

# TECHNICAL REPORT



**High-voltage switchgear and controlgear –  
Part 305: Capacitive current switching capability of air-insulated disconnectors  
for rated voltages above 52 kV**

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Part 305: Capacitive current switching capability of air-insulated disconnectors  
for rated voltages above 52 kV**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

**Part 305: Capacitive current switching capability of air-insulated  
disconnectors for rated voltages above 52 kV**

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IEC 62271-305, which is a technical report, has been prepared by subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
17A/872/DTR	17A/885/RVC

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

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

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

The contents of the corrigendum of June 2017 have been included in this copy.

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## HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

### Part 305: Capacitive current switching capability of air-insulated disconnectors for rated voltages above 52 kV

#### 1 Scope

This technical report applies to high-voltage air-insulated disconnectors for rated voltages above 52 kV. The report describes the capacitive current switching duty and provides guidance on laboratory testing to demonstrate the switching capability. Air-insulated disconnectors equipped with auxiliary interrupting devices are included under this scope.

NOTE For manually operated disconnectors, the in-service safety of the operator should be considered and it should be recognized that the results of the switching tests described herein (performed using motor-operated disconnectors) are not necessarily representative of the performance of such disconnectors in actual service. Due diligence should be exercised if the switching tests indicate that prolonged arc durations are probable.

#### 2 Normative references

The following referenced documents are indispensable for the application 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 62271-1: *High-voltage switchgear and controlgear – Part 1: Common specifications*

IEC 62271-102:2001 *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

#### 3 Terms and definitions

For purposes of this part of IEC 62271 the terms and definitions in IEC 62271-1 and IEC 62271-102 apply.

#### 4 Background and purpose

Disconnectors do not have current interrupting ratings but, by virtue of having one or more moving contacts during opening operations, they have a certain current switching capability. For capacitive currents and air-insulated disconnectors, this capability has in the past been taken as 0,5 A or less and no testing was defined. For gas-insulated disconnectors, the required capacitive current switching capability and test requirements are specified in Annex F of IEC 62271-102.

User requirements for capacitive current switching using air-insulated disconnectors frequently exceed the above-stated 0,5 A. The purpose, therefore, of this report is to provide an analysis of the switching duty (refer to Annex A) and to define testing procedures.

#### 5 Switching tests

##### 5.1 Arrangement of the disconnector for tests

The disconnector under test should be completely mounted on its own support or on an equivalent support. For safety reasons and to obtain consistent results, only motor operation should be used. Motor operation should be at the minimum supply voltage.

Before commencing switching tests, resistance measurement of the main circuit and no-load operations should be made and details of the operating characteristics of the disconnector such as contact separation (arc initiation), closing time and opening time, should be recorded. Only single-phase tests on one pole of a three-pole disconnector need be performed provided that the pole is not in a more favourable condition than the complete three-pole disconnector with respect to

- closing time;
- opening time;
- influence of adjacent phases.

NOTE Single-phase tests are adequate to demonstrate the switching performance of a disconnector provided that the arcing time and arc reach are such that there is no possibility of involvement of an adjacent phase. If excessive arc reach is encountered during single-phase testing, then three-phase testing should be performed. A reach of the tip of the arc towards an adjacent phase equal to or greater than half the metal-to-metal spacing between phases is to be considered as excessive.

## 5.2 Earthing of the test circuit and disconnector

The frame of the disconnector should be earthed and the current to earth should be measured.

## 5.3 Test frequency

Disconnectors may be tested using either 50 Hz or 60 Hz since both frequencies are considered to be equivalent.

## 5.4 Test voltage

The test voltage should be the phase-to-earth voltage based on the rated voltage of the disconnector. In the event of three-phase testing, the test voltage should be the rated voltage of the disconnector applied on a three-phase basis.

NOTE Due to laboratory limitations, testing on one break of double break disconnectors at half the test voltage is permissible. An even voltage distribution across the two breaks can be assumed.

