

# TECHNICAL SPECIFICATION



This full version of IEC TS 62271-318:2024 includes the content of the references made to TS IEC 62271-5:2024

**High-voltage switchgear and controlgear –  
Part 318: DC gas-insulated metal-enclosed switchgear for rated voltages  
including and above 100 kV**

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

### HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

#### Part 318: DC gas-insulated metal-enclosed switchgear for rated voltages including and above 100 kV

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**This extended version (EXV) of the official IEC Standard provides the user with the full content of the Standard.**

**IEC TS 62271-318:2024 EXV includes the content of IEC TS 62271-318:2024, and the references made to IEC TS 62271-5:2024.**

**The specific content of IEC TS 62271-318:2024 is displayed on a blue background.**

IEC TS 62271-318 has been prepared by subcommittee 17C: Assemblies, of IEC technical committee 17: High-voltage switchgear and controlgear. It is a Technical Specification.

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

|             |                  |
|-------------|------------------|
| Draft       | Report on voting |
| 17C/930/DTS | 17C/937/RVDTS    |

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

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/standardsdev/publications](http://www.iec.ch/standardsdev/publications).

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

This document should be read in conjunction with IEC TS 62271-5:2024, to which it refers and which is applicable unless otherwise specified. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in IEC TS 62271-5:2024. Amendments to these clauses and subclauses are given under the same numbering, whilst additional subclauses, are numbered from 101.

The reader's attention is drawn to the fact that Annex E lists all of the "in-some-country" clauses on differing practices of a less permanent nature relating to the subject of this document.

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

- reconfirmed,
- withdrawn, or
- revised.

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## INTRODUCTION to IEC TS 62271-5:2024

This Technical Specification has been prepared by TC 17 and it defines common specifications for high-voltage direct current (HVDC) switchgear and controlgear covering both types of air insulated (AIS) and gas insulated (GIS) equipment of HVDC substations. This document includes rules for service conditions, ratings, design and construction requirements. Test requirements and criteria to proof for passing type and routine tests are defined in this document for development and manufacturing of HVDC switchgear.

This specification is applicable for both LCC and VSC HVDC technology.

SC 17A is in the process of preparing documents for the following HVDC switching devices:

- circuit-breakers (IEC TS 62271-313 [1])<sup>1</sup>;
- disconnectors and earthing switches (IEC TS 62271-314 [2]);
- transfer switches (IEC TS 62271-315 [3]);
- by-pass switches and paralleling switches (IEC TS 62271-316 [4]).

SC 17C is in the process of preparing a document for DC gas insulated switchgears (IEC TS 62271-318 [5]).

Standardization of direct voltages is the responsibility of TC 8 (System aspects of electrical energy supply).

TC 99 (Insulation co-ordination and system engineering of high voltage electrical power installations above 1,0 kV AC and 1,5 kV DC) defines requirements of DC substations for safety of insulation, equipment, installation and earthing (IEC 61936-2).

TC 115 (High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV) is responsible for DC transmission system aspects. It is the responsibility of TC 115 to define requirements for different equipment (e. g. switching devices) from system point of view. These definitions are implemented in documents from other TCs. Several Working Groups and Maintenance Teams are preparing documents on reliability, EMC, asset management, system design, DC harmonics, testing, HVDC grids, VSC and LCC converter and insulation coordination for HVDC systems.

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<sup>1</sup> Numbers in square brackets refer to the Bibliography.

## HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

### Part 318: DC gas-insulated metal-enclosed switchgear for rated voltages including and above 100 kV

#### 1 Scope

This part of IEC 62271 specifies requirements for gas-insulated metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas or gas mixture other than air at atmospheric pressure, for direct current of rated voltages including and above 100 kV, for indoor and outdoor installation. This document includes rules for service conditions, ratings, design, and construction requirements. Test requirements and criteria for proof for passing type and routine tests are defined in this document for development and manufacturing of DC switchgear.

For the purpose of this document, the terms "DC GIS" and "DC switchgear" are used for "DC gas-insulated metal-enclosed switchgear".

This specification is applicable for both Line Commutated Converter (LCC) and Voltage Sourced Converter (VSC) for HVDC systems.

The DC gas-insulated metal-enclosed switchgear covered by this document consists of individual components intended to be directly connected together and able to operate only in this manner.

This document completes and amends, if applicable, the various relevant documents applying to the individual components constituting DC gas-insulated metal-enclosed switchgear.

#### 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 60038:2009, *IEC standard voltages*

IEC 60050-614:2016, *International Electrotechnical Vocabulary (IEV) – Part 614: Generation, transmission and distribution of electricity – Operation*

IEC 60050-811, *International Electrotechnical Vocabulary (IEV) – Part 811: Electric traction*

IEC 60050-826:2022, *International Electrotechnical Vocabulary (IEV) – Part 826: Electrical installations*

IEC 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-2-1:2007, *Environmental testing – Part 2-1: Tests – Test A: Cold*

IEC 60068-2-2:2007, *Environmental testing – Part 2-2: Tests – Test B: Dry heat*

IEC 60068-2-11:2021, *Environmental testing – Part 2-11: Tests – Test Ka: Salt mist*

IEC 60068-2-17:2023, *Environmental testing – Part 2-17: Tests – Test Q: Sealing*

IEC 60068-2-30:2005, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60071-1:2019, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2:2018, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60071-11:2022, *Insulation co-ordination – Part 11: Definitions, principles and rules for HVDC system*

IEC 60085:2007, *Electrical insulation – Thermal evaluation and designation*

IEC 60099-4:2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60099-9:2014, *Surge arresters – Part 9: Metal-oxide surge arresters without gaps for HVDC converter stations*

IEC 60137:2017, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60255-21-1:1988, *Electrical relays – Part 21: Vibration, shock, bump and seismic tests on measuring relays and protection equipment – Section One: Vibration tests (sinusoidal)*

IEC 60270:2000, *High-voltage test techniques – Partial discharge measurements*  
IEC 60270:2000/AMD1:2015

IEC 60296, *Fluids for electrotechnical applications – Mineral insulating oils for electrical equipment*

IEC 60376:2018, *Specification of technical grade sulphur hexafluoride (SF<sub>6</sub>) and complementary gases to be used in its mixtures for use in electrical equipment*

IEC 60417:2006, *Graphical symbols for use on equipment (available at <http://www.graphical-symbols.info/equipment>)*

IEC 60437, *Radio interference test on high-voltage insulators*

IEC 60480:2019, *Specifications for the re-use of sulphur hexafluoride (SF<sub>6</sub>) and its mixtures in electrical equipment*

IEC 60512-2-2, *Connectors for electronic equipment – Tests and measurements – Part 2-2: Electrical continuity and contact resistance tests – Test 2b: Contact resistance – Specified test current method*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*  
IEC 60529:1989/AMD1:1999  
IEC 60529:1989/AMD2:2013

IEC 60633:2019, *High-voltage direct current (HVDC) transmission – Vocabulary*

IEC TS 60815-1:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC TS 60815-4:2016, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 4: Insulators for DC systems*

IEC 61869-15:2018, *Instrument transformers – Part 15: Additional requirements for voltage transformers for DC applications*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-11, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current up to 16 A per phase*

IEC 61000-4-17:1999, *Electromagnetic compatibility (EMC) – Part 4-17: Testing and measurement techniques – Ripple on d.c. input power port immunity test*

IEC 61000-4-18, *Electromagnetic compatibility (EMC) – Part 4-18: Testing and measurement techniques – Damped oscillatory wave immunity test*

IEC 61000-4-29, *Electromagnetic compatibility (EMC) – Part 4-29: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations on DC input power port immunity tests*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments*

IEC 61000-6-5, *Electromagnetic compatibility (EMC) – Part 6-5: Generic standards – Immunity for equipment used in power station and substation environment*

IEC 61180, *High-voltage test techniques for low-voltage equipment – Definitions, test and procedure requirements, test equipment*

IEC TS 61245, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on DC systems*

IEC 61810-7:2006, *Electromechanical elementary relays – Part 7: Test and measurement procedures*

IEC 62262:2002, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

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

IEC 62271-1:2017/AMD1:2021

IEC 62271-4, *High-voltage switchgear and controlgear – Part 4: Handling procedures for gases for insulation and/or switching*

IEC TS 62271-5:2024, *High-voltage switchgear and controlgear – Part 5: Common specifications for direct current switchgear*

IEC 62271-209:2019, *High-voltage switchgear and controlgear – Part 209: Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV – Fluid-filled and*

*extruded insulation cables – Fluid-filled and dry-type cable terminations*  
IEC 62271-209:2019/AMD1:2022

IEC 62271-211:2014, *High-voltage switchgear and controlgear – Part 211: Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

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

IEC TS 62271-313, *High-voltage switchgear and controlgear – Part 314: Direct current disconnectors and earthing switches*

IEC TS 62271-314:2024, *High-voltage switchgear and controlgear – Part 314: Direct current disconnectors and earthing switches*

IEC TS 62271-315:20—<sup>2</sup>, *High voltage switchgear and controlgear – Part 315: Direct current (DC) transfer switches*

IEC 62895:2017, *High voltage direct current (HVDC) power transmission – Cables with extruded insulation and their accessories for rated voltages up to 320 kV for land applications – Test methods and requirements*

IEC/IEEE 60076-57-129:2017, *Power transformers – Part 57-129: Transformers for HVDC applications*

IEC/IEEE 65700-19-03:2014, *Bushings for DC application*

ISO 22479:2019, *Corrosion of metals and alloys – Sulfur dioxide test in a humid atmosphere (fixed gas method)*

CISPR 11:2015, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*

CISPR 16-1 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1: Radio disturbance and immunity measuring apparatus*

CISPR TR 18-2, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60633 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>

<sup>2</sup> Under preparation. Stage at the time of publication: IEC CDTS 62271-315:2024.

NOTE Terms and definitions are classified in accordance with IEC 60050-441. References from other parts than IEC 60050-441 are classified so as to be aligned with the classification used in IEC 60050-441.

### 3.1 General terms and definitions

#### 3.1.1

##### **switchgear and controlgear**

general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures

[SOURCE: IEC 60050-441:1984, 441-11-01]

#### 3.1.2

##### **nominal direct voltage**

mean value of the direct voltage required to transmit nominal power at nominal current

[SOURCE: IEC 60071-11:2022, 3.2, modified – Replacement of “DC” with “direct”.]

#### 3.1.3

##### **HVDC system**

electrical power system which transfers energy in the form of high-voltage direct current between two or more AC buses

[SOURCE: IEC 60633:2019, 8.1]

#### 3.1.4

##### **HVDC transmission system**

HVDC system which transfers energy between two or more geographic locations

[SOURCE: IEC 60633:2019, 8.2]

#### 3.1.5

##### **two-terminal HVDC transmission system**

HVDC transmission system consisting of two HVDC substations and the connecting HVDC transmission line(s)

[SOURCE: IEC 60633:2019, 8.2.1]

#### 3.1.6

##### **multiterminal HVDC transmission system**

HVDC transmission system consisting of more than two separated HVDC substations and the interconnecting HVDC transmission lines

[SOURCE: IEC 60633:2019, 8.2.2]

#### 3.1.7

##### **HVDC system pole**

part of an HVDC system consisting of all the equipment in the HVDC substations and the interconnecting transmission lines, if any, which during normal operation exhibit a common direct voltage polarity with respect to earth

[SOURCE: IEC 60633:2019, 8.5]

### 3.1.8

#### **HVDC substation**

#### **HVDC converter station**

part of an HVDC system which consists of one or more converter units installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment

Note 1 to entry: An HVDC substation forming part of an HVDC transmission system may be referred to as an HVDC transmission substation.

[SOURCE: IEC 60633:2019, 8.12]

### 3.1.9

#### **HVDC substation pole**

part of an HVDC system pole which is contained within a substation

[SOURCE: IEC 60633:2019, 8.14]

### 3.1.10

#### **external insulation**

distances in atmospheric air and along the surfaces in contact with atmospheric air of solid insulation of the equipment which are subject to dielectric stresses and to the effects of atmospheric and other environmental conditions from the site

Note 1 to entry: Examples of environmental conditions are pollution, humidity, vermin, etc.

[SOURCE: IEC 60050-614:2016, 614-03-02]

### 3.1.11

#### **internal insulation**

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

[SOURCE: IEC 60050-614:2016, 614-03-03, modified – Addition of “parts of the”.]

### 3.1.12

#### **degree of protection**

extent of protection provided by an enclosure against access to hazardous parts, against ingress of solid foreign objects and/or ingress of water and against mechanical impact

[SOURCE: IEC 60529:1989, 3.3, modified – Deletion of “verified by standardized test methods” and addition of “against mechanical impact” after “water and”.]

### 3.1.13

#### **IP code**

coding system to indicate the degrees of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects, ingress of water and to give additional information in connection with such protection

[SOURCE: IEC 60529:1989, 3.4]

### 3.1.14

#### **protection provided by an enclosure against access to hazardous parts**

protection of persons against

- contact with hazardous low-voltage live parts;
- contact with hazardous mechanical parts;

- approach to hazardous high-voltage live parts below adequate clearance inside an enclosure

Note 1 to entry: This protection may be provided:

- by means of the enclosure itself;
- by means of barriers as part of the enclosure or distances inside the enclosure.

[SOURCE: IEC 60529:1989, 3.6]

### **3.1.15**

#### **IK code**

coding system to indicate the degree of protection provided by an enclosure against harmful external mechanical impacts

[SOURCE: IEC 62262:2002, 3.3]

### **3.1.16**

#### **maintenance**

combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required

Note 1 to entry: Management is assumed to include supervision activities.

[SOURCE: IEC 60050-192:2015, 192-06-01]

### **3.1.17**

#### **visual inspection**

visual investigation of the principal features of the switchgear and controlgear

Note 1 to entry: This inspection is generally directed toward pressures and/or levels of fluids, tightness, position of relays, pollution of insulating parts, but actions such as lubricating, cleaning, washing, etc. which can be carried out with the switchgear and controlgear in service are also included.

Note 2 to entry: Observations resulting from inspection can lead to the decision to carry out overhaul.

Note 3 to entry: This inspection can be used for determining the state of tested objects on e.g. cracks in solid insulators.

[SOURCE: IEC 62271-1:2017, 3.1.8]

### **3.1.18**

#### **diagnostic test**

comparative test of the characteristic parameters of switchgear and controlgear to verify that it performs its functions, by measuring one or more of these parameters

Note 1 to entry: The result from a diagnostic test can lead to the decision to carry out overhaul.

[SOURCE: IEC 62271-1:2017, 3.1.9]

### **3.1.19**

#### **overhaul**

work performed with the objective of repairing or replacing parts which are found to be out of tolerance by inspection, diagnostic test, examination or as required by manufacturer's maintenance manual, in order to restore the component and/or the switchgear and controlgear to an acceptable condition (within tolerance)

[SOURCE: IEC 62271-1:2017, 3.1.10]

### **3.1.20**

#### **failure**

loss of ability to perform as required

Note 1 to entry: A failure of an item is an event that results in a fault of that item: see fault (IEC 60050-192:2015, 192-04-01).

Note 2 to entry: Qualifiers, such as catastrophic, critical, major, minor, marginal and insignificant, can be used to categorize failures according to the severity of consequences, the choice and definitions of severity criteria depending upon the field of application.

Note 3 to entry: Qualifiers, such as misuse, mishandling and weakness, may be used to categorize failures according to the cause of failure.

[SOURCE: IEC 60050-192:2015, 192-03-01]

### 3.1.21

#### **major failure**

<of switchgear and controlgear> failure of switchgear and controlgear which causes the cessation of one or more of its fundamental functions

Note 1 to entry: A major failure may result in an immediate change in the system operating conditions, for example, the backup protective equipment will be required to remove the fault or will result in mandatory removal from service within 30 min for unscheduled maintenance.

[SOURCE: IEC 62271-1:2017, 3.1.12]

### 3.1.22

#### **minor failure**

<of switchgear and controlgear> any failure of a constructional element or a subassembly which does not cause a major failure of the switchgear and controlgear

[SOURCE: IEC 62271-1:2017, 3.1.13]

### 3.1.23

#### **defect**

imperfection in the state of an item (or inherent weakness) which can result in one or more failures of the item itself, or of another item under the specific service or environmental or maintenance conditions, for a stated period of time

[SOURCE: IEC 62271-1:2017, 3.1.14]

### 3.1.24

#### **ambient air temperature**

temperature, determined under prescribed conditions, of the air surrounding the complete switching device or fuse

Note 1 to entry: For switching devices or fuses installed inside an enclosure, it is the temperature of the air outside the enclosure.

[SOURCE: IEC 60050-441:1984, 441-11-13]

### 3.1.25

#### **monitoring**

observation of the operation of a system or part of a system to verify correct functioning by detecting incorrect functioning, this being done by measuring one or more variables of the system and comparing the measured values with the specified values

Note 1 to entry: Some definitions are given for this term in IEC 60050 (all parts). They are related to different cases of application.

[SOURCE: IEC 62271-1:2017, 3.1.16]

### 3.1.26

#### **supervision**

activity, performed either manually or automatically, intended to observe the state of an item

Note 1 to entry: Automatic supervision may be performed internally or externally to the item.

[SOURCE: IEC 62271-1:2017, 3.1.17]

### 3.1.27

#### **Unified Specific Creepage Distance**

##### **USCD**

creepage distance of an insulator divided by the maximum operating voltage across the insulator.

Note 1 to entry: It is generally expressed in mm/kV.

[SOURCE: IEC TS 60815-4:2016, 3.1.1, modified – Removal of the note to entry.]

### 3.1.28

#### **Reference DC Unified Specific Creepage Distance**

##### **RUSCDDC**

value of Unified Specific Creepage Distance for a DC system at a pollution site determined from ESDD and NSDD value corrected for NSDD, CUR, etc. according to IEC TS 60815-4:2016

Note 1 to entry: This is generally expressed in mm/kV.

[SOURCE: IEC 60815-4:2016, 3.1.2, modified – Replacement of “this document” with “IEC 60815-4:2016”.]

### 3.1.29

#### **Hydrophobicity Transfer Material**

##### **HTM**

polymer materials which exhibit hydrophobicity and the capability to transfer hydrophobicity to the layer of pollution

Note 1 to entry: Further information on HTM is given in Annex A of IEC 60185-4:2016.

[SOURCE: IEC 60815-4:2016, 3.1.4, modified – Addition “of IEC 60815-4:2016” in Note 1 to entry.]

### 3.1.30

#### **multi-part test**

series of tests which adequately demonstrate the specified performance, in the case that this performance cannot be verified with a single test

Note 1 to entry: Multi-part tests are applicable for short-time withstand current and peak withstand current tests, as well as for short-circuit making and breaking tests.

Note 2 to entry: Because of, for example, limitations of test field, maybe not all parameters concerning test current, test voltage or dissipated energy can be fulfilled in one test setup. In this case the test may be split in two or more parts with same current stress but different voltages stresses or different energy dissipation devices to cover all requirements. For each partial test of this series, the number of tests steps shall be the same as the number required for the respective test-duty.

## **3.2 Assemblies of switchgear and controlgear**

### 3.2.1

#### **test object**

equipment needed to represent the switchgear and controlgear for a particular type test

[SOURCE: IEC 62271-1:2017, 3.2.1]

### 3.3 Parts of assemblies

#### 3.3.1

##### **transport unit**

part of switchgear and controlgear intended for transportation without being dismantled

[SOURCE: IEC 62271-1:2017, 3.3.1]

#### 3.3.2

##### **busbar**

low-impedance conductor to which several electric circuits can be connected at separate points

Note 1 to entry: In many cases, the busbar consists of a bar.

[SOURCE: IEC 60050-151:2001, 151-12-30]

### 3.4 Switching devices

Various types of switching devices are used in HVDC substations as their examples are given in Annex A (informative). This subclause provides only the definitions of fundamental switching devices. Regarding each switching device, see IEC 60633, IEC TS 63014-1 and the relevant product standards.

#### 3.4.1

##### **mechanical switching device**

switching device designed to close and open one or more electric circuits by means of separable contacts

Note 1 to entry: Any mechanical switching device may be designated according to the medium in which its contacts open and close, e.g. air, SF<sub>6</sub>, oil.

[SOURCE: IEC 60050-441:1984, 441-14-02]

#### 3.4.2

##### **DC circuit-breaker**

type of switchgear used in an HVDC scheme, capable of making, carrying and breaking direct currents and also making, carrying for a specified time and breaking in specified time direct currents under specified abnormal circuit conditions such as those of short-circuit

#### 3.4.3

##### **disconnector**

mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements

Note 1 to entry: A disconnector is capable of opening and closing a circuit when either negligible current is broken or made, or when no significant change in the voltage across the terminals of the disconnector occurs. It is also capable of carrying currents under normal circuit conditions and carrying currents for a specified time under abnormal conditions such as those of short-circuit.

[SOURCE: IEC 60050-441:1984, 441-14-05]

#### 3.4.4

##### **earthing switch**

mechanical switching device for earthing parts of a circuit, capable of withstanding for a specified time currents under abnormal conditions such as those of short circuit, but not required to carry current under normal conditions of the circuit

Note 1 to entry: An earthing switch may have a short-circuit making capacity.

[SOURCE: IEC 60050-441:1984, 441-14-11]

### 3.4.5

#### **high-speed DC switch**

type of switchgear used on an HVDC scheme, required to open or close rapidly ( $< 1$  s), including in some cases the need to commute load current into a parallel conducting path, but with no requirement to interrupt fault or load current

Note 1 to entry: DC switchgear is usually based on a single-phase unit of an AC circuit-breaker, appropriately modified for their DC applications. Their capabilities to perform faster opening and closing than disconnect switches are used but the function of breaking short-circuit currents is not required.

[SOURCE: IEC 60633:2019, 9.20]

### 3.4.6

#### **DC transfer switch**

high-speed DC switch used to transfer direct current from one return path to another return path

Note 1 to entry: High speed switch in DC transfer switch application will usually include an oscillating branch.

### 3.4.7

#### **by-pass switch**

##### **BPS**

high-speed DC switch connected across each converter valve group in HVDC schemes using more than one independent converter per pole, designed to close rapidly to by-pass a converter group that is being taken out of service and commute the current back into a valve group that is being taken back in service

[SOURCE: IEC 60633:2019, 9.30]

### 3.4.8

#### **paralleling switch**

##### **PS**

mechanical switching device intended for rapid configuration of a HVDC system

Note 1 to entry: A PS can either be a converter paralleling switch or a line paralleling switch.

[SOURCE: IEC TS 62271-316:20—, 3.4.104]

## 3.5 **Parts of switchgear and controlgear**

### 3.5.1

#### **enclosure**

housing affording the type and degree of protection suitable for the intended application

Note 1 to entry: Enclosures provide protection of persons or livestock against access to hazardous parts. Barriers, shapes of openings or any other means (whether attached to the enclosure or formed by the enclosed equipment) suitable to prevent or limit the penetration of the specified test probes, are considered as a part of the enclosure, when they are secured in position either by means of interlocks, keys, or by hardware requiring a tool to be removed.

[SOURCE: IEC 60050-826:2022, 826-12-20, modified – Addition of Note 1 to entry.]

### 3.5.2

#### **hazardous part**

part that is hazardous to approach or touch

[SOURCE: IEC 60529:1989, 3.5]

### 3.5.3

#### **main circuit**

<of a switching device> all the conductive parts of a switching device included in the circuit which it is designed to close or open

[SOURCE: IEC 60050-441:1984, 441-15-02]

### 3.5.4

#### **auxiliary circuit**

<of a switching device> all the conductive parts of a switching device which are intended to be included in a circuit other than the main circuit, the earthing circuit and the control circuits of the device

Note 1 to entry: Some auxiliary circuits fulfil supplementary functions such as signalling, interlocking, etc., and, as such, they may be part of the control circuit of another switching device.

[SOURCE: IEC 60050-441:1984, 441-15-04, modified – Addition of “earthing circuit”.]

