les courants d'essai définis en 4.3.3 et 4.3.4 démontrent la capacité de l'appareil de connexion à établir et à couper des courants de moteurs à haute tension jusqu'à son pouvoir de coupure assigné.

Pour les essais sur site, les circuits réels sont utilisés avec un réseau d'alimentation du côté source et un câble et un moteur du côté charge. Il peut y avoir aussi un transformateur entre l'appareil de connexion et le moteur. Cependant, les résultats de tels essais sur site ne sont valables que pour les appareils de connexion insérés dans des circuits similaires à ceux utilisés pour les essais.

L'appareil en essai comprend l'appareil de connexion avec des dispositifs de protection contre les surtensions, s'ils sont équipés normalement.

NOTE 1 Des surtensions peuvent être produites à l'établissement ou à la coupure de moteurs en rotation normale. Cette condition n'est pas représentée par le circuit de substitution, et est généralement considérée comme moins sévère que le cas du moteur bloqué.

NOTE 2 En période de démarrage, l'établissement et la coupure d'un moteur à bagues sont généralement moins sévères à cause de l'effet de la résistance de démarrage.



Légende

U_r	tension assignée	
Z_e	impédance de mise à la terre	impédance assez forte pour limiter le courant de défaut phase-terre au-dessous du courant d'essai (peut être infinie)
L_s	inductance côté source	$\omega L_s \leq 0{,}1\omega L$, mais le courant de court-circuit présumé ≤ au courant de court-circuit assigné de l'appareil de connexion en essai
C_s	capacité côté alimentation	0,03 µF à 0,05 µF pour le circuit d'alimentation A 1,5 µF à 2 µF pour le circuit d'alimentation B
L_{b1}	inductance des condensateurs et du raccordement	≤ 2 µH
Représentation du jeu de barres		5 m à 7 m de longueur espacés suivant la tension assignée
L_{b2}	inductance des connexions	≤ 5 µH
Câble		100 m ± 10 m, à écran, impédance caractéristique 30 Ω à 50 Ω
L	inductance de substitution du moteur	circuit de charge 1: 100 A ± 10 A circuit de charge 2: 300 A ± 30 A
R	résistance de substitution du moteur	cos $\varphi \leq 0{,}2$
C_p	capacité parallèle de substitution du moteur	fréquence 10 kHz à 15 kHz
R_p	résistance parallèle de substitution du moteur	facteur d'amplitude 1,6 à 1,8

Figure 1 – Circuit d'essai d'établissement et de coupure de moteur et résumé des paramètres

4.3.3 Caractéristiques des circuits d'alimentation

4.3.3.1 Généralités

Un circuit d'alimentation triphasé doit être utilisé. Les essais doivent être effectués en utilisant deux circuits d'alimentation différents A et B, tel que spécifié respectivement en 4.3.3.2 et 4.3.3.3. Le circuit d'alimentation A représente le cas d'un moteur connecté directement à un transformateur. Le circuit d'alimentation B représente le cas dans lequel des câbles en parallèle sont connectés sur le côté alimentation.

4.3.3.2 Circuit d'alimentation A

L'alimentation triphasée peut être mise à la terre par l'intermédiaire d'une impédance de forte valeur ohmique, de telle sorte que la tension d'alimentation soit définie par rapport à la terre. La valeur de l'impédance doit être assez grande pour limiter le courant présumé d'un défaut entre phase et terre à une valeur inférieure au courant d'essai.

L'inductance de la source L_s ne doit pas être inférieure à celle qui correspond au courant assigné de coupure de court-circuit de l'appareil de connexion soumis à l'essai. Son impédance doit aussi ne pas être supérieure à 0,1 fois l'impédance de l'inductance du circuit de charge (voir 4.3.4).

La capacité C_s du circuit d'alimentation est représentée par trois condensateurs branchés en étoile, dont le point commun est mis à la terre. Leur valeur, y compris les capacités naturelles du circuit, doit être de 0,04 µF ± 0,01 µF. L'inductance L_{b1} des condensateurs et de leurs raccordements ne doit pas dépasser 2 µH.