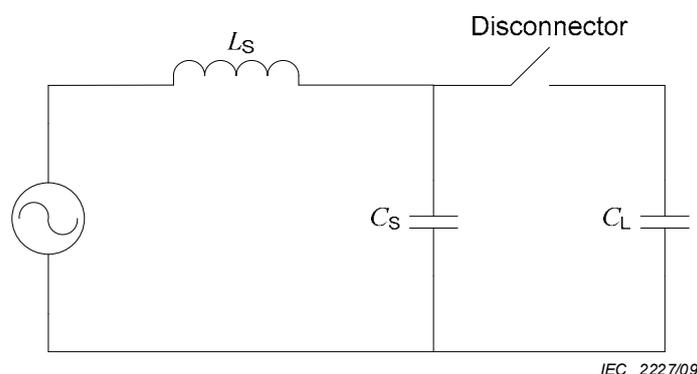
## 5.5 Test current

The test current, or currents if more than one current level is to be tested, should be as agreed between the manufacturer and the user.

NOTE Typical capacitive charging current values for station equipment and lines are shown in Annex B.

## 5.6 Test circuit

The test circuit in principle should be as shown in Figure 1.

**Key** $L_S$  Short-circuit inductance $C_S$  Supply side capacitance $C_L$  Load side capacitance**Figure 1 – Test circuit in principle for capacitive current switching**

$L_S$  should be based on the rated short-time withstand current at the rated voltage of the disconnector under test. However this will require a circuit with a strong source, which is impractical in many cases. An alternative circuit is described in Annex C.

For each test current, the ratio  $C_S/C_L$  should be agreed between the manufacturer and the user.

The permissible tolerances for the test quantities are as shown in Table 1.

**Table 1 – Test tolerances**

Test quantity	Tolerance
Test voltage	±5 %
Test current	±10 %
$C_S/C_L$	±20 %

**5.7 Tests****5.7.1 Test duties and measurements**

Twenty CO operations should be made for each test current with no trapped charge on the load capacitance prior to closing. Twenty such operations are considered to be statistically acceptable. The recovery voltage shall be maintained for ten seconds (10 s) after the disconnector reaches its fully open position.

The following measurements should be made during the test:

- power frequency source voltage and load side dc and transient overvoltages;
- current;
- arc duration;
- video recordings of arc propagation (the intent is to record the extreme vertical and horizontal reach of the arc as viewed along the longitudinal line of the disconnector).

NOTE If the tests are performed outdoors, atmospheric conditions should be recorded to include wind direction and velocity, humidity, air pressure and ambient temperature. No corrections for such elements are required.

### 5.7.2 Behaviour of disconnecter during tests

The disconnecter shall meet the following requirements during the tests:

- a) the disconnecter shall interrupt the current before the moving blade or blades reach their fully open position;
- b) no earth faults, or phase-to-phase faults in the event of three-phase testing, shall occur.

### 5.7.3 Condition of disconnecter after tests

The disconnecter shall meet the following requirements after the tests:

- a) a visual inspection is considered sufficient to verify that the mechanical parts and insulators are in essentially the same condition as before the tests;
- b) the condition of the main contacts, in particular with regard to wear, contact area, pressure and freedom of movement, shall be such that they are capable of carrying the rated normal current of the disconnecter;
- c) the resistance of the main circuit after the test shall not exceed that before the test by more than +10 %;
- d) the operating times before and after the tests shall be essentially the same.

## 5.8 Test reports

The results of all tests should be recorded in test reports. Sufficient information should be included so that the essential parts of the disconnecter tested can be identified.