### 3.5.5

#### **control circuit**

<of a switching device> all the conductive parts (other than the main circuit) of a switching device which are included in a circuit used for the closing operation or opening operation, or both, of the device

[SOURCE: IEC 60050-441:1984, 441-15-03]

### 3.5.6

#### **contact**

<of a switching device> conductive parts designed to establish circuit continuity when they touch and which, due to their relative motion during an operation, open or close a circuit or, in the case of hinged or sliding contacts, maintain circuit continuity

[SOURCE: IEC 60050-441:1984, 441-15-05]

### 3.5.7

#### **auxiliary contact**

contact included in an auxiliary circuit and operated by the switching device

[SOURCE: IEC 60050-441:1984, 441-15-10, modified – Deletion of “mechanically”.]

### 3.5.8

#### **control contact**

contact included in a control circuit of a switching device and operated by this device

[SOURCE: IEC 60050-441:1984, 441-15-09, modified – Deletion of “mechanical” and “mechanically”]

### 3.5.9

#### **auxiliary switch**

<of a switching device> switch containing one or more control and/or auxiliary contacts mechanically operated by a switching device

[SOURCE: IEC 60050-441:1984, 441-15-11]

### 3.5.10

#### **control switch**

<for control and auxiliary circuits> mechanical switching device which serves the purpose of controlling the operation of switchgear or controlgear, including signalling, electrical interlocking, etc.

Note 1 to entry: A control switch consists of one or more contact elements with a common actuating system.

[SOURCE: IEC 60050-441:1984, 441-14-46]

### 3.5.11

#### **connection**

<bolted or the equivalent> two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

[SOURCE: IEC 62271-1:2017, 3.5.10]

### 3.5.12

#### **position indicating device**

part of a mechanical switching device which indicates whether it is in the open, closed, or where appropriate, earthed position

[SOURCE: IEC 60050-441:1984, 441-15-25]

### 3.5.13

#### **monitoring device**

device intended to observe automatically the status of an item

[SOURCE: IEC 62271-1:2017, 3.5.12]

### 3.5.14

#### **pilot switch**

non-manual control switch actuated in response to specified conditions of an actuating quantity

Note 1 to entry: The actuating quantity may be pressure, temperature, velocity, liquid level, elapsed time, etc.

[SOURCE: IEC 60050-441:1984, 441-14-48]

### 3.5.15

#### **partition**

<of an assembly> part of an assembly separating one compartment from other compartments

[SOURCE: IEC 60050-441:1984, 441-13-06]

### 3.5.16

#### **actuator**

part of the actuating system to which an external actuating force is applied

Note 1 to entry: The actuator may take the form of a handle, knob, push-button, roller, plunger, etc.

[SOURCE: IEC 60050-441:1984, 441-15-22]

### 3.5.17

#### **splice**

connecting device with barrel(s) accommodating electrical conductor(s) with or without additional provision to accommodate and secure the insulation

[SOURCE: IEC 60050-581:2008, 581-24-19, modified – Addition of “electrical”.]

### 3.5.18

#### **terminal**

point of interconnection of an electric circuit element, an electric circuit or a network with other electric circuit elements, electric circuits or networks

Note 1 to entry: For an electric circuit element, the terminals are the points at which or between which the related integral quantities are defined. At each terminal, there is only one electric current from outside into the element.

Note 2 to entry: The term “terminal” has a related meaning in IEC 60050-151.

[SOURCE: IEC 60050-131:2002, 131-11-11]

### **3.5.19**

#### **terminal block**

assembly of terminals in a housing or body of insulating material to facilitate interconnection between multiple conductors

[SOURCE: IEC 60050-581:2008, 581-26-26]

### **3.5.20**

#### **contactor**

##### **mechanical contactor**

mechanical switching device having only one position of rest, operated otherwise than by hand, capable of making, carrying and breaking currents under normal circuit conditions including operating overload conditions

Note 1 to entry: Contactors may be designated according to the method by which the force for closing the main contacts is provided.

[SOURCE: IEC 60050-441:1984, 441-14-33, modified – Deletion of “Mechanical” in Note 1 to entry.]

### **3.5.21**

#### **starter**

combination of all the switching means necessary to start and stop a motor in combination with suitable overload protection

Note 1 to entry: Starters may be designated according to the method by which the force for closing the main contacts is provided.

[SOURCE: IEC 60050-441:1984, 441-14-38]

### **3.5.22**

#### **vacuum interrupter**

component being part of a switching device in which electrical contacts operate in a highly evacuated, hermetically sealed environment

[SOURCE: IEC 62271-1:2017, 3.5.21]

### **3.5.23**

#### **operation counter**

device indicating the number of operating cycles a mechanical switching device has accomplished

[SOURCE: IEC 62271-1:2017, 3.5.22]

### **3.5.24**

#### **coil**

set of series-connected turns, usually coaxial

[SOURCE: IEC 60050-151:2001, 151-13-15]

### **3.5.25**

#### **auxiliary and control circuits**

entity of

- control and auxiliary circuits, mounted on or adjacent to the switchgear or controlgear, including circuits in central control cubicles;

- equipment for monitoring, diagnostics, etc. that is part of the auxiliary circuits of the switchgear or controlgear;
- circuits connected to the secondary terminals of instrument transformers, that are part of the switchgear or controlgear

[SOURCE: IEC 62271-1:2017, 3.5.24]

### **3.5.26**

#### **subassembly**

<of auxiliary and control circuits> part of auxiliary and control circuits, with regard to function or position, having its own interface and normally placed in a separate enclosure

[SOURCE: IEC 62271-1:2017, 3.5.25]

### **3.5.27**

#### **interchangeable subassembly**

<of auxiliary and control circuits> subassembly which is intended to be placed in various positions within an auxiliary and control circuits, or intended to be replaced by other similar subassemblies

Note 1 to entry: An interchangeable subassembly has an accessible interface.

[SOURCE: IEC 62271-1:2017, 3.5.26]

### **3.5.28**

#### **interlocking device**

device which makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment

[SOURCE: IEC 60050-441:1984, 441-16-49]

## **3.6 Operational characteristics of switchgear and controlgear**

### **3.6.1**

#### **dependent power operation**

<of a mechanical switching device> operation by means of energy other than manual, where the completion of the operation is dependent upon the continuity of the power supply (to solenoids, electric or pneumatic motors, etc.)

[SOURCE: IEC 60050-441:1984, 441-16-14]

### **3.6.2**

#### **stored energy operation**

<of a mechanical switching device> operation by means of energy stored in the drive mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions

Note 1 to entry: This kind of operation may be subdivided according to:

- the manner of storing the energy (spring, weight, etc.);
- the origin of the energy (manual, electric, etc.);
- the manner of releasing the energy (manual, electric, etc.).

[SOURCE: IEC 60050-441:1984, 441-16-15, modified – Addition of “drive”.]

### **3.6.3**

#### **independent unlatched operation**

stored energy operation where energy is stored and released in one continuous operation such that the speed and force of the operation are independent of the rate of applied energy

Note 1 to entry: The energy stored for the operation may originate from the operator (manual) or a power source.

[SOURCE: IEC 62271-1:2017, 3.6.3]

### 3.6.4

#### **positively driven operation**

operation which, in accordance with specified requirements, is designed to ensure that auxiliary contacts of a mechanical switching device are in the respective positions corresponding to the open or closed position of the main contacts

Note 1 to entry: A positively driven operating device is made by the association of a moving part, linked mechanically to the main contact of the primary circuit, without the use of springs, and a sensing element. In the case of mechanical auxiliary contacts, this sensing element can be simply the fixed contact, directly connected to the secondary terminal. In the case where the function is achieved electronically, the sensing element can be a static transducer (optical, magnetic, etc.) associated with a static switch, or associated with an electronic or electro-optic transmitting element.

[SOURCE: IEC 60050-441:1984, 441-16-12, modified – Addition of Note 1 to entry.]

### 3.6.5 Terms and definitions relative to pressure (or density)

#### 3.6.5.1

##### **filling pressure for insulation and/or switching**

$p_{re}$

##### **filling density for insulation and/or switching**

$\rho_{re}$

pressure (in Pa), for insulation and/or for switching, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the assembly is filled before being put into service, or automatically replenished

[SOURCE: IEC 62271-1:2017, 3.6.5.1]

#### 3.6.5.2

##### **filling pressure for operation**

$p_{rm}$

##### **filling density for operation**

$\rho_{rm}$

pressure (in Pa), for operation, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the energy storage device is filled before being put into service or automatically replenished

[SOURCE: IEC 62271-1:2017, 3.6.5.2]

#### 3.6.5.3

##### **alarm pressure for insulation and/or switching**

$p_{ae}$

##### **alarm density for insulation and/or switching**

$\rho_{ae}$

pressure (in Pa), for insulation and/or for switching, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which a monitoring signal may be provided

[SOURCE: IEC 62271-1:2017, 3.6.5.3]

#### 3.6.5.4

##### **alarm pressure for operation**

$p_{am}$

##### **alarm density for operation**

$\rho_{am}$

pressure (in Pa), for operation, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which a monitoring signal from the energy storage device may be provided

[SOURCE: IEC 62271-1:2017, 3.6.5.4]

#### 3.6.5.5

##### **minimum functional pressure for insulation and/or switching**

$p_{me}$

##### **minimum functional density for insulation and/or switching**

$\rho_{me}$

pressure (in Pa), for insulation and/or for switching, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which and above which rated characteristics of switchgear and controlgear are maintained

[SOURCE: IEC 62271-1:2017, 3.6.5.5]

#### 3.6.5.6

##### **minimum functional pressure for operation**

$p_{mm}$

##### **minimum functional density for operation**

$\rho_{mm}$

pressure (in Pa), for operation, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which and above which rated characteristics of switchgear and controlgear are maintained and at which a replenishment of the energy storage device becomes necessary

Note 1 to entry: This pressure is often designated as interlocking or lockout pressure.

[SOURCE: IEC 62271-1:2017, 3.6.5.6]

### **3.6.6 Terms and definitions relating to gas and vacuum tightness**

#### 3.6.6.1

##### **controlled pressure system for gas**

volume which is automatically replenished from an external compressed gas supply or internal gas source

Note 1 to entry: Examples of controlled pressure systems are air-blast circuit-breakers or pneumatic drive mechanisms.

Note 2 to entry: A volume may consist of several permanently connected gas-filled compartments.

[SOURCE: IEC 62271-1:2017, 3.6.6.1]

#### 3.6.6.2

##### **closed pressure system for gas**

volume which is replenished when needed by manual connection to an external gas source

Note 1 to entry: Example of closed pressure systems are SF<sub>6</sub> single-pressure circuit-breakers.

[SOURCE: IEC 62271-1:2017, 3.6.6.2]

### 3.6.6.3

#### **sealed pressure system**

volume for which no further liquid, gas or vacuum processing is required during its expected operating duration

Note 1 to entry: Examples of sealed pressure systems are vacuum interrupters or some SF<sub>6</sub> circuit-breakers.

Note 2 to entry: Sealed pressure systems are completely assembled and tested in the factory.

Note 3 to entry: Expected operating duration starts when the device is sealed.

[SOURCE: IEC 62271-1:2017, 3.6.6.3]

### 3.6.6.4

#### **absolute leakage rate of a gas**

$F$

amount of gas escaped by time unit

Note 1 to entry: The absolute leakage rate is usually expressed in Pa × m<sup>3</sup> × s<sup>-1</sup>.

[SOURCE: IEC 62271-1:2017, 3.6.6.4]

### 3.6.6.5

#### **permissible leakage rate of a gas**

$F_p$

maximum permissible absolute leakage rate of gas specified for a part, a component or a sub-assembly, or by using the tightness coordination chart, for an arrangement of parts, components or subassemblies connected together in one pressure system

[SOURCE: IEC 62271-1:2017, 3.6.6.5]

### 3.6.6.6

#### **relative leakage rate**

$F_{rel}$

absolute leakage rate related to the total amount of gas in the system at filling pressure (or density)

Note 1 to entry: The relative leakage rate is expressed in percentage per year or per day.

[SOURCE: IEC 62271-1:2017, 3.6.6.6]

### 3.6.6.7

#### **time between replenishments**

$t_r$

time elapsed between two replenishments performed manually when the pressure (density) reaches the alarm level, to compensate the leakage rate  $F$

Note 1 to entry: This value is applicable to closed pressure systems.

[SOURCE: IEC 62271-1:2017, 3.6.6.7]

### 3.6.6.8

#### **number of replenishments per day of a gas**

$N$

number of replenishments to compensate the leakage rate  $F$

Note 1 to entry: This value is applicable to controlled pressure systems.

[SOURCE: IEC 62271-1:2017, 3.6.6.8]

### 3.6.6.9

#### **pressure drop of a gas**

$\Delta p$

drop of pressure in a given time caused by the leakage rate  $F$ , without replenishment

[SOURCE: IEC 62271-1:2017, 3.6.6.9]

### 3.6.6.10

#### **tightness coordination chart**

survey document supplied by the manufacturer, used when testing parts, components or sub-assemblies, to demonstrate the relationship between the tightness of a complete system and that of the parts, components or sub-assemblies

[SOURCE: IEC 62271-1:2017, 3.6.6.10, modified – Replacement of “and/or” with “or”.]

### 3.6.6.11

#### **sniffing**

action of slowly moving a leak meter sensing probe around an assembly to locate a gas leak

[SOURCE: IEC 62271-1:2017, 3.6.6.11]

### 3.6.6.12

#### **cumulative leakage measurement**

measurement which takes into account all the leaks from a given assembly to determine the leakage rate

[SOURCE: IEC 62271-1:2017, 3.6.6.12]

## **3.6.7 Terms and definitions relating to liquid tightness**

### 3.6.7.1

#### **absolute leakage rate of a liquid**

$F_{\text{liq}}$

amount of liquid escaped by time unit

Note 1 to entry: The absolute leakage rate is usually expressed in  $\text{cm}^3 \times \text{s}^{-1}$ .

[SOURCE: IEC 62271-1:2017, 3.6.7.1]

### 3.6.7.2

#### **permissible leakage rate of a liquid**

$F_{\text{p(liq)}}$

maximum permissible leakage rate specified by the manufacturer for a liquid pressure system

[SOURCE: IEC 62271-1:2017, 3.6.7.2]

### 3.6.7.3

#### **number of replenishments per day of a liquid**

$N_{\text{liq}}$

number of replenishments to compensate the leakage rate  $F_{\text{liq}}$

[SOURCE: IEC 62271-1:2017, 3.6.7.3]

#### 3.6.7.4

##### **pressure drop of a liquid**

$\Delta p_{\text{liq}}$

drop in pressure in a given time caused by the leakage rate  $F_{\text{liq}}$  without replenishment

[SOURCE: IEC 62271-1:2017, 3.6.7.4]

### 3.7 Characteristic quantities

#### 3.7.1

##### **rated value**

value of a quantity used for specification purposes, established for a specified set of operating conditions of a component, device, equipment or system

[SOURCE: IEC 60050-151:2001, 151-16-08]

#### 3.7.2

##### **isolating distance**

<of a mechanical switching device> clearance between open contacts meeting the withstand voltage requirements specified for disconnectors

[SOURCE: IEC 60050-441:1984, 441-17-35, modified – Deletion of “of a pole” from the term and replacement of “safety” with “withstand voltage”.]

#### 3.7.3

##### **highest voltage for equipment**

$U_m$

greatest value of pole-to-earth voltage for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards

Note 1 to entry: Under normal service conditions specified by the relevant apparatus committee, this voltage can be applied continuously to the equipment.

[SOURCE: IEC 60050-614:2016, 614-03-01, modified – Replacement of “line-to-line voltage (RMS value)” with “pole-to-earth voltage”, and addition of Note 1 to entry.]

#### 3.7.4

##### **supply voltage**

<of auxiliary and control circuits> RMS value or, if applicable, the DC value, of the voltage existing at a given instant at a point of supply, measured over a given time interval

Note 1 to entry: If a supply voltage is specified for instance in the supply contract, then it is called “declared supply voltage”.

Note 2 to entry: The supply voltage of auxiliary and control circuits is measured at the circuit terminals of the apparatus itself during its operation, including, if necessary, the auxiliary resistors or accessories supplied or required by the manufacturer to be installed in series with it, but not including the conductors for the connection to the electricity supply.

[SOURCE: IEC 60050-614:2016, 614-01-03, modified – Addition of Note 2 to entry.]

#### 3.7.5

##### **diode bridge current feed for VSC converter**

<HVDC substation using VSC> steady-state value of the short-circuit current supplied from AC system through VSC diode bridge before AC circuit-breaker opens

### 3.101

#### **metal-enclosed switchgear and controlgear**

switchgear and controlgear assemblies with an external metal enclosure intended to be earthed, and complete except for external connections

[SOURCE: IEC 60050-441:1984, 441-12-04, modified – The note was deleted.]

### 3.102

#### **DC gas-insulated metal-enclosed switchgear**

metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas or gas mixture other than air at atmospheric pressure and used for DC applications

Note 1 to entry: This term generally applies to high-voltage switchgear and controlgear.

[SOURCE: IEC 60050-441:1984, 441-12-05, modified – "or gas mixture" and "and used for DC applications" has been added in the definition.]

### 3.103

#### **DC gas-insulated switchgear enclosure**

part of DC gas-insulated metal-enclosed switchgear retaining the insulating gas under the prescribed conditions necessary to maintain safely the highest insulation level, protecting the equipment against external influences and providing a high degree of protection to personnel

[SOURCE: IEC 62271-203:2022, 3.103, modified – Addition of "DC" in the main term and in the definition.]

### 3.104

#### **isolating link**

part of the conductor which can easily be opened or removed in order to isolate two parts of the GIS from each other

Note 1 to entry: The open gap is designed to withstand the test voltages across isolating distance according to IEC TS 62271-5:2024, Table 1.

Note 2 to entry: The purpose of an isolating link is to ensure electrical isolation between sections of a GIS e.g., during maintenance and repair work.

[SOURCE: IEC 62271-203:2022, 3.104, modified – New reference to Table 1 of IEC TS 62271-5:2024 in Note 1 to entry.]

### 3.105

#### **removable link**

part of the conductor which can easily be opened or removed in order to isolate two parts of the GIS from each other

Note 1 to entry: The open gap is designed to withstand the phase-to-earth test voltages according to IEC TS 62271-5:2024, Table 1.

[SOURCE: IEC 62271-203:2022, 3.105, modified – In the definition, "separate" was replaced with "isolate"; addition of a new reference to Table in Note 1 to entry; deletion of Note 2 to entry.]

### 3.106

#### **compartment**

part of DC gas-insulated metal-enclosed switchgear, which is gastight and enclosed

Note 1 to entry: A compartment can be designated by the main component contained therein, e.g., busbar compartment.

[SOURCE: IEC 62271-203:2022, 3.106, modified – Addition of "DC" in the definition; deletion of "circuit-breaker compartment" as an example in Note 1 to entry.]

### **3.107**

#### **component**

essential part of the main or earthing circuits of DC gas-insulated metal-enclosed switchgear which serves a specific function

Note 1 to entry: Examples for components are disconnecter, switch, DCVT, DCCT, bushing, busbar.

[SOURCE: IEC 62271-203:2022, 3.107, modified – Addition of "DC" in the definition; deletion of "circuit-breaker compartment", "switch", "fuse", "instrument transformer" as examples and addition of "DCVT" and "DCCT" as examples.]

### **3.108**

#### **support insulator**

internal insulator supporting one or more conductors

[SOURCE: IEC 62271-203:2022-05, 3.108]

### **3.109**

#### **partition**

gas tight support insulator of DC gas-insulated metal-enclosed switchgear separating two adjacent compartments

[SOURCE: IEC 62271-203:2022-05, 3.109, modified – Addition of "DC" in the definition.]

### **3.110**

#### **bushing**

device that enables one or several conductors to pass through an enclosure and insulate the conductors from it

[SOURCE: IEC 60050-471:2007, 471-02-01, modified – In the definition, "an enclosure" inserted after "pass through" and "a partition such as a wall or a tank" deleted. Deletion of Note 1 to entry and Note 2 to entry.]

### **3.111**

#### **main circuit**

all the conductive parts of DC gas-insulated metal-enclosed switchgear included in a circuit which is intended to transmit electrical energy

[SOURCE: IEC 60050-441:1984, 441-13-02, modified – "DC gas-insulated metal-enclosed switchgear" inserted after "parts of" and "an assembly" deleted.]

### **3.112**

#### **auxiliary circuit**

all the conductive parts of DC gas-insulated metal-enclosed switchgear included in a circuit intended to control, measure, signal and regulate

Note 1 to entry: The auxiliary circuits of DC gas-insulated metal-enclosed switchgear include the control and auxiliary circuits of the switching devices.

[SOURCE: IEC 62271-203:2022, 3.112, modified – Addition of "DC" in the definition and in Note 1 to entry.]

### **3.113**

#### **enclosure design temperature**

maximum temperature that the enclosures can reach under specified maximum service conditions

[SOURCE: IEC 62271-203:2022, 3.113]

### **3.114**

#### **enclosure design pressure**

relative pressure used to determine the design of the enclosure

Note 1 to entry: It is at least equal to the maximum pressure in the enclosure at the highest temperature that the gas used for insulation can reach under specified maximum service conditions.

[SOURCE: IEC 62271-203:2022, 3.114, modified – Note 2 to entry deleted.]

### **3.115**

#### **partition design pressure**

relative pressure across the partition

Note 1 to entry: It is at least equal to the maximum differential pressure across the partition during maintenance activities.

[SOURCE: IEC 62271-203:2022, 3.115, modified – In the definition, deletion of "used to determine the design of the partition"; Note 2 to entry deleted.]

### **3.116**

#### **operating pressure**

<pressure relief device> relative pressure chosen for the opening operation of pressure relief devices

[SOURCE: IEC 62271-203:2022, 3.116]

### **3.117**

#### **routine test pressure**

<enclosures and partitions> relative pressure to which all enclosures and partitions are subjected after manufacturing

[SOURCE: IEC 62271-203:2022, 3.117]

### **3.118**

#### **type test pressure**

<enclosures and partitions> relative pressure to which all enclosures and partitions are subjected for type test

[SOURCE: IEC 62271-203:2022, 3.118]

### **3.119**

#### **fragmentation**

damage to enclosure due to pressure rise with projection of solid material

[SOURCE: IEC 62271-203:2022, 3.119]

### **3.120**

#### **disruptive discharge**

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

[SOURCE: IEC 62271-203:2022, 3.120]

### 3.121

#### **transport unit**

part of DC gas-insulated metal-enclosed switchgear suitable for shipment without being dismantled

[SOURCE: IEC 62271-203:2022, 3.121, modified – Addition of "DC" in the definition.]

### 3.122

#### **functional unit**

part of metal-enclosed switchgear and controlgear comprising all the components of the main circuits and auxiliary circuits that contribute to the fulfilment of a single function

Note 1 to entry: Functional units may be distinguished according to the function for which they are intended, for example complete bay or functional parts of a bay like complete, disconnector, earthing switch, current transducer, operating mechanism, enclosure, etc.

[SOURCE: IEC 60050-441:1984, 441-13-04, modified – "metal-enclosed" inserted after "part of" and "an assembly of" deleted. In the note the examples have been exchanged with examples relevant for GIS.]

### 3.123

#### **zero-load**

ZL

no current flowing through conductor

### 3.124

#### **high-load**

HL

continuous heating period at rated continuous current, which duration is not less than the thermal stabilization time (time  $d_g$ )

### 3.125

#### **thermal stabilisation time**

duration  $d_g$

period of time from load current applied to reach thermal steady state

### 3.126

#### **thermal steady state**

thermal steady state is defined as when the increase of temperature rise does not exceed 1 K in 1 h

### 3.127

#### **DC steady state**

DC steady state is defined as when minimum 90 % of the resistive field distribution is reached

Note 1 to entry: DC steady state is reached at the end of the transition from a capacitive to a resistive field distribution in the DC GIS. Depending on insulating material properties that are affected by temperature, electric field strength, etc., the transition to a resistive field distribution takes from hours to months.