L'inductance du jeu de barres est représentée par trois barres longues de 6 m ± 1 m chacune et espacées d'une distance appropriée à la tension assignée.

4.3.3.3 Circuit d'alimentation B

Comme le circuit d'alimentation A, avec une valeur de capacité du circuit d'alimentation portée à 1,75 µF ± 0,25 µF.

4.3.4 Caractéristiques du circuit de charge

4.3.4.1 Généralités

Un circuit de charge triphasé doit être utilisé. Le circuit de substitution de moteur est raccordé à l'appareil de connexion en essai par un câble à écran de 100 m ± 10 m de long. Il est recommandé de connecter directement le câble aux bornes du moteur ou du circuit de substitution.

Il convient que l'inductance de toute connexion intermédiaire ne dépasse pas 3 µH. Les deux extrémités de l'écran du câble doivent être mises à la terre, tel que représenté à la Figure 1. Les essais doivent être effectués en utilisant deux circuits de substitution de moteur différents, tel que spécifié en 4.3.4.2 et 4.3.4.3. L'inductance L_{b2} des connexions entre l'appareil de connexion et le câble ne doit pas dépasser 5 µH.

NOTE L'utilisation d'un circuit d'essai triphasé est nécessaire afin de permettre l'éventualité d'un arrachement virtuel du courant.

4.3.4.2 Circuit 1 de substitution de moteur

Une résistance et une inductance doivent être montées en série pour obtenir un courant de 100 A ± 10 A, avec un facteur de puissance inférieur à 0,2 en retard. Le point commun ne doit pas être raccordé à la terre. Une résistance R_p doit être connectée en parallèle avec l'impédance de chaque phase et la capacité C_p entre chaque phase et la terre, de sorte que le circuit de substitution du moteur ait une fréquence propre de 12,5 kHz ± 2,5 kHz et un facteur d'amplitude de 1,7 ± 0,1, mesurés sur chaque phase avec les deux autres phases connectées à la terre. Les valeurs présumées des tensions transitoires de rétablissement doivent être déterminées conformément à l'Annexe F de l'IEC 62271-100:2008. Un transformateur peut être introduit à l'extrémité aval du câble. Celui-ci doit être considéré comme faisant partie du circuit de substitution du moteur.

4.3.4.3 Circuit 2 de substitution de moteur

Comme le circuit 1 de substitution de moteur, mais en réduisant la résistance en série et l'inductance pour obtenir un courant de 300 A ± 30 A avec un facteur de puissance inférieur à

0,2 en retard. La tension transitoire de rétablissement présumée doit être la même que celle qui est spécifiée pour le circuit 1 de substitution de moteur.

4.3.5 Tension d'essai

a) La moyenne des tensions appliquées ne doit pas être inférieure à la tension assignée U_r divisée par √3 ni dépasser cette valeur de plus de 10 % sans l'accord du constructeur.

   Les différences entre la valeur moyenne et les tensions appliquées à chaque pôle ne doivent pas dépasser 5 %.

   La tension assignée U_r est celle de l'appareil de connexion lorsque le circuit de substitution est utilisé, mais elle est celle du moteur lorsqu'un moteur réel est utilisé.

b) La tension de rétablissement à fréquence industrielle du circuit d'essai peut être indiquée en pourcentage de la tension de rétablissement à fréquence industrielle spécifiée ci-après. Elle ne doit pas être inférieure à 95 % de la valeur spécifiée et doit être maintenue conformément au 6.104.7 de l'IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012.

   La moyenne des tensions de rétablissement à fréquence industrielle ne doit pas être inférieure à la tension assignée U_r de l'appareil de connexion divisée par √3.

   Il convient que la tension de rétablissement à fréquence industrielle de n'importe quel pôle ne soit pas différente de plus de 20 % de la valeur moyenne à la fin de la durée pendant laquelle elle est maintenue.