The test report should at least contain the following information:

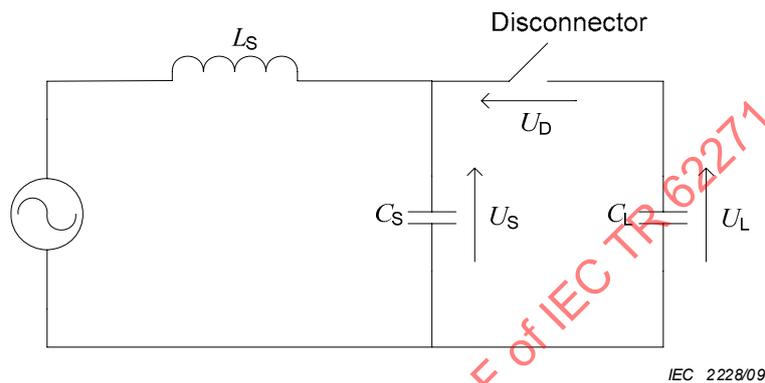
- a) typical oscillographic or similar records of the tests performed;
- b) test circuit;
- c) test currents;
- d) test voltages including overvoltages;
- e) arc durations;
- f) arc extreme reach in vertical and horizontal directions;
- g) number of CO operations;
- h) record of the condition of the of the main and arcing contacts after test;
- i) resistance of the main circuit before and after the test sequence;
- j) operating times before and after the tests.
- k) Atmospheric conditions: ambient temperature, air pressure, humidity and, if outdoors, wind velocity and direction.

General information concerning the supporting structure of the disconnecter should be included. The type of operating device employed during the tests should be recorded.

## Annex A (informative)

### Analysis

Capacitive current switching is a circuit and arc interactive event with varying severities of restriking and arc duration. The severity of restriking both in terms of frequency, current and overvoltage magnitudes, is dependent on the relative values of the source side ( $C_S$ ) and load side ( $C_L$ ) capacitances as shown in the basic capacitive current switching circuit Figure A.1.

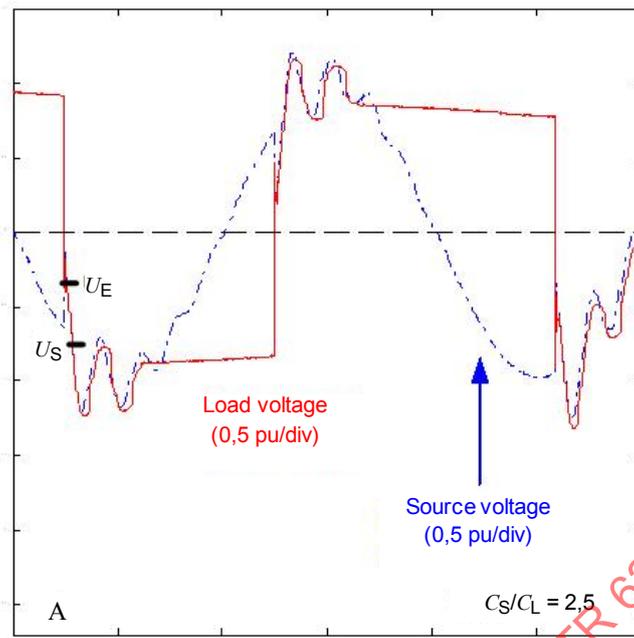


#### Key

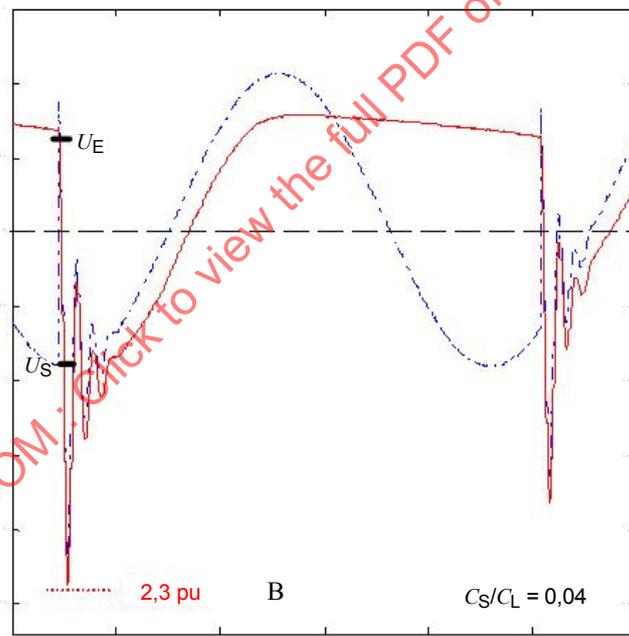
$L_S$	Short-circuit inductance
$C_S$	Supply side capacitance
$C_L$	Load side capacitance
$U_S$	Source side voltage
$U_L$	Load side voltage
$U_D$	Voltage across disconnector