### 3.128

#### **electric field transition time**

duration  $d_{DC}$

period of time from direct voltage application to the DC steady state

**3.129****superimposed impulse voltage test**

S/IMP

simultaneous stress consisting of the direct voltage and the lightning or switching impulse voltage superimposed upon it

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**4 Normal and special service conditions****4.1 Normal service conditions**

Subclause 4.1 of IEC TS 62271-5:2024 is applicable, taking into account the recommended values presented in Table 1 of this document.

**4.1.1 General**

Unless otherwise specified, high-voltage switchgear and controlgear, including the operating devices and the auxiliary equipment which form an integral part of them, are intended to be used in accordance with their rated characteristics and the normal service conditions listed in 4.1.

Operation under normal service conditions is considered to be covered by the type tests according to this document and the relevant product standard.

**4.1.2 Indoor switchgear and controlgear**

The normal service conditions for indoor switchgear and controlgear are:

- a) the ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h does not exceed 35 °C. The ambient air temperature does not drop below -5 °C;
- b) there is no influence from solar radiation;
- c) the altitude does not exceed 1 000 m;
- d) the ambient air is not significantly polluted by dust, smoke, corrosive and/or flammable gases, vapours or salt;

NOTE 1 Usually DC site severity is covered by a RUSCDDC between 20 mm/kV and 30 mm/kV (reference Annex B (informative)).

- e) the conditions of humidity are as follows;
  - the average value of the relative humidity, measured over a period of 24 h, does not exceed 95 %;
  - the average value of the water vapour pressure, over a period of 24 h, does not exceed 2,2 kPa;
  - the average value of the relative humidity, over a period of one month, does not exceed 90 %;
  - the average value of the water vapour pressure, over a period of one month, does not exceed 1,8 kPa.

NOTE 2 Condensation can be expected where sudden temperature changes occur in periods of high humidity.

NOTE 3 High humidity can also be due to ground level rainwater or for underground applications, from incoming cable raceways connected to switchgear.

- f) vibrations due to causes external to the switchgear and controlgear or earth tremors do not exceed the impact of vibrations caused by operation of the switchgear itself.

#### 4.1.3 Outdoor switchgear and controlgear

The normal service conditions for outdoor switchgear and controlgear are:

- a) the ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h, does not exceed 35 °C;  
the ambient air temperature does not drop below -25 °C;

NOTE 1 Rapid temperature changes can occur, for example a hot sunny day followed by a sudden rain.

- b) solar radiation does not exceed a level of 1 000 W/m<sup>2</sup>;

NOTE 2 Details of global solar radiation are given in IEC 60721-2-4 [38].

- c) the altitude does not exceed 1 000 m;
- d) the ambient air can be polluted by dust, smoke, corrosive gas, vapours or salt;

NOTE 3 Usually DC site severity is covered by a RUSCDDC of 60 mm/kV for non-HTM insulators and 45 mm/kV for HTM insulators (reference Annex B (informative)).

- e) ice coating does not exceed 20 mm;
- f) the wind speed does not exceed 34 m/s;

NOTE 4 Characteristics of wind are defined in IEC 60721-2-2 [37].

- g) the average humidity values given in 4.1.2 e) can be exceeded. Condensation or precipitation can occur;

NOTE 5 Characteristics of precipitation are defined in IEC 60721-2-2 [37].

NOTE 6 The conditions of humidity are always the effect of a combination of relative humidity with other environmental parameters, primarily temperature and rapid change of temperature.

- h) vibrations due to causes external to the switchgear and controlgear or earth tremors do not exceed the impact of vibrations caused by operation of the switchgear itself.

## 4.2 Special service conditions

Subclause 4.2 of IEC TS 62271-5:2024 is applicable, taking into account the recommended values presented in Table 1 of this document.

In the cases where higher than (>) is used in the table, the values shall be specified by the user as described in IEC TS 62271-5:2024.

NOTE Seismic evaluation is part of IEC 62271-207.

### 4.2.1 General

When high-voltage switchgear and controlgear is expected to be used under conditions different from the normal service conditions given in 4.1, the user's requirements should refer to standardized steps in 4.2.2 up to 4.2.7 if not provided by product standards.

NOTE 1 Appropriate actions are also taken to ensure proper operation under such conditions of other components, such as relays.

NOTE 2 Detailed information concerning classification of environmental conditions is given in IEC 60721-3-3 [40] (indoor) and IEC 60721-3-4 [41] (outdoor).

### 4.2.2 Altitude

For altitudes higher than 1 000 m, the equation provided in 4.5.1.1 b) of IEC TR 62271-306:2012 [62] and in H.3.4 of IEC 60071-2:2018 shall be used, i.e.  $k_{alt} = e^{m(H-1000/8150)}$ , where  $H$  is the altitude above sea level in m. Conservative values for the exponent  $m$  are stated in Table 4 of IEC TR 62271-306:2012 [62]. For further details, see H.4 of IEC 60071-2:2018.

NOTE 1 For internal insulation, the dielectric characteristics are identical at any altitude and no special precautions are taken. For external and internal insulation, refer to IEC 60071-2:2018.

NOTE 2 For low-voltage auxiliary and control equipment, no special precautions are taken if the altitude is lower than 2 000 m. For higher altitudes, refer to IEC 60664-1 [31].

### 4.2.3 Exposure to pollution

For outdoor application ambient air that can be polluted by dust, smoke, corrosive gas, vapours or salt at a level that exceeds DC site severity covered by a RUSCDDC of 60 mm/kV for non-HTM insulators and 45 mm/kV for HTM insulators, more information can be found in Annex B (informative).

For indoor application, ambient air that can be polluted by dust, smoke, corrosive gas, vapours or salt at a level that exceeds DC site severity covered by a RUSCDDC between 20 mm/kV and 30 mm/kV, more information can be found in Annex B (informative).

### 4.2.4 Temperature and humidity

For installation at a location where the ambient temperature can be different from the normal service condition ranges stated in 4.1, the ranges of minimum and maximum temperature to be specified should be:

- a) -50 °C to 40 °C for extremely cold climates;
- b) -40 °C to 40 °C for very cold climates;
- c) -30 °C to 40 °C for cold climates;
- d) -25 °C to 40 °C for cold climates (indoor conditions);
- e) -15 °C to 40 °C for moderate climates (indoor conditions);
- f) -5 °C to 55 °C for very hot climates.

In tropical indoor conditions, the average value of relative humidity measured during a period of 24 h can be up to 98 %.

NOTE 1 In certain regions with frequent occurrence of warm humid winds, sudden changes of temperature and/or atmospheric pressure can occur.

NOTE 2 For special indoor conditions with power electronics, a temperature range of +5 °C to +60 °C and a very low humidity can be reasonable. Reference is made to IEC 111-1:2023, Table 2.

#### 4.2.5 Exposure to abnormal vibrations, shock or tilting

Standard switchgear and controlgear is designed for mounting on substantially level structures, free from excessive vibration, shock, or tilting. Where any of these standard conditions do not exist, the requirements for the particular application should be specified by the user.

For installations where earthquakes are likely to occur, the severity level according to a relevant publication or specification should be specified by the user. In case of earthquake risk, the user should specify the operational requirements and admissible damage level.

Installations with other unusual forms of vibration shall be identified, such as installations in close proximity to mine blasting or mobile applications.

NOTE Other relevant publications for seismic evaluations are IEEE 693 [68] and IEEE C37.81 [69].

#### 4.2.6 Wind speed

If the wind speed is expected to be in excess of the normal service wind speed of 34 m/s, the user should specify the requirements for a particular application.

#### 4.2.7 Other parameters

When special environmental conditions prevail at the location where switchgear and controlgear shall be placed in service, they should be specified by the user by reference to IEC 60721-1 [35], IEC 60721-2 (all parts) [36] and IEC 60721-3 (all parts) [39].

### 4.101 General

**Table 1 – Reference table of service conditions relevant to DC GIS**

| Item                                                                                                 | Normal                                               |                                                      | Special                                              |                                                      |
|------------------------------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|
|                                                                                                      | Indoor                                               | Outdoor                                              | Indoor                                               | Outdoor                                              |
| Ambient air temperature:                                                                             |                                                      |                                                      |                                                      |                                                      |
| Minimum (°C)                                                                                         | –5                                                   | –25                                                  | –25                                                  | –50                                                  |
| Maximum (°C)                                                                                         | +40                                                  | +40                                                  | +50                                                  | +50                                                  |
| Solar radiation (W/m <sup>2</sup> )                                                                  | Not applicable                                       | 1 000                                                | Not applicable                                       | >1 000                                               |
| Altitude (m)                                                                                         | 1 000                                                | 1 000                                                | >1 000                                               | >1 000                                               |
| RUSCDdc <sup>a</sup>                                                                                 | reference is made to IEC TS 62271-5:2024, Clause B.2 | reference is made to IEC TS 62271-5:2024, Clause B.2 | Reference is made to IEC TS 62271-5:2024, Clause B.3 | Reference is made to IEC TS 62271-5:2024, Clause B.3 |
| Ice coating (mm)                                                                                     | Not applicable                                       | 20                                                   | Not applicable                                       | >20                                                  |
| Wind (m/s)                                                                                           | Not applicable                                       | 34                                                   | Not applicable                                       | >34                                                  |
| Average humidity over 24 hours (%)                                                                   | 95                                                   | 100                                                  | 98                                                   | 100                                                  |
| Condensation or precipitation                                                                        | Occasional                                           | Yes                                                  | Yes                                                  | Yes                                                  |
| Abnormal vibrations, shock or tilting                                                                | Not applicable                                       | Not applicable                                       | Applicable                                           | Applicable                                           |
| NOTE The user's specification can use any combination of normal or special service conditions above. |                                                      |                                                      |                                                      |                                                      |

<sup>a</sup> Usually DC site severity is covered by a reference d.c. Unified Specific Creepage Distance, and IEC TS 60815-4:2016 gives information on how to determine  $RUSCD_{dc}$ .

At any altitude the dielectric characteristics of the internal insulation are identical with those measured at sea-level. For this internal insulation no specific requirements concerning the altitude are applicable.

Some items of a DC GIS such as pressure relief devices and pressure and density monitoring devices can be affected by altitude. The manufacturer shall take appropriate measures if necessary.

## 5 Ratings

### 5.1 General

The common ratings of switchgear and controlgear assigned by the manufacturer, including their operating devices and auxiliary equipment, shall be selected from the following (as applicable):

- a) rated direct voltage ( $U_{rd}$ );
- b) rated insulation level ( $U_{dd}$ ,  $U_s$  and  $U_p$  where applicable);
- c) rated continuous current ( $I_{rd}$ );
- d) rated short-time withstand direct current ( $I_{kd}$ );
- e) rated peak withstand current ( $I_{pd}$ );
- f) rated duration of short-circuit ( $t_{kd}$ );
- g) rated supply voltage of auxiliary and control circuits ( $U_a$ );
- h) rated supply frequency of auxiliary and control circuits;
- i) rated pressure of compressed gas supply for controlled pressure systems.
- j) rated values of the components forming part of DC gas-insulated metal-enclosed switchgear, including their operating devices and auxiliary equipment.

NOTE Other ratings can be necessary and will be specified in the relevant IEC product standards.

Ratings define the common specifications of the switchgear and controlgear that are necessary for adequate selection and use in a particular network. Other important characteristics of the switchgear and controlgear are defined in Clause 3, e.g., minimum functional pressure for insulation, some of which are included on the nameplate but are not ratings. Still other characteristics refer to installation, operation and maintenance; they are not considered as ratings since they are related to the technology used for switchgear and controlgear. Examples include normal filling level or filling / alarm pressure (density) of fluids and tightness for liquids, gas and vacuum systems.

### 5.2 Rated direct voltage ( $U_{rd}$ )

Components forming part of the DC GIS can have individual values of rated voltage for equipment in accordance with the relevant documents.

#### 5.2.1 General

The rated direct voltage of HV switchgear and controlgear ( $U_{rd}$ ) is the highest direct voltage pole to earth that include harmonics for which it is designed in respect of its insulation as well as other characteristics, to operate as specified for the service life (lifetime).

The typical system direct voltage ( $U_{\text{typ,d}}$ ) is a system voltage in normal operation condition. This is a rounded value that is derived as an average from multiple projects and typical values are shown in Table 1. Depending on the configuration of the DC system, other values that do not exceed the rated direct voltage might be reasonable. Voltage ripple and harmonics of the system are included in the values given.

The rated direct voltage and the typical system direct voltage can differ from component-specific voltages, e.g. rated voltage for transfer switches and rated voltage for bypass switch can be different. Reference is made to IEC TS 62271-315 [3] and TS 62271-316 [4].

NOTE 1 The inclusion of voltage ripple and harmonics in the values is in line with CIGRE recommendations [75] and [73].

The rated direct voltages ( $U_{\text{rd}}$ ) are given in 5.2.2 below.

NOTE 2 The term “rated maximum voltage” used in most IEEE switchgear standards has the same meaning as the term “rated direct voltage” as used in this document.

### 5.2.2 Rated voltages

105 kV – 160 kV – 210 kV – 265 kV – 340 kV – 420 kV – 525 kV – 630 kV – 840 kV

NOTE Values for rated voltages lower than 100 kV cannot be defined adequately. The reason is the lack of applications or products. However, as an indication, for preferred voltages lower than 100 kV values are provided as a guide in Annex C (informative).

### 5.3 Rated insulation level ( $U_{\text{dd}}$ , $U_{\text{p}}$ , $U_{\text{s}}$ )

The insulation levels for rated voltages of 105 kV and above should be selected from the preferred rated values given in Table 1.

NOTE 1 Examples of preferred insulation levels for rated voltages lower than 105 kV are given in Annex C (informative).

Withstand values given in Table 1 cover the application of switchgear and controlgear under normal service conditions defined in 4.1 including altitudes from sea level up to 1 000 m. However, for testing purposes to verify a rating or capability, they shall be considered as insulation values at the standardized reference atmosphere temperature (20 °C), pressure (101,3 kPa) and humidity (11 g/m<sup>3</sup>) specified in IEC 60071-1:2019, 5.9.2. For special service conditions, refer to IEC TR 62271-306 [62].

NOTE 2 The normal environmental conditions and the standard reference atmospheric conditions are currently not stated in IEC 60071-1:2022. In terms of these conditions, 5.9.1 and 5.9.2 of IEC 60071-1:2019 are applied in this document.

NOTE 3 The insulation levels in Table 1 are considered being applicable in the temperature range of -40 °C up to 40 °C for DC systems. Reference is made to IEC 60071-1:2019, 5.9.1 for AC systems.

The rated withstand voltage values for lightning impulse voltage ( $U_{\text{p}}$ ), switching impulse voltage ( $U_{\text{s}}$ ) (when applicable), and direct voltage ( $U_{\text{dd}}$ ) shall be selected without crossing the horizontal marked lines in Table 1.

The superimposed voltage is a composite voltage consisting of the rated direct voltage  $U_{\text{rd}}$  and the lightning impulse voltage  $U_{\text{p}}$  or switching impulse voltage  $U_{\text{s}}$ , as shown in Figure 1.

The DC GIS comprises components having a definite insulation level. Although internal faults can largely be avoided by the choice of a suitable insulation level, measures to limit external overvoltages (e.g. surge arresters,) should be considered.

NOTE 1 Regarding the external parts of bushings (if any), see to IEC/IEEE 65700-19-03:2014.

NOTE 2 The waveforms are standardized lightning impulse and switching impulse shapes, pending the results of studies on the ability of this equipment to withstand other types of impulses.

NOTE 3 The choice between alternative insulation levels for a particular rated voltage for equipment can be based on insulation coordination studies, taking into account also the self-generated transient overvoltages due to switching.

NOTE 4 Annex H provides further information about DC switchgear located on a neutral bus.

**Table 1 – Preferred rated insulation levels**

| Typical system direct voltage<br>$U_{typ,d}$<br>kV<br>(NOTE 1) | Rated direct voltage<br>$U_{rd}$<br>kV<br>(NOTE 2) | Rated direct withstand voltage<br>$U_{dd}$<br>kV                                  | Rated switching impulse withstand voltage<br>$U_s$<br>kV (peak value) |                                        | Rated lightning impulse withstand voltage<br>$U_p$<br>kV (peak value) |                                                                     |
|----------------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------|
|                                                                |                                                    | Pole-to-earth, across open switching device and/or isolating distance<br>(NOTE 3) | Pole-to-earth and across open switching device<br>(NOTE 4)            | Across isolating distance <sup>a</sup> | Pole-to-earth<br>(NOTE 4)                                             | Across open switching device and/or isolating distance <sup>a</sup> |
| (1)                                                            | (2)                                                | (3)                                                                               | (4)                                                                   | (5)                                    | (6)                                                                   | (7)                                                                 |
| 100                                                            | 105                                                | 160                                                                               | --                                                                    | --                                     | 380                                                                   | 380(+105)                                                           |
| 150                                                            | 160                                                | 240                                                                               | --                                                                    | --                                     | 450                                                                   | 450(+160)                                                           |
| 200                                                            | 210                                                | 315                                                                               | 550                                                                   | 550(+210)                              | 550                                                                   | 550(+210)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 650                                                                   | 650(+210)                                                           |
| 250                                                            | 265                                                | 395                                                                               | 550                                                                   | 550(+265)                              | 550                                                                   | 550(+265)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 650                                                                   | 650(+265)                                                           |
|                                                                |                                                    |                                                                                   | 650                                                                   | 650(+265)                              | 650                                                                   | 650(+265)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 750                                                                   | 750(+265)                                                           |
| 320                                                            | 340                                                | 505                                                                               | 650                                                                   | 650(+340)                              | 650                                                                   | 650(+340)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 750                                                                   | 750(+340)                                                           |
|                                                                |                                                    |                                                                                   | 750                                                                   | 750(+340)                              | 750                                                                   | 750(+340)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 850                                                                   | 850(+340)                                                           |
|                                                                |                                                    |                                                                                   | 850                                                                   | 850(+340)                              | 850                                                                   | 850(+340)                                                           |
| 400                                                            | 420                                                | 630                                                                               | 850                                                                   | 850(+420)                              | 850                                                                   | 850(+420)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 950                                                                   | 950(+420)                                                           |
|                                                                |                                                    |                                                                                   | 950                                                                   | 950(+420)                              | 950                                                                   | 950(+420)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 050                                                                 | 1 050(+420)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 175                                                                 | 1 175(+420)                                                         |
| 500                                                            | 525 <sup>b</sup>                                   | 790                                                                               | 950                                                                   | 950(+525)                              | 950                                                                   | 950(+525)                                                           |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 050                                                                 | 1 050(+525)                                                         |
|                                                                |                                                    |                                                                                   | 1 050                                                                 | 1 050(+525)                            | 1 050                                                                 | 1 050(+525)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 175                                                                 | 1 175(+525)                                                         |
|                                                                |                                                    |                                                                                   | 1 175                                                                 | 1 175(+525)                            | 1 175                                                                 | 1 175(+525)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 300                                                                 | 1 300(+525)                                                         |
| 600                                                            | 630                                                | 945                                                                               | 1 175                                                                 | 1 175(+630)                            | 1 175                                                                 | 1 175(+630)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 300                                                                 | 1 300(+630)                                                         |

| Typical system direct voltage<br>$U_{typ,d}$<br>kV<br>(NOTE 1) | Rated direct voltage<br>$U_{rd}$<br>kV<br>(NOTE 2) | Rated direct withstand voltage<br>$U_{dd}$<br>kV                                  | Rated switching impulse withstand voltage<br>$U_s$<br>kV (peak value) |                                        | Rated lightning impulse withstand voltage<br>$U_p$<br>kV (peak value) |                                                                     |
|----------------------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------|
|                                                                |                                                    | Pole-to-earth, across open switching device and/or isolating distance<br>(NOTE 3) | Pole-to-earth and across open switching device<br>(NOTE 4)            | Across isolating distance <sup>a</sup> | Pole-to-earth<br>(NOTE 4)                                             | Across open switching device and/or isolating distance <sup>a</sup> |
| (1)                                                            | (2)                                                | (3)                                                                               | (4)                                                                   | (5)                                    | (6)                                                                   | (7)                                                                 |
|                                                                |                                                    |                                                                                   | 1 300                                                                 | 1 300(+630)                            | 1 300                                                                 | 1 300(+630)                                                         |
|                                                                |                                                    |                                                                                   | 1 425                                                                 | 1 425(+630)                            | 1 425                                                                 | 1 425(+630)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 425                                                                 | 1 425(+630)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 550                                                                 | 1 550(+630)                                                         |
| 800                                                            | 840                                                | 1 260                                                                             | 1 550                                                                 | 1 550(+840)                            | 1 550                                                                 | 1 550(+840)                                                         |
|                                                                |                                                    |                                                                                   | 1 675                                                                 | 1 675(+840)                            | 1 675                                                                 | 1 675(+840)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 675                                                                 | 1 675(+840)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 800                                                                 | 1 800(+840)                                                         |
|                                                                |                                                    |                                                                                   |                                                                       |                                        | 1 950                                                                 | 1 950(+840)                                                         |

NOTE 1 The typical system direct voltage values in column (1) are referred to IEC 60071-11:2022, Annex C.

NOTE 2 The rated direct voltage  $U_{rd}$  takes into account 5 % of ripple and harmonics to the typical system direct voltage, based on that the ripples and harmonics are in the range of 2 to 5 % of the typical system direct voltage. Reference is made to CIGRE Technical Brochure 684 [73].

NOTE 3 The rated direct withstand voltage  $U_{dd}$  is 150 % of the rated direct voltage  $U_{rd}$  of the HVDC system, reference is made to IEC TS 63014-1.

NOTE 4 The values in column (4) and (6) are mainly referred to IEC 60071-11:2022, Annex C.

<sup>a</sup> In column (5) and (7), values in brackets are the rated direct voltage applied to the opposite terminal (combined voltage). For multi-terminal grids or other system configurations, where the full direct voltage can occur at the opposite terminal, the 100 % rated direct voltage shall be applied. For typical two terminal DC systems, where no higher values can occur at the opposite terminal, the value of 10 % of rated direct voltage should be chosen. For equipment not subjected to direct voltage at the opposite terminal, columns (5) and (7) are not applicable.

<sup>b</sup> Instead of  $U_{rd} = 525$  kV rated direct voltage,  $U_{rd} = 550$  kV can also be reasonable. Reference is made to IEC 60071-11:2022, Annex C. In this case, the values in brackets of column (5) and (7) has to be adapted to the higher value of  $U_{rd}$  and the rated direct withstand voltage in column (3) shall be re-calculated according to NOTE 2.

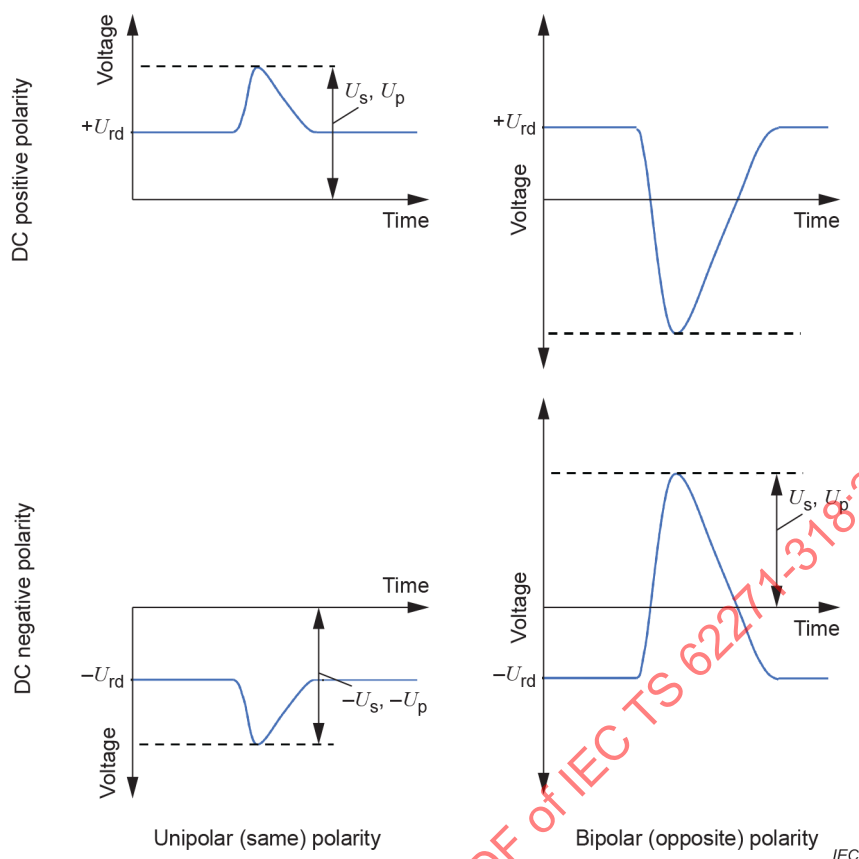


**Figure 1 – Schematic representation of superimposed impulse voltage tests**

#### 5.4 Rated continuous current ( $I_{rd}$ )

This rating defines the value of the current the switchgear and controlgear can carry continuously for its service conditions (see Clause 4).