   La tension de rétablissement à fréquence industrielle doit être mesurée entre les bornes d'un pôle dans chaque phase du circuit d'essai. Sa valeur efficace doit être déterminée sur l'oscillogramme entre une demi-période et une période à la fréquence d'essai après l'extinction finale de l'arc, comme indiqué sur la Figure 44 de l'IEC 62271-100:2008. La distance verticale (respectivement V_1, V_2 et V_3) entre la crête de la deuxième demi-période et la ligne droite joignant les crêtes respectives des demi-périodes précédente et suivante, doit être mesurée puis divisée par 2√2 et multipliée par le facteur d'étalonnage approprié pour donner la valeur efficace de la tension enregistrée de rétablissement à fréquence industrielle.

4.3.6 Séquences d'essais

Les essais d'établissement et de coupure de courants de moteurs doivent consister en quatre séquences d'essais, tel que spécifié au Tableau 1.

Tableau 1 – Séquences d'essais d'établissement et de coupure de courants de moteurs

Séquence d'essais	Circuit d'alimentation	Circuit de substitution de moteur
1	A	1
2	A	2
3	B	1
4	B	2

Chaque séquence d'essais doit comprendre 20 essais avec les débuts des ordres de fermeture et d'ouverture répartis à des intervalles de 9 degrés électriques environ.

Les essais ci-dessus doivent être des cycles établissements–coupures ou des établissements et coupures séparés, sauf pour les essais avec un moteur réel, pour lesquels ils doivent être seulement des établissements–coupures. Lorsque les essais sont effectués à l'aide du circuit de substitution de moteur, les contacts de l'appareil de connexion ne doivent pas être séparés tant que toute composante continue du courant est inférieure à 20 %. Une durée d'établissement–coupure de 200 ms est recommandée pour les essais avec un moteur réel.

4.3.7 Mesurages d'essai

Les grandeurs suivantes, au moins, doivent être enregistrées à l'oscillographe ou avec d'autres techniques d’enregistrement adéquates, avec une bande passante et une résolution en temps suffisantes pour mesurer:

– la tension à fréquence industrielle;
– le courant à fréquence industrielle;
– la tension phase-terre aux bornes du moteur ou du circuit de substitution du moteur, dans les trois phases.

4.3.8 Comportement et état de l’appareil de connexion

Les critères permettant à un disjoncteur de satisfaire aux essais sont les suivants:

a) le comportement du disjoncteur pendant les essais d'établissement et de coupure de courants de moteur est conforme aux conditions applicables données en 6.102.8 de l’IEC 62271-100:2008;
b) les essais de tension doivent être effectués conformément à 6.2.11 de l’IEC 62271-100:2008+IEC 62271-100:2008/AMD1:2012;
c) tous les réallumages doivent se produire entre les contacts d'arc.

Les critères permettant aux contacteurs de satisfaire aux essais sont énoncés en 6.102.9 de l’IEC 62271-106:2011.

4.3.9 Rapport d’essai

En plus des exigences de l'Annexe C de l’IEC 62271-100:2008, le rapport d'essai doit comprendre une description minutieuse du circuit, y compris des détails suivants:

a) les dimensions principales et caractéristiques du jeu de barres et des connexions à l’appareil de connexion;
b) les caractéristiques du câble:
    1) longueur;
    2) valeurs assignées;
    3) type;
    4) diélectrique de l'isolation principale – polyéthylène réticulé (XLPE, *cross-linked polyethylene*), papier/huile, etc.;
    5) mise à la terre;
    6) capacités;
    7) impédance caractéristique.
c) les paramètres du circuit de substitution de moteur:
    1) fréquence propre;
    2) facteur d'amplitude;
    3) courant;
    4) facteur de puissance.
d) ou les détails du moteur réel:
    1) type et caractéristiques assignées;
    2) tension assignée;
    3) branchement des enroulements;
    4) courant assigné du moteur;
    5) courant de démarrage et facteur de puissance correspondant.