**Figure A.1 – Basic capacitive current switching circuit**

Typical test oscillograms are shown in Figure A.2 and this behaviour is explained in the following.



IEC 2229/09



IEC 2230/09

**Key**

$C_S$	Source side capacitance	$U_E$	Equalization voltage
$C_L$	Load side capacitance	$U_S$	Supply side voltage

**Figure A.2 – Test oscillograms for current of 2 A and  $C_S/C_L$  ratios of 2,5 (Trace A) and 0,04 (Trace B)**

When a restrike occurs, the voltage on  $C_S$  and  $C_L$  will first equalize at  $U_E$  (equalization voltage). Taking the voltages on the source and load side capacitances as  $U_S$  and  $U_L$ , the corresponding charges are:

$$Q_S = U_S C_S$$

$$Q_L = -U_L C_L$$

and  $Q_{total} = U_S C_S + (-U_L C_L)$

After restriking and charge redistribution,  $U_E$  is given by:

$$U_E = \frac{Q_{total}}{C_S + C_L}$$

or 
$$U_E = \frac{U_S C_S - U_L C_L}{C_S + C_L} \quad (A.1)$$

Prior to restriking the voltage across the disconnector,  $U_D$  is:

$$U_D = U_S + U_L$$

and substituting in Equation (A.1) for  $U_L$

$$U_E = \frac{U_S C_S - C_L (U_D - U_S)}{C_S + C_L}$$

or 
$$U_E = U_S - \frac{U_D}{1 + C_S / C_L} \quad (A.2)$$

The peak overvoltage value to ground  $U_{OV}$  is given by:

$$U_{OV} = U_S + \beta (U_S - U_E) \quad (A.3)$$

where  $\beta$  is the damping factor of value less than 1.

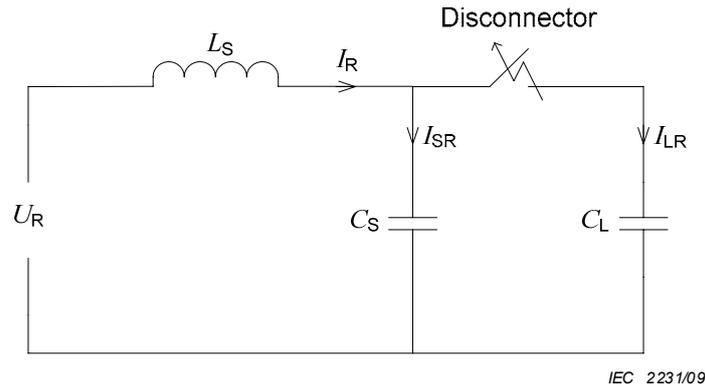
Substituting from Equation (A.2):

$$U_{OV} = U_S + \beta \left( \frac{U_D}{1 + C_S / C_L} \right) \quad (A.4)$$

The dependency on the ratio  $C_S / C_L$  is evident and can be summarized as follows:

- $C_S / C_L > 1$ , the difference between  $U_S$  and  $U_E$  will be low, giving lower values of  $U_{OV}$  and shorter arcing times due to lower injected energy into the arc (Figure A.2, Trace A);
- $C_S / C_L < 1$ , the difference between  $U_S$  and  $U_E$  will be high, giving higher values of  $U_{OV}$  and longer arcing times due to higher injected energy into the arc (Figure A.2, Trace B).