The values of rated continuous current should be selected from the R 10 series, specified in IEC 60059 [11].

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

NOTE 2 Continuous current defined in this document does not include any harmonics or induced current.

Some main circuits of DC GIS (e.g. busbars, feeder circuits, etc.) can have different values of rated continuous current. However, these values should also be selected from R10 series.

#### 5.5 Rated values of short-time withstand current

##### 5.5.1 Typical waveform of short-circuit current

Figure 2 shows typical waveforms of short-circuit current in an HVDC system.

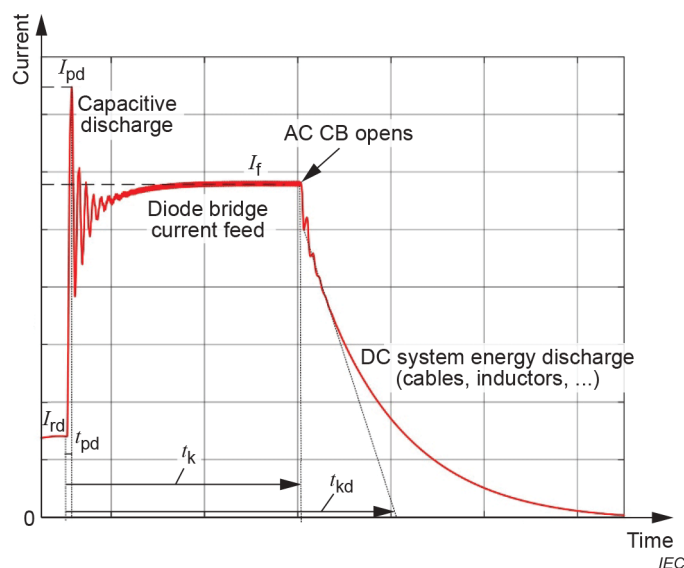
- The current waveform in Figure 2a) corresponds to a typical half-bridge MMC (Modular Multilevel Converter), in a 2-terminal VSC HVDC and station switchgear in DC grids;
- The current waveform in Figure 2b) corresponds to a typical LCC (Line Commutated Converter), in a 2-terminal LCC HVDC; A special case of LCC under DC fault, that generally gives higher current stress, is discussed in Annex D (informative); This waveform also applies to 2-terminal, full-bridge MMC HVDC systems;
- The current waveform in Figure 2c) corresponds to a DC-line in HVDC system (2-terminal, multi-terminal or DC grid) with at least one DC CB installed.

Annex D (informative) gives further information on the circuit topologies, assumptions, and calculations.

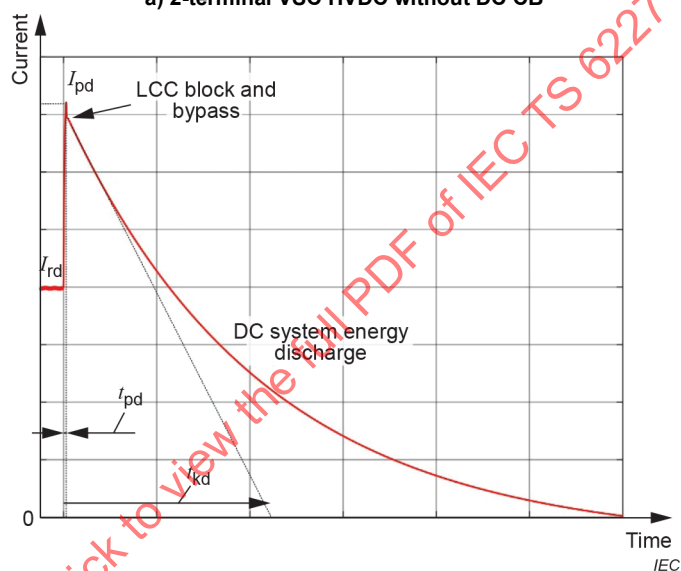
In Figure 2c), the positive slope ( $S_p$ ) is determined by the total series reactance in the fault path, as shown in Figure D.5. A typical value is  $2 \text{ kA/ms} < S_p < 10 \text{ kA/ms}$ .

NOTE The definition of typical waveform for DC short-circuit currents is in the scope of IEC TC 73 (Short-circuit currents) activities. The definitions in 5.5 are provisionally provided by IEC TC 17 (High-voltage switchgear and controlgear) for the purpose of this document, and will be updated when definitions from TC 73 become available.

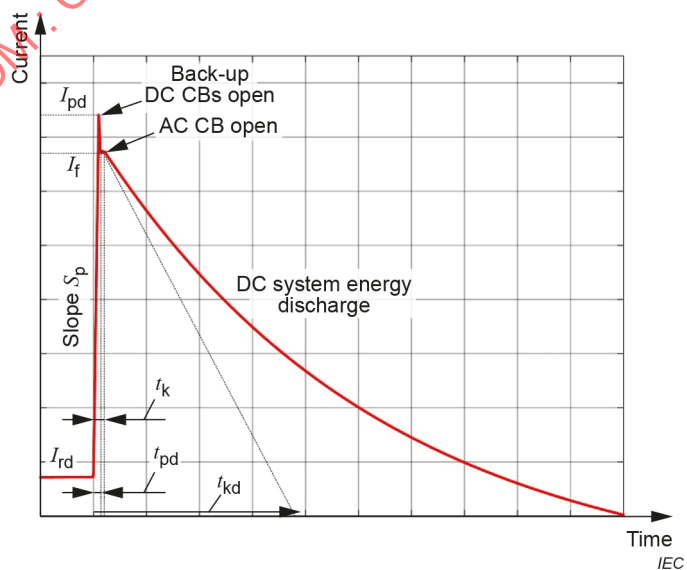
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a) 2-terminal VSC HVDC without DC CB



b) 2-terminal LCC HVDC without DC CB



c) HVDC system (or DC grid) with DC CB

Figure 2 – Typical waveform of a short-circuit current in an HVDC system

### 5.5.2 Rated short-time withstand direct current ( $I_{kd}$ )

This rating defines the value of the short-circuit direct current that the switchgear and controlgear can carry in the closed position during its rated duration (see 5.5.4) under its service conditions (see Clause 4).

The value of rated short-time withstand direct current shall be determined so that it meets the necessary thermal withstand capability considering the type of waveform shown in Figure 2. D.4 gives the methodology for determining the value. The final value should be selected from the R 10 series specified in IEC 60059.

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

### 5.5.3 Rated peak withstand current ( $I_{pd}$ )

This rating defines the peak value of the short circuit current. The value of rated peak withstand current depends on the type of waveform. Annex D (informative) gives the details.

The preferred value of rated peak withstand current is:

- for circuit in Figure 2a),  $1,5 I_f$ ;
- for circuit in Figure 2b),  $2,0 I_{rd}$ ;
- for circuit in Figure 2c),  $S_p t_{pd}$ .

where  $I_f$  is diode bridge current feed for VSC converter in Figure 2a) (see D.1) and  $S_p$  and  $t_{pd}$  are positive slope and time to peak of short-circuit current time in Figure 2c), respectively (see D.3).

An alternative value higher than above may be chosen.

The time to peak short-circuit current, is around 0,01 s for Figure 2a) and 0,07 s for Figure 2b) and 0,01 s for Figure 2c) but it will depend on the operating time of DC CB and protection (or back-up protection) time. D.4 gives further information.

### 5.5.4 Rated duration of short-circuit ( $t_{kd}$ )

This rating defines the interval of time for which the switchgear and controlgear can carry, in the closed position, a current equal to its rated short-time withstand direct current.

The preferred value of rated duration of short circuit is:

- for circuit in Figure 2a), 0,7 s;
- for circuit in Figure 2b), 0,7 s; In case of full-bridge MMC HVDC a much smaller value may be chosen, depending on the DC circuit and the converter controller;
- for circuit in Figure 2c), 0,5 s.

An alternative value higher than above may be chosen.

## 5.6 Rated supply voltage of auxiliary and control circuits ( $U_a$ )

### 5.6.1 General

Several auxiliary voltages can be used on a single type of switchgear and controlgear.

### 5.6.2 Rated supply voltage ( $U_a$ )

The rated supply voltage should be selected from the standard values given in Table 2 and Table 3.

**Table 2 – Direct voltage of auxiliary and control circuits**

| $U_a$<br>V |
|------------|
| 24         |
| 48         |
| 60         |
| 110        |
| 125        |
| 220        |
| 250        |

**Table 3 – Alternating voltage of auxiliary and control circuits**

| Line number | Three-phase, three-wire or four-wire systems<br>V | Single-phase, three-wire systems<br>V | Single-phase, two-wire systems<br>V |
|-------------|---------------------------------------------------|---------------------------------------|-------------------------------------|
| (1)         | (2)                                               | (3)                                   | (4)                                 |
| 1           | –                                                 | 120/240                               | 120                                 |
| 2           | 120/208                                           | –                                     | 120                                 |
| 3           | (220/380)                                         | –                                     | (220)                               |
| 4           | 230/400                                           | –                                     | 230                                 |
| 5           | (240/415)                                         | –                                     | (240)                               |
| 6           | 277/480                                           | –                                     | 277                                 |
| 7           | 347/600                                           | –                                     | 347                                 |

NOTE 1 The value 230/400 V indicated in line 4 of this table will be, in the future, the IEC standard voltage replacing the values 220/380 V and 240/415 V in lines 3 and 5. The voltage variations of existing systems at 220/380 V and 240/415 V will be brought within the range 230/400 V  $\pm$  23/40 V. The reduction of this range will be considered in the next and subsequent revisions.

NOTE 2 The lower values in the column (2) of this table are voltages to neutral and the higher values are voltages between phases. The lower value in the column (3) is the voltage to neutral and the higher value is the voltage between lines.

### 5.7 Rated supply frequency of auxiliary and control circuits

When alternating current supply voltage is used, the preferred values of rated supply frequency are 50 Hz and 60 Hz.

### 5.8 Rated pressure of compressed gas supply for controlled pressure systems

Annex E provides further information about notes concerning certain countries.

The preferred values of rated pressure (relative pressure) are:

0,5 MPa – 1 MPa – 1,6 MPa – 2 MPa – 3 MPa – 4 MPa.

NOTE A example of controlled pressure systems is pneumatic drive mechanism.

## 6 Design and construction

### 6.1 Requirements for liquids in switchgear and controlgear

The manufacturer shall specify the type and the required quantity and quality of the liquid used in switchgear and controlgear.

The manufacturer shall provide the user with necessary instructions for renewing the liquid and maintaining its required quantity and quality (refer to 11.5.2) except for sealed pressure systems.

For oil-filled switchgear and controlgear, insulating oil complying with IEC 60296 shall be used.

### 6.2 Requirements for gases in switchgear and controlgear

The manufacturer shall specify the type and the required quantity, and quality of the gas used in switchgear and controlgear.

The manufacturer shall provide the user with necessary instructions for renewing the gas and maintaining its required quantity and quality (refer to 11.5.2 and item a) of 11.5.3). This requirement does not apply to sealed pressure systems.

For sulphur hexafluoride ( $\text{SF}_6$ ) filled switchgear and controlgear,  $\text{SF}_6$  in accordance with IEC 60376 for new  $\text{SF}_6$  and its mixture and IEC 60480 for reused  $\text{SF}_6$  and its mixture shall be used. For gas handling of switchgear and controlgear with gas, reference is made to IEC 62271-4.

In order to prevent condensation, the maximum allowable humidity content within gas-filled switchgear and controlgear at the filling density for insulation shall be such that the dew point at filling pressure (density) for insulation is not higher than  $-5\text{ °C}$  for a measurement at  $20\text{ °C}$  during service life, refer to 11.3.6.

### 6.3 Earthing of switchgear and controlgear

Switchgear and controlgear shall be provided with a reliable earthing point for connection of an earthing conductor suitable for specified fault conditions. The connecting point shall be marked with the “protective earth” symbol, as indicated by symbol IEC 60417-5019:2006-08. Conductive parts of the switchgear and controlgear intended to be connected to the earthing system, can be designed to be part of the earthing circuit.

All conductive components and enclosures that can be touched during normal operating conditions and are intended to be earthed shall be designed to carry 30 A (DC) with a voltage drop of maximum 3 V to the earthing point provided at the switchgear and controlgear.

NOTE For guidance on the connection of the earthing point of the switchgear and controlgear to the main station earth, Clause 10 of IEC 61936-1:2021 [58] and IEC 61936-2:2015 [59] applies.

#### 6.3.101 Earthing of the main circuit

To ensure safety during maintenance work, all parts of the main circuit to which access is required or provided shall be capable of being earthed.

Earthing can be made by:

- g) earthing switches with a making capacity equal to the rated peak withstand current, if there is still a possibility that the circuit connected is energised;
- h) earthing switches without a making capacity or with a making capacity lower than the rated peak withstand current, if there is certainty that the circuit connected is not energised.

Furthermore, it shall be possible, after opening the enclosure, to connect removable earthing devices for the duration of the work on a circuit element previously earthed via an earthing switch. The removable earthing device shall have the relevant short-circuit withstand capability and/or induced current capability.

The earthing circuit can be degraded after being subjected to the short-circuit current. After such event, it can be applicable to replace the earthing circuit.

### 6.3.102 Earthing of the enclosure

The enclosures shall be connected to earth. All metal parts which do not belong to a main or an auxiliary circuit shall be earthed. For the interconnection of enclosures, frames, etc., fastening (e.g. bolting or welding) is acceptable for providing electrical continuity.

The continuity of the earthing circuits can be ensured taking into account the thermal and electrical stresses caused by the current they have to carry.

## 6.4 Auxiliary and control equipment and circuits

### 6.4.1 General

Switchgear and controlgear include all auxiliary and control equipment and circuits, including but not limited to, electronic controls, supervision, monitoring and communication.

Auxiliary and control equipment and circuits shall operate normally when the voltage measured during operation at the supply terminals of the auxiliary and control equipment and circuits:

- is within 85 % to 110 % of rated supply voltage ( $U_a$ );
- in the case of DC, a ripple voltage is not greater than 5 % of  $U_a$ ;
- is free of the voltage dips and interruptions which exceed the limits declared by the manufacturer according to IEC 61000-4-29 (DC supply voltage) and IEC 61000-4-11 (AC supply voltage).

In case of supply interruptions (also during operations) that exceed the duration limits declared by the manufacturer for normal operation:

- there shall be no false operation, false alarms or false remote signalling resulting from the interruption or re-instatement of the supply;
- the manufacturer shall state the behaviour of the device when the supply voltage gets interrupted (for example impact on internal energy storage);
- the manufacturer shall state the behaviour of the device when the supply voltage returns;
- subsequent actions shall only be completed in response to a new valid operational command (where applicable).

The fulfilment of the above conditions can be demonstrated at any convenient dip duration that exceeds the declared limit.

NOTE 1 Possible actions can be:

- i) completing the pending action without manual intervention such that the equipment achieves a defined, safe operating state for example open, closed, charged, discharged;
- j) manual intervention such that the equipment achieves a defined, safe operating state for example open, closed, charged, discharged;
- k) completing the action after giving another command for the same switching operation that was interrupted.

This choice can also be dependent on the duration of the interruption.

Specific conditions are given in 6.9 of IEC 62271-1:2017 for shunt closing releases, shunt opening releases and under-voltage releases.

For supply voltages lower than the minimum stated above, precautions shall be taken to prevent any damage to electronic equipment and/or unsafe operation.

Requirements for the interface with digital communication that ensure compliance with IEC 61850 (all parts) [57] are detailed in IEC 62271-3 [61].

NOTE 2 The logical nodes in IEC 62271-3:2015 (XCBR, XSWI) and their additional data objects described in Annex B of IEC 62271-3:2015 cover only some properties required by the electronic nameplates of some switchgear and controlgear of the IEC 62271 series of standards. The other properties required for the physical nameplate, tendering, quotation and ordering phases are not covered.

## **6.4.2 Protection against electric shock**

### **6.4.2.1 Protection of auxiliary and control circuits from the main circuit**

Auxiliary and control circuits that are installed on the frame of switchgear and controlgear shall be suitably protected against disruptive discharge from the main circuit. This is verified by dielectric type tests specified in 7.2, see 7.2.5 f).

### **6.4.2.2 Safety clearance during service**

Auxiliary and control circuits to which access is required during service shall be accessible without the need to compromise clearances to hazardous parts.

## **6.4.3 Components installed in enclosures**

### **6.4.3.1 Selection of components**

All components used in the auxiliary and control circuits shall be designed or selected to be operational with their rated characteristics over the full range of service conditions inside auxiliary and control circuits enclosures. Suitable precautions (for example, heaters, ventilators, insulation, etc.) should be taken to ensure that those service conditions essential for proper operation of relays, contactors, low-voltage switches, meters, operation counters, push-buttons, etc. are maintained.

NOTE These internal conditions in control cabinet for auxiliary and control circuits can differ from the external service conditions specified in Clause 4.

The loss of “suitable precautions” shall not cause failure of the auxiliary and control circuits within the enclosure or untimely operation of the switchgear within the specified time. Selection of components should take into account the temperature obtained in the cabinet of the control and auxiliary circuit during a 2-hour period following the loss of the “suitable precautions” in order to ensure the proper operation of switchgear and controlgear until the end of this 2-hour period.

After this 2-hour period non-operation is acceptable. If the loss of the “suitable precautions” is longer than 2 h but does not exceed 24 h in total, the functionality of the switchgear and controlgear shall come back to its original characteristics when the service conditions are recovered.

Where heating is essential for correct functioning of the equipment, monitoring of the heating circuit shall be provided.

In the case of switchgear and controlgear designed for outdoor installation, suitable arrangements (ventilation and/or internal heating, etc.) can be necessary to prevent harmful condensation in auxiliary and control circuit enclosures.

### **6.4.3.2 Accessibility**

Closing and opening actuators and emergency shut-down system actuators shall be located between 0,4 m and 2 m above the floor, ground or operating platform normally used by operating personnel.

Other actuators should be located at such a height that they can be easily operated. Indicating devices should be located at such a height as to be readily legible.

Where a component needs adjustment during its service life, access shall be provided with protection level of at least IP XXB, refer to IEC 60529:1989, IEC 60529:1989/AMD1:1999 and IEC 60529:1989/AMD2:2013.

#### **6.4.3.3 Identification**

Identification of components installed in enclosures shall be in agreement with the indication on the wiring diagrams and drawings. If a component is of the plug-in type, an identifying mark should be placed on the component and on the fixed part where the component plugs in.

#### **6.4.3.4 Requirements for auxiliary and control circuit components**

##### **6.4.3.4.1 General**

The auxiliary and control circuit components shall comply with applicable IEC standards if one exists. Annex E (informative) is provided as a quick reference to many of the component standards.

##### **6.4.3.4.2 Cables and wiring**

Where a facility for external wiring is provided, it shall be through an appropriate connecting device, e.g. terminal blocks or plug-in terminations.

Polarity reversal at the interfacing point shall not damage auxiliary and control circuits.

Terminal blocks should be fixed. Cables between two terminal blocks shall have no intermediate splices or soldered joints.

Cables and wiring shall be adequately supported and shall not rest against sharp edges.

The available wiring space for external connection shall permit spreading of the cores of multi-core cables and the proper termination of the conductors without undue stresses.

Conductors connected to components mounted on doors shall be so installed that no mechanical damage can occur to the conductors as a result of movement of these doors.

##### **6.4.3.4.3 Terminals**

If facilities are provided for connecting incoming and outgoing neutral, protective and PEN (protective earthed neutral) conductors, they shall be situated in the vicinity of the associated phase conductor terminal.

##### **6.4.3.4.4 Auxiliary switches**

Auxiliary switches shall be suitable for the number of operating cycles specified for the high-voltage switching device to which they are linked.

Auxiliary switches which are operated in conjunction with the main contacts shall be positively driven in both directions. An auxiliary switch can consist of a set of two one-way positively driven auxiliary contacts (one for each direction).

##### **6.4.3.4.5 Auxiliary and control contacts**

Auxiliary and control contacts shall be suitable for the number of operating cycles specified for the switching device. This requirement is verified by the mechanical endurance test of the high-voltage switching devices to which they are linked.

The operational characteristics of the auxiliary contacts that are made available to the user shall comply with one of the classes shown in Table 4.

Examples of the use of the three contact classes are shown in Figure 3.

**Table 4 – Auxiliary contact classes**

| Direct current |                          |                                    |                         |                                             |
|----------------|--------------------------|------------------------------------|-------------------------|---------------------------------------------|
| Class          | Rated continuous current | Rated short-time withstand current | Breaking capacity       |                                             |
|                |                          |                                    | $U_a \leq 48 \text{ V}$ | $110 \text{ V} \leq U_a \leq 250 \text{ V}$ |
| 1              | 10 A                     | 100 A/30 ms                        |                         | 440 W                                       |
| 2              | 2 A                      | 100 A/30 ms                        |                         | 22 W                                        |
| 3              | 200 mA                   | 1 A/30 ms                          | 50 mA                   |                                             |

NOTE 1 Control contacts which are included in a control circuit of a mechanical switching device can be covered by this table.

NOTE 2 If insufficient current is flowing through the contact, oxidation can increase the resistance. Therefore, a minimum value of current is specified for class 1 contact.

NOTE 3 In the case of the application of solid state contacts, the rated short-time withstand current can be reduced if current-limiting equipment, other than fuses, is employed.

NOTE 4 For all classes, breaking capacity are based on a circuit time constant of 20 ms with a tolerance of  $^{+20}_0$  %.

NOTE 5 An auxiliary contact which complies with class 1, 2 or 3 for DC is normally able to handle corresponding AC current and voltage.

NOTE 6 Breaking current at a defined voltage value between 110 V and 250 V can be deduced from the indicated power value for class 1 and class 2 contacts (for example, 2 A at 220 V DC for a class 1 contact).

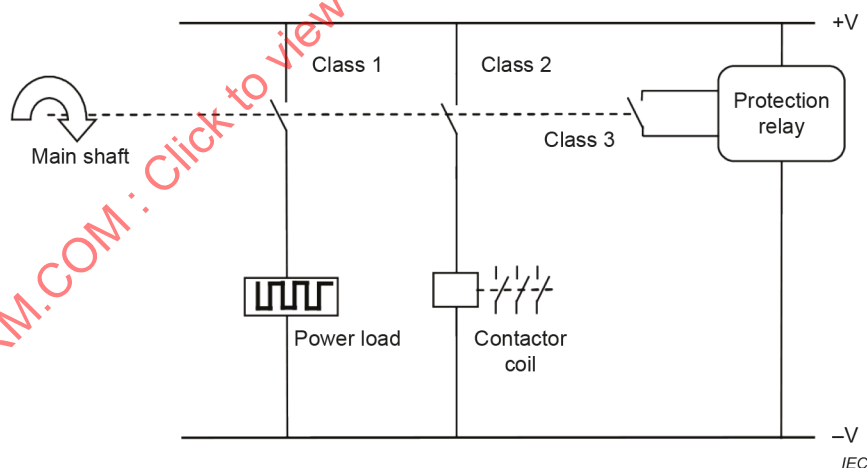


**Figure 3 – Examples of classes of contacts**

#### 6.4.3.4.6 Heating elements

All heating elements shall be designed to prevent touching an electrically live part.

Where contact with a heater or shield can occur accidentally, the surface temperature shall not exceed the temperature limits for accessible parts not to be touched in normal operation, as specified in 7.4.6.

#### 6.4.3.5 Operation counter

Operation counters shall be suitable for their intended duty in terms of environmental conditions and for the number of operating cycles specified for the switching devices.

### 6.5 Dependent power operation

A switching device arranged for dependent power operation with external energy supply shall be able to switch its rated making and/or breaking currents (if any) when the voltage or the pressure of the power supply of the operating device is at the lower of the limits specified under 6.4.1 and 6.6.2 (the term “operating device” here embraces intermediate control relays and contactors where provided).

Except for slow operation during maintenance, the main contacts shall only move under the action of the drive mechanism and in the designed manner. The closed or open position of the main contacts shall not change as a result of loss of the energy supply or the re-application of the energy supply after a loss of energy, to the closing and/or opening device.

### 6.6 Stored energy operation

#### 6.6.1 General

A switching device arranged for stored energy operation shall be capable of making and breaking all currents up to its rated values when the energy storage device is suitably charged. Except for slow operation during maintenance, the main contacts shall only move under the action of the drive mechanism and in the designed manner, and not due to re-application of the energy supply after a loss of energy (electric power or pressure supply).

A device indicating when the energy storage device is charged shall be mounted on the switching device except in the case of an independent unlatched operation.

It shall not be possible for the moving contacts to move from one position to the other, unless the stored energy is sufficient for satisfactory completion of the opening or closing operation. Stored energy devices shall be able to be discharged to a safe level prior to access.

#### 6.6.2 Energy storage in gas receivers or hydraulic accumulators

When the energy storage device is a gas receiver or hydraulic accumulator, the requirements of 6.6.1 apply at operating pressures between the limits specified in items a) and b).

##### l) External pneumatic or hydraulic supply

Unless otherwise specified by the manufacturer, the limits of the operating pressure are 85 % and 110 % of their specified rated pressure.

These limits do not apply when the gas receivers also store compressed gas for interruption.

##### m) Compressor or pump integral with the switching device or the operating device

The limits of operating pressure shall be stated by the manufacturer.

#### 6.6.3 Energy storage in springs (or weights)

When the energy storage device is a spring (or weight), the requirements of 6.6.1 apply when the spring is charged (or the weight lifted).

#### 6.6.4 Manual charging

If a spring (or weight) is charged by hand, the direction of motion of the handle shall be marked.

The manual charging facility shall be designed such that the handle is not driven by the operation of the switching device.

The maximum actuating force required for manually charging a spring (or weight) shall not exceed 250 N.

#### **6.6.5 Motor charging**

Motors, and their electrically operated auxiliary equipment for charging a spring (or weight) or for driving a compressor or pump, shall operate satisfactorily between 85 % and 110 % of the rated supply voltage (refer to 5.6), the frequency, in the case of AC, being the rated supply frequency (refer to 5.7).

For electric motors, the limits do not imply the use of non-standard motors but only the selection of a motor which at these values provides the necessary power, and the rated voltage of the motor does not need to be equal to the rated supply voltage of the auxiliary and control circuits.

#### **6.6.6 Energy storage in capacitors**

When the energy storage is a charged capacitor, the requirements of 6.6.1 apply when the capacitor is charged.

#### **6.7 Independent unlatched operation (independent manual or power operation)**

The mechanism shall not reach the energy release point of a close operation if the switching device is in the closed state or of an open operation if it is open.

NOTE 1 This requirement is to prevent the inadvertent, and potentially damaging, discharge of stored energy against an already closed or already open switching device.

It shall not be possible to progressively store energy by incomplete operations against an interlock, if supplied. During the operation, any movement of the contacts prior to release of the energy shall not reduce any electrically stressed gap to below that which will withstand rated insulation levels.

For a switching device with short-circuit making capacity but no short-circuit current breaking capacity, a time delay shall be introduced between the closing and opening operation. This time delay shall be not less than the rated duration of the short-circuit (refer to 5.5.4).

NOTE 2 The intention of the provision is to let the switching device "ride out" the short-circuit in the closed position until a back-up device safely clears the fault.

#### **6.8 Manually operated actuators**

Subclause 6.8 of IEC TS 62271-5:2024 is not applicable.

#### **6.9 Operation of releases**

##### **6.9.1 General**

See 6.4.1 for the basis of operation limits with respect to supply voltage.

##### **6.9.2 Shunt closing release**

A shunt closing release shall be able to operate within a voltage range of the power supply, measured at the input terminals, between 85 % and 110 % of the rated supply voltage of the closing device (refer to 5.6), the frequency, in the case of AC, being the rated supply frequency of the closing device (refer to 5.7).

##### **6.9.3 Shunt opening release**

A shunt opening release shall be able to operate under all operating conditions of the switching device up to its rated short-circuit breaking current (if any), and between 70 % in the case of DC – or 85 % in the case of AC – and 110 % of the rated supply voltage of the opening device

measured at the input terminals (refer to 5.6), the frequency, in the case of AC, being the rated supply frequency of the opening device (refer to 5.7).

#### 6.9.4 Capacitor operation of shunt releases

When a rectifier-capacitor combination is provided as an integral part of the switching device for stored energy of a shunt release, the charge of the capacitors derived from the voltage of the main circuit or auxiliary supply, shall be sufficient for satisfactory operation of the release 5 s after the voltage supply has been disconnected from the terminals of the combination and replaced by a short-circuiting link.

The voltages of the main circuit before disconnection shall be taken as the lowest voltage of the system associated with the rated voltage of the switching device. IEC 60038:2009 shall be referred to for the relation between “highest voltage for equipment” and system voltages.

#### 6.9.5 Under-voltage release

When an under-voltage release is provided, it shall operate to open and prevent closing of the switching device for all values of the voltage at its terminals below 35 % of its rated supply voltage.

Between 70 % and 35 % of its rated supply voltage, the under-voltage release can operate, opening the switching device and preventing its closing.

On the other hand, the under-voltage release shall not operate to open the switching device when the voltage at its terminals exceeds 70 % (AC or DC) of its rated supply voltage.

The closing of the switching device shall be possible when the value of the voltage at the terminals of the release is equal to or greater than 85 % of its rated voltage.

#### 6.10 Pressure/level indication

The performance of the DC GIS is dependent upon the gas density of the pure gas or the gas mixtures.

For DC GIS it is not sufficient to monitor the gas pressure without temperature compensation.

The gas density or temperature compensated gas pressure in each compartment shall be continuously monitored. The monitoring device shall provide at least two alarm levels for pressure or density (alarm and minimum functional pressure or density). The correct functioning of gas monitoring devices shall be able to be checked with the high-voltage equipment in service.

NOTE 1 When the filling density differs between adjacent compartments, an additional alarm indicating over pressure or density can be used, if the DC GIS design requires it.

NOTE 2 Tolerances of the monitoring device, as well as possible differences in temperature (e.g. inside/outside of a building) between the monitoring device and the volume of gas being monitored, can be considered.

NOTE 3 Checking of gas monitoring can initiate wrong alarms which can initiate or inhibit switching operations.

NOTE 4 It is preferable for gas monitoring devices to be placed as close as possible to the gas compartment which is being monitored to ensure measuring accuracy and minimum leakage, however consideration can be given to safety and accessibility when choosing the location.

NOTE 5 The preferred solution for checking the gas monitoring device is to separate the density monitor from the gas compartment without mechanically removing it from the DC GIS, in order to minimize gas losses.

##### 6.10.1 Gas pressure

Closed pressure systems filled with compressed gas for insulation and/or operation and having a minimum functional pressure for insulation and/or operation above 0,2 MPa (absolute pressure), shall be provided with a device capable of monitoring the pressure (or density).

The uncertainty of the gas monitoring device should be established and take into account pressure coordination (filling, minimum functional and alarm pressure) and leakage rate.

### 6.10.2 Liquid level

A device for checking the liquid level, with indication of minimum and maximum limits permissible for correct operation, shall be provided. This requirement is not applicable to dashpots or shock-absorbers.

### 6.11 Nameplates

A common nameplate shall be provided to identify the DC GIS. It shall, as a minimum, detail the ratings listed in Clause 5 of this document. The common nameplate shall be clearly readable from the position of local operation side.

For each individual device a nameplate according to its relevant document is required where ratings are not detailed on the common nameplate.

The nameplates shall be durable and clearly legible for the lifetime of the DC GIS.

The manufacturer shall give information of the type, volume and mass of the gas contained in each gas compartment as well as the total mass for the entire DC GIS installation either on the nameplate or on a label placed in a visible location. If required, more information shall be provided in the instruction manual.

#### 6.11.1 General

Switchgear and controlgear (and their operating devices where applicable) shall be provided with nameplates that contain the information required to identify the equipment, its ratings and appropriate operating parameters as specified in the relevant IEC standards.

#### 6.11.2 Application

Table 5 shall be used where applicable if the product standard does not provide more specific information.

In particular, the terminology, symbols and units given in the table shall be used as appropriate. Annex F (informative) provides an extended list including non-rated values. The following recommendations should be considered as appropriate:

- a) the type and mass of insulating fluid should be noted either on a nameplate or on a label placed in a visible location;
- b) it should be stated whether pressures are absolute or relative values;
- c) switchgear and controlgear installed outdoors or in high humidity should have nameplates and have methods of attachment that are weather-proof and corrosion-proof;
- d) for an operating device combined with a switchgear device, it may be sufficient to use only one combined nameplate;
- e) nameplates should be visible in the position of normal service and installation;
- f) technical characteristics on nameplates and/or in documents which are common to several kinds of high-voltage switchgear and controlgear should be represented by the same symbols;
- g) since other characteristics (such as type of gas or temperature limits) are specialized, they shall be represented by the symbols which are used in the relevant standards.

**Table 5 – Nameplate information**

| Item                                                                                                                                        |                                                                                                   | Symbol   | Unit | (**) | Condition:<br>Marking only required<br>if |
|---------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------|------|------|-------------------------------------------|
| (1)                                                                                                                                         | (2)                                                                                               | (3)      | (4)  | (5)  | (6)                                       |
| 1                                                                                                                                           | Name of manufacturer                                                                              |          |      | X    |                                           |
| 2                                                                                                                                           | Type designation and serial number                                                                |          |      | X    |                                           |
| 3                                                                                                                                           | Rated direct voltage                                                                              | $U_{rd}$ | kV   | X    |                                           |
| 4                                                                                                                                           | Rated direct withstand voltage                                                                    | $U_{dd}$ | kV   | X    |                                           |
| 5                                                                                                                                           | Rated lightning impulse withstand voltage                                                         | $U_p$    | kV   | X    |                                           |
| 6                                                                                                                                           | Rated switching impulse withstand voltage                                                         | $U_s$    | kV   | Y    | rated direct voltage<br>210 kV and above  |
| 7                                                                                                                                           | Rated continuous current                                                                          | $I_{rd}$ | A    | X    |                                           |
| 8                                                                                                                                           | Rated short-time withstand direct current                                                         | $I_{kd}$ | kA   | X    |                                           |
| 9                                                                                                                                           | Rated peak withstand current                                                                      | $I_{pd}$ | kA   | X    |                                           |
| 10                                                                                                                                          | Rated duration of short-circuit                                                                   | $t_{kd}$ | s    | X    |                                           |
| 11                                                                                                                                          | Filling pressure for operation(*)                                                                 | $p_{rm}$ | MPa  | X    |                                           |
| 12                                                                                                                                          | Filling pressure for insulation(*)                                                                | $p_{re}$ | MPa  | X    |                                           |
| 13                                                                                                                                          | Alarm pressure for insulation(*)                                                                  | $p_{ae}$ | MPa  | X    |                                           |
| 14                                                                                                                                          | Alarm pressure for operation(*)                                                                   | $p_{am}$ | MPa  | X    |                                           |
| 15                                                                                                                                          | Minimum functional pressure for insulation and/or switching(*)                                    | $p_{me}$ | MPa  | X    |                                           |
| 16                                                                                                                                          | Minimum functional pressure for operation(*)                                                      | $p_{mm}$ | MPa  | X    |                                           |
| 17                                                                                                                                          | Rated supply voltage(s) of auxiliary and control circuits. Specify DC / AC (with rated frequency) | $U_a$    | V    | X    |                                           |
| 18                                                                                                                                          | Type and mass of fluid (liquid or gas) for insulation                                             | $M_f$    | kg   | X    |                                           |
| 19                                                                                                                                          | Mass of switchgear and controlgear (including any fluid)                                          | $M$      | kg   | Y    | more than 300 kg                          |
| 20                                                                                                                                          | Year of manufacture                                                                               |          |      | X    |                                           |
| 21                                                                                                                                          | Minimum and maximum ambient air temperature                                                       |          | °C   | Y    | different from -5 °C<br>and/or 40 °C      |
| (*) Absolute pressure (abs.) or relative pressure (rel.) to be stated on the nameplate.                                                     |                                                                                                   |          |      |      |                                           |
| (**) X = the marking of these values is mandatory, where applicable.<br>Y = conditions for marking of these values are given in column (6). |                                                                                                   |          |      |      |                                           |
| NOTE 1 The symbol in column (3) can be used instead of the terms in column (2) to be stated on the nameplate.                               |                                                                                                   |          |      |      |                                           |
| NOTE 2 When terms in column (2) are used, the word “rated” can be omitted.                                                                  |                                                                                                   |          |      |      |                                           |

## 6.12 Locking devices

Switching devices, the incorrect operation of which can cause damage or which are used for assuring isolating distances, shall be provided with locking facilities (for example, provision for padlocks).

The following provisions are mandatory for apparatus installed in main circuits which are used as isolating distance and earthing:

- apparatus installed in main circuits, which are used for ensuring isolating distances during maintenance work, shall be provided with visible locking devices to prevent closing (e.g. padlock);
- earthing switches shall be provided with locking devices to avoid opening during maintenance work.

### 6.13 Position indication

Indication of the actual position of the main contacts of the switching devices shall be provided unless the contacts themselves are visible in all positions.

Requirements for position indicating devices are as follows:

- it shall be possible to read the position-indicating device when operating locally;
- all stable positions such as open, closed and test positions shall be clearly indicated.

Identification of the open, closed and where appropriate earthed positions should use symbols and/or colours defined by the relevant IEC publications: IEC 60073 [14] for colours, IEC 60417 [27] for symbols and IEC 60617 [30] for diagrams.

In case of disconnector switch and earthing switch subclause 6.104.2 of IEC TS 62271-314:2024 is applicable.

### 6.14 Degrees of protection provided by enclosures

#### 6.14.1 General

The enclosures shall provide degrees of protection in accordance with 6.14.2 through 6.14.4.

#### 6.14.2 Protection of persons against access to hazardous parts and protection of the equipment against ingress of solid foreign objects (IP coding)

The degree of protection of persons and of equipment provided by an enclosure against access to hazardous parts of the main circuit, control and/or auxiliary circuits and to any hazardous moving parts and against ingress of solid foreign objects shall be at least IP1XB according to IEC 60529:1989, IEC 60529:1989/AMD1:1999 and IEC 60529:1989/AMD2:2013.

#### 6.14.3 Protection against ingress of water (IP coding)

For equipment of indoor installation, no minimum degree of protection against harmful ingress of water is specified, i.e. the second characteristic numeral of the IP code is X according to IEC 60529:1989, IEC 60529:1989/AMD1:1999 and IEC 60529:1989/AMD2:2013.

Equipment for outdoor installation shall be at least IPX3 according to IEC 60529:1989, IEC 60529:1989/AMD1:1999 and IEC 60529:1989/AMD2:2013. If it is provided with additional protection features against rain and other weather conditions (supplementary letter W), the performance refers to the situation with these features in place and shall be demonstrated according to Annex G (normative) (see 7.6.1).

#### 6.14.4 Protection against mechanical impact under normal service conditions (IK coding)

For indoor installation, the preferred impact level is IK07 according to IEC 62262:2002 (2 J).

For outdoor installation without additional mechanical protection, the minimum impact level shall be IK10 according to IEC 62262:2002 (20 J).

Insulators and bushings of high-voltage switchgear and controlgear are not subjected to this requirement.

### 6.15 Creepage distances for outdoor insulators

Annex B (informative) gives general rules (included RUSCDDC) that assist in choosing insulators which should give satisfactory performance under polluted conditions.

The general rules given in Annex B (informative) are applicable for glass, porcelain, composite and hybrid insulators.

This applies to bushings only.

### 6.16 Gas and vacuum tightness

#### 6.16.1 General

The following specifications apply to all switchgear and controlgear that use vacuum or gas, other than ambient air, as an insulating, switching, combined insulating and switching, or operating medium.

For vacuum tightness no leakage rate  $F$  shall be specified, instead the level of vacuum and the expected operating duration shall be given.

NOTE 1 IEC TR 62271-306 [62] and CIGRE Brochure 430 [71] give some information, examples and guidance for tightness.

The absolute leakage rate  $F$  shall not exceed the specified value of the permissible leakage rate  $F_p$  at standardized ambient temperature of 20 °C.

An increased leakage rate at extreme temperatures is permissible, provided that this rate resets to a value not higher than the permissible value  $F_p$  at standardized ambient temperature of 20 °C. The increased temporary leakage rate shall not exceed the values given in 7.7.1.

NOTE 2 The average leakage rate observed during service life can be higher than the specified leakage rate due to the temporary increased leakage rate at temperatures above or below the standardized ambient temperature.

This applies only to insulating and switching medium, not to operating medium of switchgear and controlgear.

DC GIS shall be a closed pressure system or a sealed pressure system.

Leakage losses and handling releases shall be considered separately. The objective is to minimize the release of gas in the atmosphere due to leakage and handling (see IEC 62271-4).

The cause of any leakage shall be investigated carefully, and corrective actions shall be considered, especially if it is above the specified values.

#### 6.16.2 Controlled pressure systems for gas

The tightness of controlled pressure systems for gas is specified by the number of replenishments per day ( $N$ ) or by the pressure drop per day ( $\Delta p$ ). SF<sub>6</sub> gas and SF<sub>6</sub> mixtures are not applicable for controlled pressure systems.

NOTE Most controlled pressure systems use air as the gas; however, other gases can be used.

### 6.16.3 Closed pressure systems for gas

The tightness of closed pressure systems for gas is specified by the relative leakage rate  $F_{rel}$  of each compartment. The maximum value under the standardized ambient temperature of 20 °C is 0,5 % per year irrespective of gas type.

NOTE 1 A lower SF<sub>6</sub> leakage rate can apply to meet some local or governmental regulations, e.g. 0,1 % per year.

The tightness characteristic of a closed pressure system and the time between replenishments under normal service conditions shall be stated by the manufacturer. This time shall be at least 10 years for maintenance planning purposes. Means shall be provided to enable gas systems to be replenished while the equipment is in service.

NOTE 2 The term “in service” implies “under live conditions”.

NOTE 3 Manufacturer's instructions and the user's operating practices provide guidance for replenishing gas.

The relative leakage rate from any single compartment of DC GIS to atmosphere and between compartments shall not exceed 0,5 % per year for the expected operation duration of the equipment.

NOTE 1 Expected operation duration is typically 40 years under normal service condition as specified in Annex D.

The permissible relative leakage rate  $F_{rel}$  for type tests is specified as:

- ≤ 0,1 % per year for SF<sub>6</sub>, SF<sub>6</sub> mixtures and for other gas mixtures with GWP > 1 000.
- ≤ 0,5 % per year for other gas mixtures with GWP ≤ 1 000.

NOTE 2 The global warming potential (GWP) of gases in DC GIS is the major reason for requiring low permissible leakage rates. Solutions with alternative gases with GWP lower than 1 000 exist. GWP (100 years) of SF<sub>6</sub> is 24 300 according to the IPCC – AR6 Climate Change 2021 [1]<sup>3</sup>.

For small gas compartments containing less than 1 kg gas, the permissible relative leakage rate  $F_{rel}$  for type tests is specified as:

- ≤ 0,2 % per year for SF<sub>6</sub>, SF<sub>6</sub> mixtures and for other gas mixtures with GWP > 1 000.

### 6.16.4 Sealed pressure systems

The tightness of sealed pressure systems is specified by their expected operating duration. The expected operating duration shall be specified by the manufacturer and shall be at least 20 years. Other preferred values are 30 years and 40 years.

The tightness of gas insulated switchgear and controlgear shall be designed in a way to ensure that the minimum functional pressure (density) shall not be attained before the expected end of life. The manufacturer shall specify a permissible leakage rate.

NOTE 1 For some designs verification of an expected operating duration greater than 20 years can be impractical for a type or routine test.

NOTE 2 Sealed SF<sub>6</sub> switchgear and controlgear is considered to have insignificant SF<sub>6</sub> losses (less than 0,1 % per year) during their expected operating duration.

#### 6.16.101 Leakage

In accordance with standardized procedure defined in Clause 10 of IEC TR 62271-306:2012 and IEC TR 62271-306:2012/AMD1:2018, the manufacturer shall demonstrate that the relative

<sup>3</sup> Numbers in square brackets refer to the Bibliography.

leakage rate from any compartment of DC GIS or between compartments complies with 6.16.3 or 6.16.4.

#### **6.16.102 Gas handling**

The DC GIS shall be designed to minimize life cycle gas-handling losses (including end of life activities). The manufacturer shall specify test and maintenance procedures for minimizing gas-handling releases and shall identify the gas releases associated with each procedure.

Procedures for gas handling according to IEC 62271-4 shall be used.

#### **6.17 Tightness for liquid systems**

Subclause 6.17 of IEC TS 62271-5:2024 is not applicable.

#### **6.18 Fire hazard (flammability)**

No technical requirement is defined for high-voltage switchgear and controlgear due to the large variety of designs and lack of acceptance criteria. The information below is provided for guidance.

IEC 60695-1 (all parts) [33] provides guidance for assessing the fire hazard of electrotechnical products.

IEC 60695-7 (all parts) [34] provides guidance on the minimization of toxic hazards due to fires involving electrotechnical products.

#### **6.19 Electromagnetic compatibility (EMC)**

Switchgear and controlgear shall be capable of satisfying the EMC tests specified in 7.8.

#### **6.20 X-ray emission**

This subclause is applicable to vacuum interrupters used in switchgear and controlgear. Vacuum interrupters shall be designed in such a way that the acceptance criteria about X-ray emission levels specified in 7.10.3 are satisfied when subjected to the test specified in 7.10.

#### **6.21 Corrosion**

Due to the large number of parameters to be considered no standard requirements can be given. General recommendations are given in IEC TR 62271-306 [62].

The continuity of the earthing circuits shall be ensured taking into account the corrosion of bolted and screwed assemblies.

#### **6.22 Filling levels for insulation, switching and/or operation**

The pressure (or density) or liquid mass shall be assigned by the manufacturer. The pressure (or density) of gas is referred to atmospheric conditions of 20 °C at which gas-filled switchgear is filled before being put into service.

In addition to the filling levels the following values shall be assigned by the manufacturer (when applicable):

- alarm pressure  $p_{ae}$  (or density  $\rho_{ae}$ ) for insulation and/or switching;
- alarm pressure  $p_{am}$  (or density  $\rho_{am}$ ) for operation;
- minimum functional pressure  $p_{me}$  (or density  $\rho_{me}$ ) for insulation and/or switching;

- minimum functional pressure  $p_{mm}$  (or density  $\rho_{mm}$ ) for operation.

### 6.101 General requirements for DC GIS

DC GIS shall be designed so that normal service, inspection and maintenance operations, earthing of connected cables, locating of cable faults, voltage tests on connected cables or other apparatus and the elimination of dangerous electrostatic charges, can be carried out safely, after installation and extension.