The restriking current  $I_{LR}$  through the arc to  $C_L$  is calculated using the circuit in Figure A.3.



**Key**

- |          |   |          |                         |
|----------|---|----------|-------------------------|
| $U_R$    | Supply side voltage                         | $I_{LR}$ | Restriking current      |
| $L_S$    | Short-circuit inductance                    | $C_S$    | Supply side capacitance |
| $I_R$    | Supply current                              | $C_L$    | Load side capacitance   |
| $I_{SR}$ | Current through the supply side capacitance |          |                         |

**Figure A.3 – Circuit for restriking current calculation**

$I_R$  is given by:

$$I_R = \frac{U_R}{\sqrt{\frac{L_S}{C_S + C_L}}}$$

where  $U_R = U_S - U_E$

$$\begin{aligned}
 I_{LR} &= \frac{I_R}{\omega(C_S + C_L)} \times \omega C_L \\
 &= U_R \sqrt{\frac{C_S + C_L}{L_S} \times \frac{C_L}{C_S + C_L}} \\
 &= U_R \sqrt{\frac{C_L}{L_S} \left( \frac{1}{1 + C_S/C_L} \right)} \tag{A.5}
 \end{aligned}$$

$I_{LR}$  is thus dependent on  $C_L$ ,  $L_S$  and the ratio  $C_S/C_L$ . Equations (A.4) and (A.5) show that these parameters should be properly represented in type test circuits in order for the testing to be valid.

For switching tests,  $C_S/C_L = 0,1$  is taken as being representative for the vast majority of applications. The value of  $L_S$  is selected on the basis of the disconnector being applied on a system with a fault level equal to the rated short-time current of the disconnector.

In addition to the influence of the ratio  $C_S/C_L$  and  $L_S$ , the arc may also exhibit thermal properties, which will tend to increase the arc duration. Based on field and laboratory test observations, arc duration dependency can be summarized as follows:

- For currents of 1 A or less, thermal effects are not significant and the arc duration is dependent mainly on achieving the minimum disconnector gap to withstand the recovery voltage and on the ratio  $C_S/C_L$ .
- For currents greater than 1 A, thermal effects become significant and the arc duration is dependent on the current magnitude in addition to achieving a minimum disconnector contact gap and on the ratio  $C_S/C_L$ .
- The longest arc durations at any current will occur when  $C_S/C_L < 1$  and due diligence should be exercised in such cases.

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**Annex B**  
(informative)

**Capacitive charging currents**

Typical capacitive charging current values for station air-insulated equipment are shown in Tables B.1, B.2 and B.3.

**Table B.1 – Capacitive charging currents at 245 kV and below**

Equipment type	Capacitive current (A) at					
	72,5 kV		145 kV		245 kV	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
CT	≤ 0,04	≤ 0,04	≤ 0,04	≤ 0,04	≤ 0,04	≤ 0,04
CVT (4000 pF)	0,05	0,06	0,11	0,13	0,18	0,21
Busbars/m	$1,7 \times 10^{-4}$	$2 \times 10^{-4}$	$0,32 \times 10^{-3}$	$0,39 \times 10^{-3}$	$0,54 \times 10^{-3}$	$0,65 \times 10^{-3}$

**Table B.2 – Capacitive charging currents at 300 kV to 550 kV**

Equipment type	Capacitive current (A) at					
	300 kV		420 kV		550 kV	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
CT	0,05	0,06	0,08	0,09	0,1	0,12
CVT (4 000 pF)	0,22	0,26	0,3	0,37	0,4	0,48
Busbars/m	$0,66 \times 10^{-3}$	$0,8 \times 10^{-3}$	$0,84 \times 10^{-3}$	$1,0 \times 10^{-3}$	$1,1 \times 10^{-3}$	$1,3 \times 10^{-3}$