The design of the equipment shall be such that the agreed permitted movement of foundations and mechanical or thermal effects do not impair the assigned performance of the equipment.

All components of the same type (rating, design and construction, etc.) which can be replaced shall be interchangeable.

The various components contained within the enclosure are subject to their relevant documents except were modified by this document.

### 6.102 Pressure coordination

The pressure inside a DC GIS can vary from the filling pressure  $p_{re}$  due to different service conditions.

In service conditions, the mechanical stresses are associated with the internal pressure which depends on the gas temperature. Consequently, the maximum pressure in service corresponds to the filling pressure at the maximum temperature the gas can reach due to continuous current and service conditions (e.g. temperature, solar radiation).

Figure 1 shows the various pressure levels and their relationship.

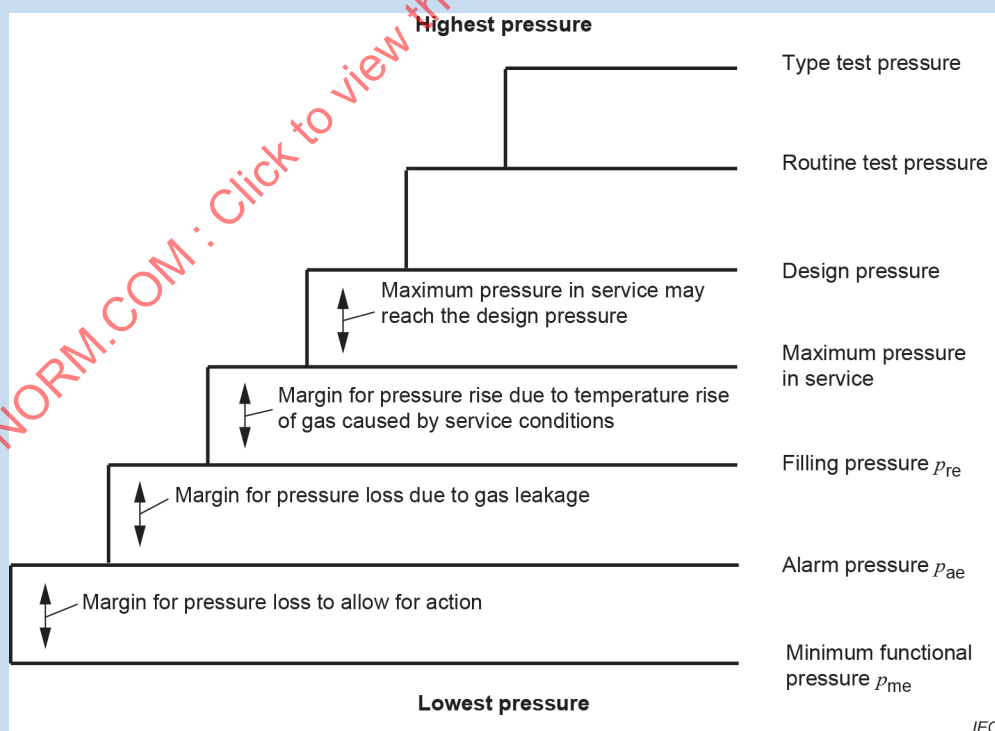


**Figure 1 – Pressure coordination**

The manufacturer is responsible for choosing the minimum functional pressure for insulation  $p_{me}$  and filling pressure  $p_{re}$ .

The manufacturer shall propose the alarm pressure  $p_{ae}$  which is related to both the filling pressure  $p_{re}$  and the minimum functional pressure. The alarm pressure  $p_{ae}$  will inform the user of any gas leak. For DC GIS using gas with a GWP > 1000, the filling pressure  $p_{re}$  and the alarm pressure  $p_{ae}$  shall be as close as possible, considering the tolerances of the density sensors, in order to make the user aware as soon as possible of gas losses.

Installation conditions (indoor, outdoor, direct solar radiations, ...), design and tolerances of the gas monitoring device shall be taken into consideration.

The time between the alarm pressure  $p_{ae}$  and the minimum functional pressure  $p_{me}$  allows corrective actions to be undertaken by the user and is dependent upon the gas leakage rate. During this period of time, the tolerances of the gas monitoring devices shall be taken into consideration.

### 6.103 Internal arc fault

#### 6.103.1 General

A fault leading to arcing within DC GIS built according to this document has a very low order of probability. This results from the application of an insulating gas other than air at atmospheric pressure which will not be altered by pollution, humidity or vermin.

DC GIS shall be designed, manufactured and operated in order to prevent the occurrence of internal fault within DC GIS. All possible measures to keep a very low probability of occurrence shall be taken such as:

- insulation co-ordination;
- gas leakage limitation and control;
- control of gas quality;
- high quality of work on-site;
- interlocking of switching device;

The very low probability of such an event shall be considered. Arrangements shall be made to minimize the effects of internal faults on service continuity (e.g. high-speed protection, remote control, additional gas compartments). The internal arc shall not propagate into adjacent gas compartments.

After such an event, an intervention will be necessary in order to isolate the faulty compartment. The general partitioning of DC GIS design shall permit the restoration of the part of DC GIS which is not affected in order to satisfy the service continuity requirements when defined (see IEC 62271-203:2022, Annex F).

#### 6.103.2 External effects of the arc

The effects of an internal arc are:

- pressure increase of gas (see Annex C),
- possible burn-through of enclosure.

The external effects of the arc shall be limited to the appearance of a hole or a tear in the enclosure without any fragmentation (by a suitable protective system). The duration of the arc is related to the performance of the protective system.

Table 2 gives the performance criteria depending on a dedicated Joule integral value of the short-circuit current derived by applying the Joule integral value  $E_j = \int i^2 dt$  for both alternating and direct short-circuit current (see IEC TS 62271-5:2024, Clause D.6).

**Table 2 – Performance criteria**

| Joule integral value ( $E_j$ )      | Explanation                                 | Performance criteria                                                            |
|-------------------------------------|---------------------------------------------|---------------------------------------------------------------------------------|
| $< 320 \text{ (kA)}^2\cdot\text{s}$ | This corresponds to the main protection.    | No external effect other than the operation of suitable pressure relief devices |
| $< 800 \text{ (kA)}^2\cdot\text{s}$ | This corresponds to the back-up protection. | No fragmentation (burn-through is acceptable)                                   |

NOTE 1 Energy limits have been calculated using the Joule integral according to IEC TS 62271-5:2024, Clause D.6 based on performance criteria of IEC 62271-203:2022, 6.103.2. Value of  $320 \text{ (kA)}^2\cdot\text{s}$  was calculated by  $E_j = \int I^2 dt$  for 40 kA RMS and 0,2 s. Value of  $800 \text{ (kA)}^2\cdot\text{s}$  was calculated by  $E_j = \int I^2 dt$  for 40 kA RMS and 0,5 s.

NOTE 2 For current and expected near term implementations of HVDC, the short-circuit current is much lower than in AC systems.

The term "no fragmentation of the enclosure" is interpreted as follows:

- no explosion of the compartment;
- no solid parts flying off from the compartment.

Exceptions are:

- parts of the pressure relief device or parts installed in these, if their ejection is directed;
- glowing particles and molten material resulting from burn-through of the enclosure.

Additionally, manufacturer and user can define a time during which an arc due to an internal fault up to a given value of short-circuit current will cause no external effects. The definition of this time shall be based on test results or an acknowledged calculation procedure. See Equation (C.1).

NOTE 3 Using an alternating current for testing, Annex C is applicable. If considering direct current for testing, there is currently insufficient experience to derive a calculation procedure.

The duration of current without burn-through for different values of the short-circuit AC current can be estimated from an acknowledged calculation procedure like CIGRE Technical Brochure 602 [2], CIGRE Session 1998 – WG 21/23/33-03 [3] and RGE: 04/82 [4].

Hence, Annex C is not applicable when using direct current for testing.

### 6.103.3 Internal fault location

The manufacturer of the DC GIS should propose appropriate methods for the determination of the location of a fault, if required by the user.

## 6.104 Enclosures

### 6.104.1 General

The enclosure shall be capable of withstanding the normal and transient pressures to which it is subjected in service.

### 6.104.2 Design of enclosures

The design of the enclosure shall be made in accordance with established documents for pressurized enclosures of gas-filled, high-voltage switchgear and controlgear with inert, non-corrosive, low pressurized gases. For further information, see EN 50052 [5], EN 50064 [6], EN 50068 [7], EN 50069 [8]. Annex E provides further information about notes concerning certain countries.

Methods for the calculation of the thickness and the construction of enclosures either by welding or casting shall be based on the design pressure (see definition in 3.114).

When designing an enclosure, account shall also be taken of the following:

- a) the possible recovery or evacuation gas or air in the enclosure as part of the normal filling process;
- b) the full differential pressure possible across the enclosure walls or partitions;
- c) the resulting pressure in the event of an accidental leak between the compartments in the case of adjacent compartments having different service pressures if overpressure is not monitored;
- d) the possibility of the occurrence of an internal fault (see 6.103);
- e) the corrosive impact on enclosures shall be considered by appropriate measures (e.g. filter material to absorb humidity and decomposition products).

In determining the design pressure, the gas temperature shall be taken as the mean of the upper limits of the enclosure temperature and the main circuit conductor temperature with rated continuous current flowing unless the design pressure can be established from existing continuous current test records.

For enclosures and parts thereof, the strength of which has not been fully determined by calculation, proof tests (see 7.103) shall be performed to demonstrate that they fulfil the requirements.

Materials used in the construction of enclosures shall be of known and certified minimum physical properties on which calculations and/or proof tests are based. The manufacturer shall be responsible for the selection of the materials and the maintenance of these minimum properties, based on certification of the material supplier, or tests conducted by the manufacturer, or both.

## **6.105 Partitions**

### **6.105.1 Design of partitions**

Partitions shall be used to separate compartments of the DC GIS and shall be gas tight such that contamination between adjacent compartments cannot occur. Partitions shall be made of material having insulating and mechanical properties so as to ensure proper operation over the lifetime of the DC GIS. Partitions shall maintain their dielectric withstand strength at voltages, which can occur in service (including temporary and transient voltages), when contaminated by by-products of gases and gas mixtures generated from normal load switching.

The design pressure of a partition is defined by the situation where the partition is pressurized on one side and maintenance is being carried out on the other side at atmospheric pressure (e.g. when maintenance is being carried out). In this case the pressure to be considered on the pressurized side of the partition is the pressure at maximum ambient temperature with solar radiation effects (where applicable) and rated continuous current (where applicable and without time limit). The pressure so derived is the design pressure of the partition.

During maintenance activities, the gas pressure can be lowered to a specified and controlled pressure. If this pressure is below the minimum functional pressure the concerned gas compartments shall be switched off. Warning notices and gas handling procedures shall be written in the operating and maintenance manuals.

Beyond the design pressure, account shall be taken of the following, if applicable:

- recovery or evacuation of gas or air in a gas compartment on one side of the partition with service pressure on the other, as part of the filling process; if there is a pressure differential

limitation, or a time limitation related to the pressure differential, these shall be clearly stated by the manufacturer in the operating and maintenance manuals;

- for non-symmetrical partitions, as far as the pressure on the partition is concerned, the worst-case pressure direction;
- superimposed loads and vibration;
- the possibility of maintenance being carried out adjacent to a pressurized partition, with special care to avoid rupture of the partition and the risk of injuries for maintenance people.

NOTE Enhanced pressure due to internal fault is not considered to establish the pressure design since in such situation, partition will be closely inspected and replaced if applicable.

### 6.105.2 Partitioning

The selection of the electrical single-line diagram is the primary consideration to fulfil service continuity requirements. Layout arrangements and introduction of dismantling facilities will influence service continuity during maintenance, repair and extension.

Partitioning of a DC GIS is influenced by the service continuity requirements during maintenance, repair and extension. Local health and safety requirements shall also be considered, see Clause 12.

Annex F of IEC 62271-203:2022 provides guidance for specifying service continuity.

NOTE 1 Annex F of IEC 62271-203:2022 applies to AC GIS. In principle, this guideline can also be applied to DC GIS.

DC GIS shall be divided into compartments in such a manner that:

- during various activities requiring de-energization of parts of the DC GIS, compartments to be taken out of service comply with the user's service continuity requirements. These activities include:
  - maintenance;
  - repair;
  - extension;
  - on-site dielectric test;
- the effects of an arc inside a compartment are limited to that compartment (see 6.103.1);
- duration of unavailability in case of major failure shall be in accordance with the user's service continuity requirements;
- the gas or air of the compartment can be recovered, evacuated and filled in a reasonable time considering the gas handling devices available.

NOTE 2 For on-site dielectric tests (after maintenance, repair or extension), see 11.101.2.

Partitions are generally of insulating material. They are not intended to provide electrical safety of personnel. For this purpose, other means such as separating by an isolating distance and earthing of the equipment can be used.

Partitions provide mechanical safety against the gas pressure still present in the adjacent compartment during maintenance, repair and extension. During such activities, other mechanical stresses than pressure should be considered on partitions, such as shock of any piece, or transient mechanical stresses from conductors in order to define the safety rules and avoid health risk for people.

Where a DC GIS bus-duct pass between indoor and outdoor locations (for example, DC GIS installed within a building with outdoor bushings), the gas compartment can be provided with a partition close to the wall, separating the compartment between the indoor and outdoor

environments to prevent problems arising from false alarms of the gas monitoring devices and condensation occurring due to indoor and outdoor temperature differences.

Each compartment shall be equipped with the following accessories:

- filling valve;
- gas monitoring device (see 6.10).

Depending on the DC GIS design or on users request each compartment can be equipped with the following accessories:

- pressure relief device (see 6.106.3);
- desiccant;
- internal arc fault location detector (see 6.103.3).

Figure 2 gives an example of an arrangement of enclosures and partitions for different types of adjacent compartments.

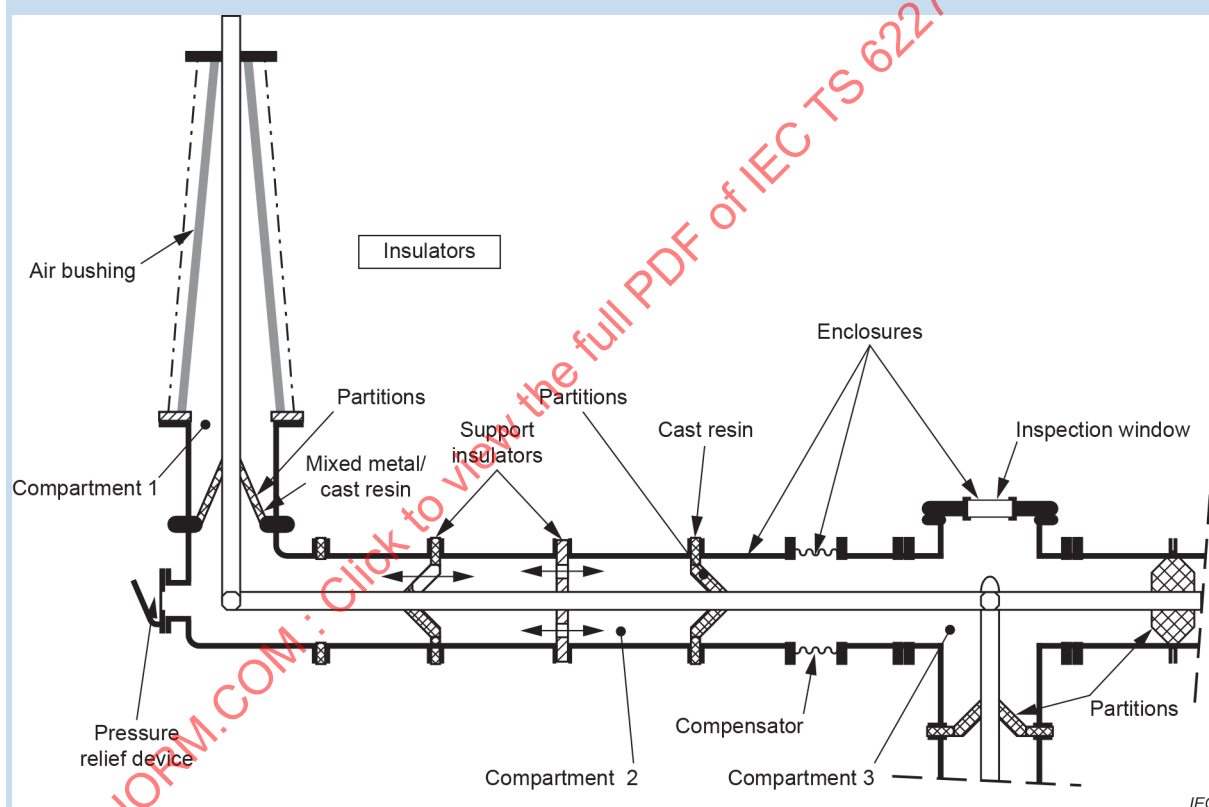


**Figure 2 – Example of arrangement of enclosures and gas compartments**

## 6.106 Pressure relief

### 6.106.1 General

Pressure relief device includes both pressure relief valves, characterized by an opening pressure and a closing pressure; and non-reclosing pressure relief devices, such as diaphragms and bursting disks. Pressure relief devices in accordance with this subclause shall be arranged so as to minimize the danger to an operator performing normal operating duties in the DC gas-insulated substation if gases or vapours are escaping under pressure.

### 6.106.2 Non-reclosing pressure relief device

Since, after an arc due to an internal fault, the damaged enclosures will be replaced, non-reclosing pressure relief devices shall only be proportioned to limit the external effects of the arc (see 6.103.2).

### 6.106.3 Pressure relief valve

For filling a gas compartment, a pressure relief valve shall be fitted to the filling pipe to prevent the gas pressure from rising to more than 10 % above the design pressure during the filling of the enclosure.

After an opening operation, a pressure relief valve shall reclose before the pressure has fallen to 75 % of the design pressure.

The filling pressure  $p_{re}$  should be corrected to take into account the gas and ambient temperature at the time of filling.

### 6.106.4 Limitation of pressure rise in the case of an internal fault

Non-reclosing pressure relief devices protect against overpressure in case of internal fault. For safety reasons and in order to limit consequences on DC GIS, it is recommended that each compartment be equipped with a non-reclosing pressure relief device, except for large volumes where the overpressure is self-limited to values which do not exceed the type test pressure.

NOTE 1 Using an alternating current for testing, calculation method of Annex C is applicable. For using a direct current for testing, currently not sufficient experience is available to derive a calculation procedure.

The pressure relief device shall be equipped with a deflector in order to control the direction of emission to secure an operator working in accessible places for normal operation. In order to avoid any pressure relief operation under normal conditions, a sufficient difference is necessary between the operation pressure of the pressure relief device and the design pressure. Moreover, transient pressure occurring during operation (if applicable) shall be taken into account when determining the operating pressure of the pressure relief device.

NOTE 2 In the case of an internal fault which causes yielding of the enclosure, enclosures of adjacent compartments can be checked for absence of distortion.

## 6.107 Noise

During an operation, the level of noise emitted by the switchgear should not exceed a specified value defined by the user. The procedure of verification should be agreed between manufacturer and user (see IEC 61672-1 [29] and IEC 61672-2 [30]).

## 6.108 Interfaces

### 6.108.1 General

In order to facilitate testing of DC GIS, isolating or removable links can be included in the design in each of the components mentioned below. This type of separation is preferable rather than dismantling. For air bushing, the high-voltage connection can be removed, preferably on the air side.

An isolating link shall be designed to withstand the test voltages across isolating distance according to Table 1 of IEC TS 62271-5:2024.

A removable link shall be designed to withstand the phase-to-earth test voltages according to Table 1 of IEC TS 62271-5:2024.

The isolating or removable links shall be designed to withstand the test voltages of the components mentioned below.

Those interfaces connected to the DC GIS shall be capable of withstanding the maximum pressure in service of the DC GIS. Typical maximum pressures in service are up to 1,1 MPa (absolute) for SF<sub>6</sub> and up to 1,5 MPa (absolute) for other gases and gas mixtures.

## **6.108.2 Cable connections**

### **6.108.2.1 General**

See IEC 62271-209.

NOTE A CIGRE Joint working group JWG B1/B3/D1.79 is developing recommendations for dielectric testing of cable connection enclosures. Resulting technical brochure will give more information.

Those parts of the DC GIS, which remain connected to the cable, shall be capable of withstanding the cable test voltages specified in the relevant cable standards for the same rated voltage for equipment.

Parts not capable of withstanding the cable test voltages should be equipped with removable or isolating links.

During dielectric tests on cables in general, the adjacent parts of the DC GIS should be de-energized and earthed, unless special measures are taken to prevent disruptive discharges in the cable affecting the energized parts of the DC GIS.

The location of bushings for cable testing should be provided at the cable connection enclosure or at the DC GIS itself (see IEC 62271-209) or (to reduce handling releases of gas) at the other end of the cable.

### **6.108.2.2 Extruded insulation cable**

According to IEC 62895, the electrical tests after installation are direct voltage tests in such case; part of the DC GIS in the vicinity of the cable termination can be subject to direct test voltage of the cable. If it is not acceptable to apply direct cable test voltages to the DC GIS, special provisions for cable testing shall be made (e.g. disconnecting facilities and/or increasing of the gas density for insulation).

### **6.108.2.3 Oil-filled cable**

According to IEC 60141-1 [9], CIGRE TB 841 [10], CIGRE TB 852 [11] and CIGRE TB 853 [12] the electrical tests after installation are direct voltage tests, in such case; if it is not acceptable to apply direct cable test voltages to the DC GIS, special provisions for cable testing shall be made (e.g. disconnecting facilities and/or increasing of the gas density for insulation).

## **6.108.3 Direct transformer connections**

In order to facilitate testing of transformers, an earthing switch, which can be insulated from the DC GIS enclosure and ground, can be included in the design of the bushing or the DC GIS.

NOTE 1 Opening of the DC GIS for the testing of the transformer can then be avoided and reduce the gas handling releases and the outage time of the equipment.

NOTE 2 Direct transformer connection is used in case of a bipolar HVDC scheme when DC GIS is applied between line-side of converter transformer and converter. See Annex G.

NOTE 3 For reference, see IEC 62271-211.

#### 6.108.4 Bushings

IEC/IEEE 65700-19-03 and IEC TS 60815-1 shall be used. See also IEC TS 60815-2 [13], IEC TS 60815-3 [14] and IEC TS 60815-4.

#### 6.108.5 Interfaces for future extensions

When an extension is planned, the locations of any possible future extension should be considered and stated by the user in the document.

In the case of later extension with another DC GIS product and if requested by the user, the manufacturer shall supply information preferably in the form of drawings giving sufficient information to enable such an interface to be designed at a later stage. The procedure to ensure confidentiality of the design details shall be agreed between the user and manufacturer. See IEEE C37.122.6 [15].

The interface should concern busbars or busducts only, and not direct connections to "active" devices such as circuit-breakers or disconnectors. If an extension is planned, it is recommended that the interface incorporates facilities for installation and testing of the extension to limit the part of the existing DC GIS to be re-tested and to allow the connection to the existing DC GIS without further dielectric testing (see Clause B.3). It shall be designed to withstand the rated insulation levels across the isolating distance.

#### 6.109 Interlocking

Disconnectors and earthing switches should be interlocked with associated equipment to prevent unintended opening or closing.

### 7 Type tests

#### 7.1 General

##### 7.1.1 Basics

The type tests are for the purpose of proving the ratings and characteristics of switchgear and controlgear, their operating devices and their auxiliary equipment. Each individual type test or type test sequence shall be made on test objects as defined in 3.2.1, in the condition as required for service (filled with the specified types and quantities of liquid or gas), with their operating devices and auxiliary equipment, all of which in principle shall be in, or restored to, a new and clean condition at the beginning of each type test or type test sequence.

Reconditioning during individual type tests or test sequence may be allowed, according to the relevant IEC product standards. The manufacturer shall provide a statement to the testing laboratory of those parts that may be renewed during the tests.