**Table B.3 – Capacitive charging currents at 800 kV to 1 200 kV**

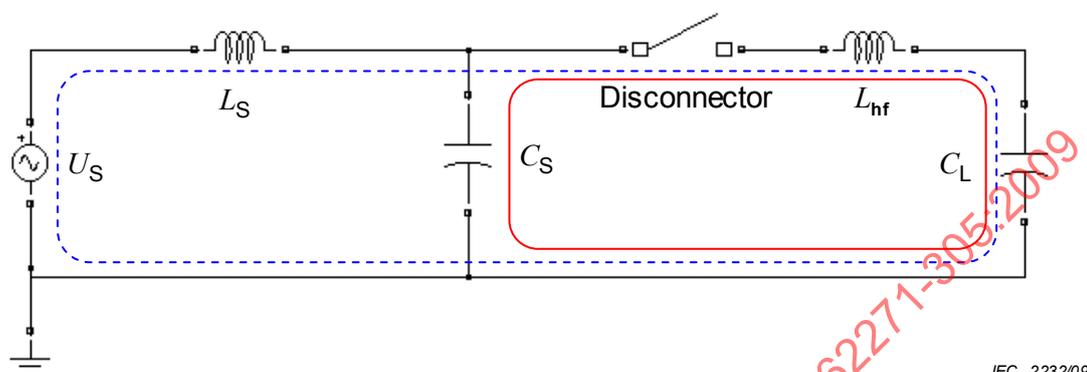
Equipment type	Capacitive current (A) at					
	800 kV		1 100 kV		1 200 kV	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
CT	0,15	0,18	TBD	TBD	TBD	TBD
CVT (5 000 pF)	0,72	0,87	1,0	1,2	1,1	1,3
Busbars/m	$1,8 \times 10^{-3}$	$2,2 \times 10^{-3}$	$2,5 \times 10^{-3}$	$3 \times 10^{-3}$	$2,8 \times 10^{-3}$	$3,3 \times 10^{-3}$

TBD = To be determined.

Optical instrument transformers, if used, will have about the same capacitance as post insulators, i.e. about 50 pF, and the associated capacitive charging currents will be negligible.

## Annex C (informative)

### Test circuits



#### Key

$U_S$	Supply side voltage	$C_L$	Load side capacitance
$L_S$	Short-circuit inductance	$L_{hf}$	Inductance $C_S$ and $C_L$ loop
$C_S$	Supply side capacitance		

**Figure C.1 – Basic capacitive current switching circuit**

The basic capacitive current switching circuit in Figure C.1 is considered to be a realistic representation of reality when the short-circuit impedance  $L_S$  is based on the short-time current for which the disconnector is rated. Upon restriking of the disconnector gap, the restriking current basically has three components:

- high-frequency (HF) component (indicated by the solid line loop of the circuit  $C_S$  - Disconnector -  $L_{hf}$  -  $C_L$ );
- medium frequency (MF) component (indicated by the dashed line loop of the circuit  $U_S$  -  $L_S$  Disconnector -  $L_{hf}$  -  $C_L$ );
- power frequency (PF) component (also in the dashed line loop of the circuit  $U_S$  -  $L_S$  Disconnector -  $L_{hf}$  -  $C_L$ ).

These currents determine the thermal energy that is injected into the arc path, the consequent heating of the arc and the ultimate recovery of the gap. Each of these components have their own contribution to thermal processes in terms of amplitude and/or duration: HF (few kA, but very short duration), MF (few hundreds of amperes, longer duration), PF (few amperes but long duration).

The circuit above, however, is unpractical, because it implies that tests with only a few amperes must be done in circuits having a very strong source (must be able to supply the short-time current). Already for moderate voltages (> 145 kV) this would imply such tests are impossible.

As an alternative, the test circuit shown in Figure C.2 is proposed.