Tolerances on test quantities are listed in Table H.1.

Information regarding the extension of validity of type tests is given in Annex I (informative).

For type tests, technical grade SF<sub>6</sub> and its mixtures in accordance with IEC 60376 or used SF<sub>6</sub> and its mixtures in accordance with IEC 60480 can be used.

If the DC GIS is designed to use any other gas than SF<sub>6</sub>, the necessary technical grade and the characteristics of the gas / gas mixture used for the type testing shall be defined and documented by the manufacturer of the DC GIS and documented in the type test reports.

NOTE A working group of IEC TC 10 is currently working on standardization of technical grade of SF<sub>6</sub> free gas mixtures (IEC 63359 [34] and IEC 63360 [35]).

In regard of gas handling, IEC 62271-4 shall be taken into account.

As a general rule, tests on DC GIS components should be carried out in accordance with their relevant documents, unless a specific test specification or condition is defined in this document. For such cases, the condition given in this document shall be taken into account.

Unless specific testing requirements are defined, type testing shall be carried out on a complete functional unit. When this is impracticable, type tests can be made on representative assemblies or sub-assemblies.

Because of the variety of types, ratings and possible combinations of components, it is impracticable to subject all arrangements of the DC GIS to type tests. The performance of any particular arrangement can be substantiated from test results obtained on representative assemblies or sub-assemblies. The user and the manufacturer shall check that tested sub-assemblies are representative of the users' arrangement.

The type tests and verifications are listed in Table 3.

**Table 3 – Type tests**

| <b>Mandatory type tests</b>                                                                                                 |                  |
|-----------------------------------------------------------------------------------------------------------------------------|------------------|
|                                                                                                                             | <b>Subclause</b> |
| a) Tests to verify the insulation level of the equipment and dielectric tests on auxiliary circuits                         | 7.2              |
| b) DC insulation system test                                                                                                | 7.2.101          |
| c) Tests to prove the radio interference voltage (RIV) level (if applicable)                                                | 7.3              |
| d) Tests to prove the continuous current of any part of the equipment and measurement of the resistance of the main circuit | 7.3 and 7.4      |
| e) Tests to prove the rated peak and the rated short-time withstand current                                                 | 7.5              |
| f) Tests to verify the making and breaking capacity of the included switching devices                                       | 7.101            |
| g) Tests to prove the satisfactory operation of the included switching devices                                              | 7.102.1          |
| h) Tests to prove the satisfactory operation at limit temperatures                                                          | 7.102.2          |
| i) Tests to prove the strength of enclosures                                                                                | 7.103            |
| j) Verification of the degree of protection of the enclosure                                                                | 7.6              |
| k) Gas tightness tests                                                                                                      | 7.7              |
| l) Electromagnetic compatibility tests (EMC)                                                                                | 7.8              |
| m) Additional tests on auxiliary and control circuits                                                                       | 7.9              |
| n) Tests on partitions                                                                                                      | 7.104            |
| o) Tests to prove performance under thermal cycling and gas tightness tests on insulators                                   | 7.106            |
| p) Corrosion test on earthing connections (if applicable)                                                                   | 7.107            |
| q) X-radiation test procedure for vacuum interrupters (if applicable)                                                       | 7.10             |
| <b>Type tests, when requested by the user</b>                                                                               |                  |
|                                                                                                                             | <b>Subclause</b> |
| r) Dielectric tests under high-load condition                                                                               | 7.2.7.101        |
| s) Tests to assess the effects of arcing due to an internal fault                                                           | 7.105            |
| t) Corrosion tests on sealing systems of enclosures and auxiliary equipment (if applicable)                                 | 7.108            |
| u) Long-term energized test                                                                                                 | 7.2.102          |

### 7.1.2 Information for identification of test objects

The manufacturer shall submit to the testing laboratory, drawings and other data containing sufficient information to unambiguously identify by type the essential details and parts of the switchgear and controlgear presented for test. A summary list of the drawings and data schedules shall be supplied by the manufacturer and shall be uniquely referenced and shall contain a statement that the manufacturer guarantees that the drawings or data sheets listed are the correct version and represent the switchgear and controlgear to be tested.

The testing laboratory shall check that drawings and data sheets adequately represent the essential details and parts of the test object but is not responsible for the accuracy of the detailed information.

Particular drawings or data required to be submitted by the manufacturer to the test laboratory for identification of essential parts of test object are specified in Annex J (normative).

### 7.1.3 Information to be included in type-test reports

The results of all type-tests shall be recorded in type-test reports containing sufficient data to prove compliance with the ratings and the test clauses of the relevant standards and sufficient information shall be included so that the essential parts of the test object can be identified. In particular, the following information shall be included:

- the manufacturer;
- the type designation and the serial number of the test object;
- the rated characteristics of the test object as specified in the relevant IEC standards.;
- the general description of the test object;
- the manufacturer, type, serial numbers and ratings of essential parts, where applicable (for example, drive mechanisms, interrupters, shunt impedances);
- the general details of the supporting structure of the switching device or enclosed switchgear of which the switching device forms an integral part;
- the details of the operating mechanism and devices employed during tests, where applicable;
- photographs to illustrate the condition of the test object before and after test;
- sufficient outline drawings and data schedules to represent the test object;
- the reference numbers of all drawings including revision number submitted to identify the essential parts of the test object;
- a statement that the test object complies with the drawings submitted;
- details of the testing arrangements (including diagram of test circuit);
- statements of the behaviour of the test object during tests, its condition after tests and any parts renewed or reconditioned during the tests;
- in case of breaking operations with some specific technologies, non-sustained disruptive discharge can occur during the recovery voltage period. Their number is of no significance to interpreting the performance of the device under test. They shall be reported in the test report only in order to differentiate them from restrikes;
- records of the test quantities during each test or test duty, as specified in the relevant IEC standards;
- the location, laboratory name where the tests were conducted and date of test.

## 7.2 Dielectric tests

### 7.2.1 General

Dielectric tests shall be performed in compliance with IEC 60060-1, unless otherwise specified in this document.

Dielectric tests performed as type tests shall be followed by a partial discharge measurement according to the test procedure described in 7.2.10.

### 7.2.2 Ambient air conditions during tests

Reference shall be made to IEC 60060-1 regarding standard reference atmospheric conditions and atmospheric correction factors.

For test objects where external insulation in ambient air is of principal concern, the atmospheric correction factor  $K_t$  shall be applied.

No atmospheric correction factors shall be applied for dielectric tests on DC GIS.

The humidity correction factor  $k_2$  shall be applied only for the dry tests where insulation in ambient air is of principal concern.

For test objects having external and internal insulation, the correction factor  $K_t$  shall be applied if its value is between 0,95 and 1,05. However, in order to avoid over-stressing of internal insulation, the application of the correction factor  $K_t$  may be omitted where the satisfactory performance of external insulation has been established.

If  $K_t$  is above 1,0 then to fully test the external insulation system, the internal insulation will be overstressed and steps may be necessary to prevent overstressing the internal insulation systems. If  $K_t$  is below 1,0 then to test the internal insulation system fully, the external insulation will be overstressed and steps may be necessary to prevent overstressing the external insulation systems. Some methods are discussed in IEC 60060-1.

For test objects having only internal insulation, the ambient air conditions are of no influence and the correction factor  $K_t$  shall not be applied.

For combined tests, parameter  $g$  shall be calculated considering the total test voltage value.

For cases where the equipment is installed where the maximum specified ambient air temperature exceeds 40 °C, test voltages shall be corrected for the most stringent combination of temperature and humidity. The combination of them provides the highest atmospheric correction among other possible combinations of temperature and humidity under service condition.

NOTE In valve halls, a combination of a high temperature and a very low humidity can happen (see 4.2.2). As an example, the most stringent combination of temperature and low humidity level can be such as 50 °C and 1 g/m<sup>3</sup>. Other combinations are also possible.

### 7.2.3 Wet test procedure

Subclause 7.2.3 of IEC TS 62271-5:2024 is not applicable but the following points shall be noted:

- the wet test is applicable to outdoor bushings only;
- the test voltage and the test procedure shall be those specified in IEC/IEEE 65700-19-03:2014.

### 7.2.4 Arrangement of the equipment

Dielectric tests shall be made on switchgear and controlgear completely assembled, as in service with any supplementary insulation such as tape or barriers if stated in the installation instructions; the outside surfaces of insulating parts shall be in clean condition.

The test object shall be mounted for test with minimum clearances as specified by the manufacturer if such surrounding influences the performance.

NOTE Each HVDC system pole usually maintains a sufficient clearance from each other.

Tests shall be performed with the test object installed at a height above ground equal to or less than the height used in service.

If arcing horns or rings are part of the design for gradient distribution, they shall remain in position for the test. If they are proposed as overvoltage protection devices for the system, they are not part of the design of the test object and shall be not installed for tests.

For test objects using compressed gas for insulation, dielectric tests shall be performed at minimum functional pressure (density) for insulation. The temperature and pressure of the gas during the tests shall be noted and recorded in the test report.

For dielectric testing of switchgear and controlgear incorporating vacuum switching devices, precautions shall be taken to ensure that the level of possible emitted X-radiation during high-voltage testing is within safe limits (see 7.10). National regulations can influence the safety measures established.

#### 7.2.5 Criteria to pass the test

##### a) Direct voltage tests

The test object shall be considered to have passed the test if no disruptive discharge occurs.

If during a wet test a disruptive discharge (as defined in IEC 60060-1) on external self-restoring insulation occurs, this test shall be repeated in the same test condition without intermediate cleaning and the test object shall be considered to have passed this test successfully if no further disruptive discharge occurs.

##### b) Impulse voltage tests

The test procedure B of 7.3.1.2 of IEC 60060-1, adapted for test objects that have self-restoring and non-self-restoring insulation, is the preferred test procedure. The test object has passed the impulse tests if the following conditions are fulfilled:

- each series has at least 15 impulses;
- the number of disruptive discharges does not exceed two for each complete series;
- no disruptive discharge on non-self-restoring insulation occurs. This is confirmed by 5 consecutive impulse withstands following the last disruptive discharge.

This procedure leads to a maximum possible number of 25 impulses per series.

##### c) Superimposed impulse tests

The test object shall be considered to have passed the tests if the following conditions are fulfilled.

- pre-stress with rated direct voltage has been applied for 2 h, and no disruptive discharge occurs;
- the number of disruptive discharges does not exceed two for each complete series;
- no disruptive discharge on non-self-restoring insulation occurs. This is confirmed by 5 consecutive impulse withstands following the last disruptive discharge.

This procedure leads to a maximum possible number of 25 impulses per series.

##### d) Polarity reversal tests

The test object shall be considered to have passed the test if no disruptive discharge occurs.

##### e) Voltage test as condition check

The test object shall be considered to have passed the test if no disruptive discharge occurs.

##### f) General comment

- When testing switchgear and controlgear, the part of equipment through which the test voltage is applied can be subjected to numerous test sequences to check the insulating properties of other downstream parts of equipment (circuit-breakers, disconnectors, other bays). It is recommended that parts be tested in sequence, starting with the first connected part. When this part has passed the test according to the above-mentioned criteria, its qualification is not impaired by possible disruptive discharges which could occur in it during further tests on other parts.

These discharges can have been generated by accumulation of discharge probability with the increased number of voltage applications or by reflected voltage after a disruptive discharge at a remote location within the equipment. To reduce the probability of occurrence of these discharges in gas-filled equipment, the pressure of compartments which are not subject of the test can be increased. Compartments at increased pressure should be clearly identified in the test report(s).

- A disruptive discharge to the auxiliary and control circuits shall be considered as a failure.

#### g) DC insulation system tests:

Test procedure A of IEC 60060-1:2010 shall be used. The test procedure is recommended for tests on degradable or non-self-restoring insulation normally, but in the case of a DC insulation system test, if a flashover in the self-restoring insulation (gas) occurs, the electric field distribution could be changed. Therefore, the procedure A is chosen as mandatory procedure. The DC GIS has passed the impulse tests if the following conditions are fulfilled:

- Each series consists of at least 3 impulses;
- Three impulses of the specified shape and polarity at the specified withstand voltage level are applied to the test object. The requirements of the test are satisfied if no indication of failure is obtained.
- A visual inspection of all insulator surfaces is mandatory. Flashover tracks are not allowed.

If any disruptive discharges occur during the type test series, it is recommended to use all possible measures (even opening of the compartment) to find the location of flashover and to analyse the reason for it.

## 7.2.6 Application of the test voltage and test conditions

### 7.2.6.1 General

Distinction shall be made between the general case, where the three test voltages (pole-to-earth, across open switching device and across the isolating distance) are the same and the special cases where the test voltages across the isolating distance is higher than the test-voltage pole to earth.

Some insulating materials retain a charge after a voltage application, and for these cases care should be taken when reversing the polarity. To allow the discharge of insulating materials, the use of appropriate methods, such as the application of two impulses between 60 % and 80 % of the rated withstand voltage in the reverse polarity before the test, is recommended.

When testing switchgear incorporating an open vacuum interrupter, for each polarity a maximum of 25 preliminary impulses maybe performed at up to and including the rated withstand voltage. The number and level of preliminary impulses shall be stated by the manufacturer. Breakdowns that are observed during these preliminary tests shall be disregarded for the purpose of withstand statistics used to determine pass or fail performance of the equipment.

The test voltages are specified in 7.2.7, 7.2.8 and 7.2.9.

Current transducers secondaries shall be short-circuited and earthed during dielectric testing.

Attention shall be given to the possibility that switching devices, in their open position, can result in less favourable field conditions. Under such conditions, the test shall be repeated in the open position. If, in the open position of a disconnector, an earthed metallic screen is interposed between the open contacts, this contact gap is not an isolating distance.

When voltage transducers and/or surge arresters forming an integral part of the DC GIS have a reduced insulation level, they can be replaced during the dielectric tests by replicas reproducing the field configuration of the high-voltage connections. Overvoltage protection devices shall be disconnected or removed during the tests. When this procedure is adopted, the voltage transducers and/or surge arresters shall be separately tested in accordance with the relevant documents.

7.2.6.2 General case

With reference to Figure 4, which shows a diagram of connection of a single pole switching device, the test voltage shall be applied according to Table 6, as applicable.

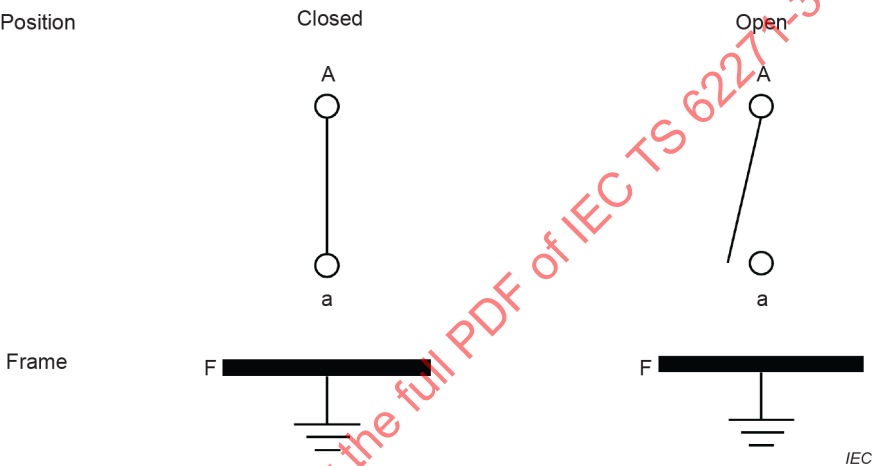


Figure 4 – Diagram of connections of a switching device

Table 6 – Test conditions in general case

| Test condition | Switching device | Voltage applied to | Earth connected to |
|----------------|------------------|--------------------|--------------------|
| 1              | Closed           | Aa                 | F                  |
| 2              | Open             | A                  | aF                 |
| 3              | Open             | a                  | AF                 |

NOTE Test condition 3 can be omitted if the arrangement of the terminals is symmetrical with respect to the frame.

7.2.6.3 Special cases

The test across the isolating distance can be performed with the test voltage applied to one side of the isolating distance and the other side earthed or according to 7.2.6.2 of IEC TS 62271-5:2024.

7.2.6.3.1 Impulse voltage tests across the isolating distance (or open switching device)

In case of impulse voltage tests across the isolating distance (or open switching device), the test voltage shall be applied according to Table 7, as applicable.

**Table 7 – Test conditions in case of impulse voltage tests across the isolating distance (or open switching device)**

| Test condition | Main part          | Complementary part | Earth connected to |
|----------------|--------------------|--------------------|--------------------|
|                | Voltage applied to |                    |                    |
| 1              | A                  | a                  | F                  |
| 2              | a                  | A                  | F                  |

NOTE Test condition 2 can be omitted if the arrangement of the terminals is symmetrical with respect to the frame.

The rated impulse withstand voltage pole-to-earth constitutes the main part of the test voltage and is applied to one terminal; the complementary voltage is supplied by another voltage source of the opposite polarity and applied to the opposite terminal. This complementary voltage may be either another impulse voltage, the peak of a power-frequency voltage or a direct voltage. The sum of the impulse voltage peak and the complementary voltage at the instant of the peak of the impulse shall be equal to the total test voltage required with a tolerance of  $\pm 3\%$ . The frame is earthed.

NOTE To date, there is no design of disconnectors with solid insulating materials between the isolating distance. This means that surface and space charge effects can be largely excluded. Pre-stressing with direct voltage is not necessary.

#### 7.2.6.3.2 Superimposed impulse tests

In case of superimposed impulse voltage tests, the voltage shall be applied according to Table 8, as applicable.

NOTE 1 This test applies to devices whose terminal is connected to high voltage side of grid system.

**Table 8 – Test conditions in case of superimposed impulse voltage tests**

| Test condition | Switching device | Voltage applied to | Earth connected to |
|----------------|------------------|--------------------|--------------------|
| 1              | Closed           | Aa                 | F                  |

NOTE 2 To date, there is no design of disconnectors with solid insulating materials between the isolating distance. This means that surface and space charge effects can be largely excluded. Pre-stressing with direct voltage in open position is not necessary.

#### 7.2.7 Tests of switchgear and controlgear

##### 7.2.7.1 General

The test voltage shall be applied according to Table 1. In the closed position, the tests shall be performed in condition 1 of Table 6. In the open position, the tests shall be performed as stated below (but refer to 7.2.4).

##### 7.2.7.2 Direct voltage tests

The test object shall be subjected to direct withstand voltage tests in accordance with IEC 60060-1. The test shall be carried out at rated direct withstand voltage and ambient temperature at positive and negative polarity. The test voltage shall be raised for each test condition to the test value and maintained for 1 h.

The tests shall be performed in dry conditions and also in wet conditions for outdoor switchgear and controlgear with external insulation.

The open switching device and/or isolating distance shall be tested in condition 2 and 3 of Table 6.

NOTE The direct voltage test is carried out to verify the withstand voltage under short-time loads. Possible DC charging effects are verified by dielectric tests specified by the relevant product standards.

**Modification:**

The test voltage shall be raised for each test condition to the test value and maintained for 1 min.

The main circuits of the DC GIS shall be subjected to direct voltage tests in dry conditions only.

The bushings shall be subjected to direct voltage tests in dry and wet conditions, as specified in IEC/IEEE 65700-19-03:2014.

### 7.2.7.3 Switching impulse voltage tests

Switching impulse voltage tests are applicable for rated direct voltages  $U_{rd}$  of 210 kV and above. The test object shall be subjected to switching impulse voltage tests. The tests shall be performed with voltages of both polarities using the standardized switching impulse according to IEC 60060-1. For outdoor switchgear and controlgear with external insulation only, wet tests shall be performed and dry tests may be omitted.

The open switching device shall be tested in condition 2 and 3 of Table 6. The isolating distance shall be tested in condition 1 and 2 of Table 7.

The main circuits of the DC GIS shall be subjected to switching impulse voltage tests in dry conditions only.

The bushings shall be subjected to switching impulse voltage tests in dry and wet conditions.

### 7.2.7.4 Lightning impulse voltage tests

The test object shall be subjected to lightning impulse voltage tests in dry conditions only. The tests shall be performed with voltages of both polarities using the standard lightning impulse 1,2/50  $\mu$ s according to IEC 60060-1.

The open switching device and/or isolating distance shall be tested in condition 1 and 2 of Table 7.

### 7.2.7.5 Superimposed impulse voltage tests

The test object shall be subjected to superimposed impulse voltage tests. The tests shall be performed in the closed position. When lightning impulse or switching impulse voltage is applied, the test object shall be in dry conditions only.

The duration of pre-stress with the rated direct voltage shall be 2 h. This pre-stress shall be applied before each superimposed impulse voltage test. A recharging time of 2 h is necessary after changing the voltage waveform or disconnecting the test object from the DC source.

The tests have to be carried out for unipolar (same polarity) and bipolar (opposite polarity) superposition of impulse voltage at the rated direct voltage as shown in Figure 1.

Each test series has at least 15 impulses. The time between two successive impulses shall be not less than 1 minute. The superposition of an impulse wave on a direct voltage is obtained by using a blocking capacitor or a sphere gap and a current limiting resistor, refer to Annex K (informative). The waveform of impulse voltage shall be according to IEC 60060-1.

### 7.2.7.6 Polarity reversal tests

Polarity reversal tests are applicable for LCC applications only. In case that there is no high stressed solid dielectric material, this test may be omitted with an agreement between user and manufacturer. The test object shall be subjected to polarity reversal tests in dry conditions and also in wet conditions for outdoor switchgear and controlgear with external insulation.

The open switching device and/or isolating distance shall be tested in conditions 2 and 3 of Table 6.

NOTE Superimposed impulse test on switchgear makes polarity reversal tests unnecessary.

Figure 5 shows the test sequence for polarity reversal test. The duration of pre-stress with  $-1,25$  times of the rated direct voltage shall be  $t_1$ . After the polarity reversal, the duration of the opposite test voltage shall be  $t_1$ . After the complete procedure, an additional direct voltage stress  $-1,25 \times U_{rd}$  shall be added with duration  $t_2$ . Preferred values for the durations of each step are given in Table 9. If, due to capacitance of the test object, polarity reversal cannot be achieved within 2 min, the duration for polarity reversals shall be agreed between user and manufacturer and the duration shall be stated in the test report.

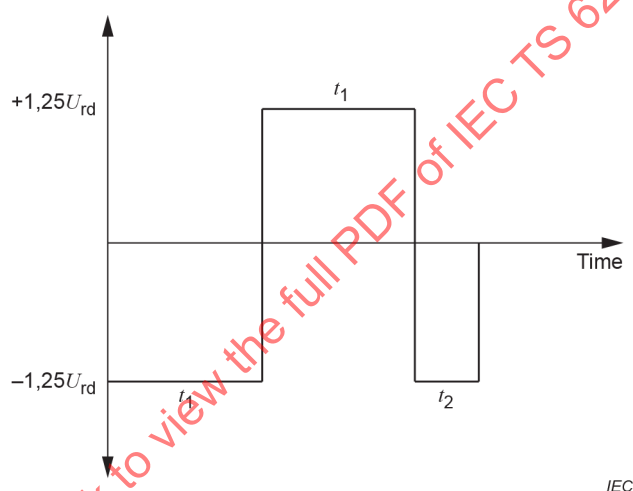


Figure 5 – Test sequence for polarity reversal tests

Table 9 – Test conditions for polarity reversal tests

| Time                                  | Value   |
|---------------------------------------|---------|
| $t_1$                                 | 90 min  |
| $t_2$                                 | 45 min  |
| Time duration for a polarity reversal | < 2 min |

#### 7.2.7.101 Dielectric tests under high-load condition

These tests are optional because these tests are covered by superimposed voltage tests along with the DC insulation system test. In case of doubt only, the following dielectric tests under high-load condition shall be carried out at ambient temperature and rated continuous direct current or equivalent alternating current.

- Direct voltage test according to 7.2.7.2. The direct voltage shall be applied for a period of 1 min after thermal stabilisation (duration  $d_9$ ).
- Superimposed impulse voltage test according to 7.2.7.5.

- If specified: polarity reversal test according to 7.2.7.6.

The heating used shall be conductor heating, and the heating shall be generated with direct or alternating current; the results are generating the same heating. The thermal steady state will normally be met after a test duration of five times the thermal time constant of the device under test.

NOTE 1 Duration  $d_g$  for gas insulated components is typically in the range of some hours.

The time for the whole test can be shortened by preheating the circuit with a higher value of current, provided that sufficient test data is recorded to enable calculation of thermal time constant.

NOTE 2 The electric field strength distribution is influenced by the temperature and the temperature distribution. The DC insulation system test was introduced as a type test under high load conditions (see 7.2.101). The dielectric tests under high-load condition can be used to verify the dielectric withstand behaviour during the transition phases or in case of doubt.

## 7.2.8 Artificial pollution tests for outdoor insulators

Artificial pollution tests are not required for insulators having creepage distances that are following the suggested values of 6.15 and Annex B (informative).

If the creepage distances differ from the suggested values given in Annex B (informative) artificial pollution tests shall be performed according to IEC TS 61245, using the rated voltage and the application factors given in IEC TS 60815-4:2016.

NOTE IEC TS 61245 describes the test procedure only for non-HTM insulators. No test procedure is available at present for HTM insulators.

This test applies only to bushings.

## 7.2.9 Partial discharge tests

Unless otherwise specified by the relevant product standard, partial discharge tests are not required. When tests are required, the measurements shall be made according to IEC 60270.

### 7.2.9.101 General

The partial discharge test at ambient temperature and under zero load condition shall be performed on those test objects which have successfully passed direct withstand voltage tests, superimposed voltage tests, and the switching and lightning impulse voltage tests.

It is preferred to carry out the test at alternating voltage stress including an alternating voltage pre-stress. If alternating voltage tests are not possible due to laboratory limitations, the partial discharge test may be carried out at direct voltage.

Partial discharge tests shall be performed, and the measurement made in accordance with IEC 60270.

The test can be carried out on assemblies or sub-assemblies of the equipment used for all dielectric type tests.

In case of alternating voltage tests, the frequency shall be within the limits given by IEC 60060-1:2010.

### 7.2.9.102 Test procedure

The applied direct or alternating voltage is raised to a pre-stress value and maintained at that value for 1 min. Partial discharges occurring during this period shall be disregarded. Then, the voltage is decreased to a specific value defined in Table 4.

The extinction voltage shall be recorded.

**Table 4 – Test voltage for measuring PD intensity**

|                                                               | PD measurement at alternating voltage<br>(preferred method)                                                                                                                                                                   |                                                                           | PD measurement at direct voltage                               |                                                                           |
|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------|
|                                                               | Pre-stress voltage<br>$U_{\text{pre-stress AC}}$<br>(1 min)                                                                                                                                                                   | Test voltage for<br>PD measurement<br>$U_{\text{pd-test AC}}$<br>(>1 min) | Pre-stress<br>voltage<br>$U_{\text{pre-stress DC}}$<br>(1 min) | Test voltage for<br>PD measurement<br>$U_{\text{pd-test DC}}$<br>(>1 min) |
| Single-phase<br>enclosures design<br>(phase-to-earth voltage) | $\hat{U}_{\text{pre-stress AC}} = 1,5 U_{\text{rd}}$                                                                                                                                                                          | $\hat{U}_{\text{pd-test AC}} = 1,2 U_{\text{rd}}$                         | $U_{\text{pre-stress DC}} = 1,5 U_{\text{rd}}$                 | $U_{\text{pd-test DC}} = 1,2 \times U_{\text{rd}}$                        |
| $\hat{U}_{\text{pre-stress AC}}$                              | the peak value of alternating pre-stress voltage $\hat{U}_{\text{pre-stress AC}} = 1,5 \times U_{\text{rd}}$ during type tests, routine tests, and on-site tests to pre-stress the equipment before PD measurements are made. |                                                                           |                                                                |                                                                           |
| $\hat{U}_{\text{pd-test AC}}$                                 | is the peak value of alternating test voltage $\hat{U}_{\text{pd-test AC}} = 1,2 \times U_{\text{rd}}$ for PD measurement during type tests, routine tests and on-site tests.                                                 |                                                                           |                                                                |                                                                           |
| $U_{\text{pre-stress DC}}$                                    | is the direct pre-stress voltage $U_{\text{pre-stress DC}} = 1,5 \times U_{\text{rd}}$ during type tests to pre-stress the equipment before PD measurements are made.                                                         |                                                                           |                                                                |                                                                           |
| $U_{\text{pd-test DC}}$                                       | is the direct test voltage $U_{\text{pd-test DC}} = 1,2 \times U_{\text{rd}}$ for PD measurement during type tests, routine tests and on-site tests.                                                                          |                                                                           |                                                                |                                                                           |

In addition, all components shall be tested in accordance with their relevant documents.

#### 7.2.9.103 Maximum permissible partial discharge intensity

The maximum permissible partial discharge level shall not exceed 5 pC at the AC test voltage specified in Table 4.

The values stated above applies to individual components as well as to the sub-assemblies in which they are contained. However, some equipment, such as voltage transducers insulated with liquid, immersed or solid, have an acceptable level of partial discharge in accordance with their relevant document greater than 5 pC. Any sub-assembly containing components with a permitted partial discharge intensity greater than 5 pC shall be considered acceptable if the discharge level does not exceed 10 pC. Components for which higher levels are accepted shall be tested individually and are not integrated to the sub-assembly during test.

The direct voltage test shall be carried out at both positive and negative polarity. The pulse train response defined in IEC 60270 is not appropriate for direct voltage tests. An accepted and agreed-upon method shall be employed in order to clearly differentiate between PD within the DC GIS under test from any external interference during the PD tests. Partial discharge shall be measured and recorded at the test voltages defined in Table 4. The method of interpretation shall be reported along with the measured values. In case of doubt, an AC PD measurement according to the preferred method defined in Table 4 shall be additionally performed.

**NOTE** The interpretation of PD measurements at direct voltage stress is briefly touched upon in IEC 60270. The two methods shown are pulse counting vs. PD-level and the other is accumulative pulse-count over a given time interval, but at present can only be considered as a rough guide for evaluating DC PD. Much further investigation is applicable for more rigorous clarification of acceptance level, count number (over time), and other acceptance criteria for direct voltage applications. A further method to identify PD under direct voltage stress is the PSA method.

#### 7.2.10 Dielectric tests on auxiliary and control circuits

The dielectric test on auxiliary and control circuits are covered under 7.9.5.

### 7.2.11 Voltage test as condition check

When a dielectric test is required as condition check, a short-duration AC power-frequency withstand voltage test in dry condition shall be applied in accordance with IEC 60060-1. The test voltage shall be raised for each test condition to the test value and maintained for 1 min.

The test voltage shall be the following value:

- For isolating distances 100 % of the rated direct withstand voltages divided by  $\sqrt{2}$ ;
- For other test situation 80 % of the rated direct withstand voltages divided by  $\sqrt{2}$ .

The rated direct withstand voltages are specified in column 3 of Table 1.

NOTE The reduction of the test voltage is motivated by the insulation coordination margin in the rated withstand voltages, which takes ageing, wear and other normal deterioration into account, and by the statistical nature of the flashover voltage.

In the closed position, the tests shall be performed in condition 1 of Table 6. In the open position, the tests shall be performed in condition 2 and 3 of Table 6.

The test voltage shall be raised for each test condition to the test value and maintained for 1 min.

Annex E provides further information about notes concerning certain countries.

### 7.2.101 DC insulation system test

#### 7.2.101.1 General

For verification of the insulation system under high-load (HL) condition and DC steady state, a long duration voltage test shall be carried out. Normally, for well-designed systems using typical cone-type or flat disk insulator geometries, the maximum electric field stress occurs on the surface of the insulator under zero-load or high-load condition. This is valid for both insulators with low electrical conductivity (duration  $d_g < \text{duration } d_{DC}$ ) and insulators with high electrical conductivity (duration  $d_g \geq \text{duration } d_{DC}$ ). The aim of the DC insulation system test is to verify the dielectric performance of DC GIS under high-load conditions. The worst-case load condition shall be defined by simulations using the real insulator geometry.

The duration of the test after reaching the thermal stability can be approximated with the following methods:

- 1) Worst case approximation of DC steady state time calculated according to the following equation:

$$d_{DC} = 2,3 \tau_m = 2,3 \varepsilon_0 \varepsilon_r / \sigma$$

where

- $\tau_m$  is the dielectric time constant;
- $\varepsilon_0$  is the vacuum permittivity;
- $\varepsilon_r$  is the relative permittivity of the insulator;
- $\sigma$  is the electrical conductivity of the insulator.

- 2) Direct electric field simulation: a simulation verified by experiments (at least by means of model arrangements) shall be used. Material and gas characterisations which are relevant for the numerical model shall be provided. The scalability of the model shall be demonstrated. Of importance are the electric field strength, temperatures, and temperature gradients; these parameters shall represent realistic service conditions.

- 3) Measurement of the direct potential field on the actual insulator surface in energized state at different locations along the insulator radius. The temperature gradient across the insulators shall represent the maximum temperature gradient (worst case) under service conditions with tolerances lower than 20 %. The direct voltage during the measurement on the actual insulator shall be representative for service conditions, which could be considered as proven for a direct voltage higher than 80 % of the rated direct voltage. If the measurements are only possible at lower direct voltages, the independence of the charging duration on the voltage shall be verified by suitable tests.

The requirements are fulfilled by demonstrating method 1), or alternatively by methods 2) or 3).

Also, the surface conductivity of the insulating material shall be measured. If the charge transport in the solid insulation is dominated by the bulk conductivity compared to the charge transport caused by a surface conductivity, only the bulk material shall be taken into account for calculation of the dielectric time constant (in case of dominant bulk conductivity).

It is the responsibility of the manufacturer to supply the relevant data and material properties.

Especially in the case of the third method, the electric field transition time  $d_{DC}$  is not directly determined. In those cases,  $d_{DC}$  is considered to be fulfilled if the rate of change of the measured potential field is lower than 10 % of the initial rate (initial time delays shall be ignored).

The electrical field transition could lead to long test durations, lasting from hours to months. The insulation system test shall be carried out once only, unless there is a substantial change in the solid insulating system with respect to materials, manufacturing processes, construction, design parameters, or requirements.

For the DC insulation system test, high load conditions shall be applied. The heating method used shall be conductor heating, and the heating shall be generated with equivalent direct or alternating current; the results are equivalent for both heating methods.

The test is valid and the relevant requirements are fulfilled by performing and passing either one of the alternative heating methods. For the insulation system tests, a higher equivalent direct or alternating current (compared to the rated direct current) is allowed because the maximum conductor temperature and maximum temperature drop across the insulation has to be safely achieved.

The thermal steady state will normally be met after a test duration of five times the thermal time constant of the device under test. Duration  $d_g$  for gas insulated components is typically in the range of some hours.

The time for the whole test can be shortened by preheating the circuit with a higher value of current, provided that sufficient test data is recorded to enable calculation of thermal time constant.

### 7.2.101.2 Test object

A minimum of 5 insulators (support and partition) of each type shall be tested.

For other insulators such as disconnector shafts, rods or tubes in minimum 3 samples shall be tested.

For surge arrestors it is only necessary to verify the insulation performance of the interface between surge arrestor and DC GIS, if the design is different from the other insulators.

### 7.2.101.3 Test sequence

The time span of the long-duration continuous direct voltage test as part of the DC insulation system test (see Table 5) depends on the electric field transition time  $d_{DC}$  and shall be calculated before starting the tests. The electric field transition time itself depends on the local temperature distribution and on the lowest temperature of the insulator.

The test can be divided into 2 to 4 test series with different direct voltage polarities (only positive or negative direct voltage for the long duration continuous direct voltage test phase) and with different superimposed impulse voltages (lightning or switching). The test can also be performed using identical test objects.

NOTE 1 The electric field transition time under high load condition (HL) can be reduced by increasing the ambient temperature, e.g. by enclosing the test device within an additional housing and providing means to circulate the air to achieve homogeneous temperature distribution inside the housing.

The electric field transition time  $d_{DC}$  is to be defined by simulations and / or measurements before the DC insulation system test.

The test shall be carried out at direct voltage, lightning impulse and switching impulse rated voltages according to sequence in Table 5:

**Table 5 – Sequence of DC insulation system test**

| Test                                                               | Conditions                                                            | Load conditions | Remark                           |
|--------------------------------------------------------------------|-----------------------------------------------------------------------|-----------------|----------------------------------|
| Thermal pre-test                                                   | Heating at defined temperature $\pm 5$ K                              | HL              | thermal calibration <sup>a</sup> |
| Dielectric pre-test                                                | PD test with alternating or direct voltage                            | ZL              | according 7.2.9 <sup>b</sup>     |
| Long-duration continuous direct voltage test                       | Rated direct voltage $U_{rd}$<br>(One polarity, positive or negative) | HL              | duration $d_{DC}$                |
| Superimposed lightning impulse voltage test (bipolar and unipolar) | Rated LIWV values, superimposed to the rated direct voltage $U_{rd}$  | HL              | 3 impulses <sup>c d e g</sup>    |
| Superimposed switching impulse voltage test (bipolar and unipolar) | Rated SIWV values, superimposed to the rated direct voltage $U_{rd}$  | HL              | 3 impulses <sup>c d e f g</sup>  |
| Long-duration continuous direct voltage test                       | Rated direct voltage $U_{rd}$<br>(other polarity)                     | HL              | duration $d_{DC}$                |
| Superimposed lightning impulse voltage test (bipolar and unipolar) | Rated LIWV values, superimposed to the rated direct voltage $U_{rd}$  | HL              | 3 impulses <sup>c d e g</sup>    |
| Superimposed switching impulse voltage test (bipolar and unipolar) | Rated SIWV values, superimposed to the rated direct voltage $U_{rd}$  | HL              | 3 impulses <sup>c d e f g</sup>  |

<sup>a</sup> During the thermal calibration test, the current has to be determined for the maximum conductor temperature and maximum temperature drop across the solid insulators. This current has to be used for the long duration voltage test. For the DC insulation system test, a higher equivalent direct or alternating current compared to direct rated current is allowed, because the maximum conductor temperature and maximum temperature drop across the insulation shall be safely achieved.

<sup>b</sup> Before starting the DC insulation system test, further pre-testing under the responsibility of the manufacturer is allowed.

<sup>c</sup> Because of laboratory constraints, it can be necessary to interrupt the heating of the test object. The maximum heating interruption time should be less than 60 min. After a heating interruption and before further tests, the steady state temperature shall be reattained.

<sup>d</sup> Due to laboratory constraints, it can be necessary to disconnect the test object from the direct voltage source. The direct voltage drop at the test object shall not exceed 5 % of the test voltage while disconnecting. To verify the voltage on the test object during the disconnect interval, the direct voltage shall be measured using adequate voltage measurement instruments. Alternatively, the electrical time constant of the whole test device (between the disconnecting points) could be measured before starting the test and used to calculate the test voltage drop.

- <sup>e</sup> The order of superimposed voltage tests is not of importance. It is possible to start with positive or negative polarity. Moreover, the order of lightning or switching impulses could be chosen according to the laboratory constraints.
- <sup>f</sup> The superimposed lightning and switching impulse voltage tests can also be carried out in separate test sequences, if a long interruption time between lightning impulse voltage and switching impulse voltage testing or vice versa becomes necessary. In this case, it shall be ensured that the DC steady state is obtained again before superimposed impulse voltage testing.
- <sup>g</sup> If the rated lightning impulse voltage is 1,3 times of the rated switching impulse voltage or larger, superimposed tests with switching impulse voltages are not mandatory.

During the long duration voltage test, partial discharges, temperature (ambient and enclosure), test current and test voltage should be monitored, and the measured data recorded. The measured temperatures should be compared to data obtained from thermal calibration test. It is also an advantage to apply arc detection and gas quality/pressure measurements.

The time between two successive impulses shall be not shorter than 1 min.

Generally, the verification of the dielectric performance under polarity reversals is covered by superimposed voltage tests. Therefore, the time to change the polarity during the insulation system tests could be chosen based on the possibilities and limitations of the laboratories (hours to months).

NOTE 2 The two test parts for the different polarities are independent tests.

If a breakdown or flashover occurs in a test object, the test of the affected direct voltage polarity shall be repeated for this particular test object. If partial discharges higher than 5 pC are detected in the DC GIS during the steady state condition before the application of the impulse test voltage, the location of the partial discharge shall be evaluated.

The insulation system test qualifies the insulators for DC applications provided that the following conditions are fulfilled:

- a) The rated direct voltage  $U_{rd}$  is not higher than that of the tested system.
- b) The maximum conductor temperature is less than or equal to that of the tested system.
- c) The maximum temperature drop across the insulator is less than or equal to that of the tested system.

## 7.2.102 Long-term energized test

This test is an optional test. The testing procedure is described in Annex F. The long-term energized test is intended to indicate the long-term performance of the complete DC GIS and is normally to be completed after the type tests have been carried out.

NOTE The long-term energized test is a long-term test developed in the CIGRE TB 842 [16] and described as a prototype installation test. The naming has been adjusted to make it easier to understand.

The long-term energized test additionally helps to qualify the manufacturer as a supplier of a DC GIS provided that the following conditions are fulfilled:

- a) The rated voltage  $U_{rd}$  of the DC GIS is not higher than that of the DC GIS tested.
- b) The rated current  $I_{rd}$  of the DC GIS is not higher than that of the DC GIS tested.
- c) The limiting temperature of the various parts in the DC GIS is not higher than that of the DC GIS tested.

## 7.3 Resistance measurement

### 7.3.1 Measurement of the resistance of auxiliary contacts class 1 and class 2

One sample of each type of class 1 and class 2 auxiliary contacts shall be inserted into a resistive load circuit through which flows a current of  $(10 \pm 2)$  mA when energized by a source

having an open circuit voltage of 6 V DC with a relative tolerance of  $\begin{smallmatrix} 0 \\ -15 \end{smallmatrix}$  % and the resistance measured according to IEC 60512-2-2.

The resistance of the closed class 1 and class 2 auxiliary contacts shall not exceed 50  $\Omega$  under these measuring conditions.

NOTE On contact materials, oxidation which decreases the effective current-carrying capabilities can occur. This results in an increased contact resistance or even no conduction at very low voltage while no problems are observed at higher voltage. This test is intended to verify the contact performance under these low-voltage conditions. The assessment criterion takes into account the non-linearity of the resistance. The 50  $\Omega$  value results from statistical considerations and has already been taken into account by users.

### 7.3.2 Measurement of the resistance of auxiliary contacts class 3

One sample of class 3 auxiliary contacts shall be inserted into a resistive load circuit through which flows a current  $\leq 10$  mA when energized by a source having an open circuit voltage  $\leq 30$  mV DC and the resistance measured according to 4.12 of IEC 61810-7:2006.

The resistance of the closed class 3 auxiliary contacts shall not exceed 1  $\Omega$ .

### 7.3.3 Electrical continuity of earthed metallic parts test

Generally visual inspection is sufficient to assess compliance with requirements in 6.3.

However, as an alternative, the metallic components and enclosures that can be touched during normal operating conditions and are intended to be earthed may be tested at 30 A (DC) to the earthing point provided. The voltage drop shall be lower than 3 V.

NOTE Coating can be removed locally at measuring points.

### 7.3.4 Resistance measurement of contacts and connections in the main circuit as a condition check

#### 7.3.4.1 Resistance measurement test procedure

When resistance measurements are called for as a condition check after a specific test, the following procedure shall be applied.

The resistance across the contacts or connections being checked shall be measured before the test. The measuring test points shall be the nearest accessible points to and on either side of the contacts or connections in question. An average value of the resistance shall be calculated based on three measurements. If the test object comprises switching devices, one no-load open and close operation cycle shall be made on each device between each of the measurements. If the test object comprises removable elements, one remove / replace cycle shall be made between each of the measurements.

The measurements shall be made with DC at full rated continuous current ( $-20$  % to  $0$  %) if less than or equal to 50 A or any convenient value of current between (and including) 50 A and the rated continuous current if it is higher than 50 A.

NOTE In some designs only a few connections and/or contacts or complete pole are practically accessible for measurement in the main circuit.

After the completion of the test, the resistance shall be measured again using the identical procedure to that used for the resistance measurements made prior to the tests. Before this resistance measurement, some conditioning of the contacts is acceptable based on the manufacturer's recommendations such as no-load operation cycles or the application of rated continuous current for some time.

The resistance measurements before and after shall be performed at ambient temperature with a maximum difference of 10 K between the measurements. The resistance increase is calculated by the difference between the average value of the measurements before and after the test.

The current used for the measurement shall be equal to or greater than 100 A direct current to obtain sufficient accuracy of the measurement.

If no-load operations cannot be made, then 3 measurements shall be made without no-load operations of the switching devices.

NOTE It is recognised that for some tests, it is not practical (for example if gas handling is required between the measurements) nor possible (for example during continuous current test because of the presence of temperature sensors within the contact system) to make any no-load operations between each of the three resistances measurements.

#### 7.3.4.2 Making and breaking tests

For making and breaking tests of any switching device, the resistance condition check of the test sample after completion of the test is considered to be satisfactory if the resistance increase determined in 7.3.4.1 is not greater than 100 %.

NOTE The acceptance criterion of 100 % increase in resistance as a condition check after making and breaking test is a default value for this document. The criterion cannot be appropriate for all switchgear designs, e.g. designs with parallel arcing and main contacts. In such cases, the relevant product standards provide their own methods or criteria for a condition check.

#### 7.3.4.3 Other tests

For tests other than making and breaking tests, the resistance condition check of the test object after completion of the test is considered to be satisfactory if the resistance increase determined in 7.3.4.1 is not greater than 20 %. If the resistance increase exceeds 20 % then a continuous current test (7.4) is applicable to determine if the test object can carry its rated continuous current.

NOTE The acceptance criterion of 20 % increase in resistance as a condition check after test is a default value for this document. The criterion cannot be appropriate for all switchgear designs, in which case, the relevant product standards provide their own methods or criteria for a condition check.

NOTE Switching of small DC currents are covered by IEC TS 62271-314.

### 7.4 Continuous current tests

#### 7.4.1 Condition of the test object

The continuous current test of the main circuits shall be made on a test object, if applicable, with clean contacts and filled with the appropriate liquid or gas at the minimum functional pressure (or density) for insulation prior to the test.

#### 7.4.2 Arrangement of the equipment

The test shall be made indoors in an environment substantially free from air currents, except those generated by heat from the test object. In practice, this condition is reached when the air velocity does not exceed 0,5 m/s.

For continuous current tests of parts other than auxiliary equipment, the test object and their accessories shall be mounted in all significant respects as in service, including all normal covers of any part of the test object (including any extra cover for testing purpose, for example cover surrounding a busbar extension), and shall be protected against undue external heating or cooling.

When the test object, according to the manufacturer's instructions, may be installed in different positions, the continuous current tests shall be made in the most unfavourable position.

These tests shall be made in principle on complete switchgear and controlgear but maybe made on a single unit provided the influence of the other units is negligible.

For particularly large test objects for which the insulation to earth has no significant influence on temperature rises, this insulation may be appreciably reduced.

Where temporary connections to the main circuit are used, they shall be such that there is no significant difference in heat conducted away from, or conveyed to, the test object compared to the connections intended to be used for service (see 7.4.4.2).

NOTE To make the continuous current test more reproducible, the type and/or sizes of the temporary connections can be specified in relevant standards.

DC GIS with single-pole enclosures shall be single-pole tested with the test current flowing through the main conductor. The test current shall not return through the enclosure.

When testing individual sub-assemblies, the neighbouring sub-assemblies should carry the currents which produce the power loss corresponding to the operating conditions. It is admissible to simulate equivalent conditions by means of heaters or heat insulation if the test cannot be made under actual conditions.

### 7.4.3 Test current and duration

#### 7.4.3.1 Test on main circuit

The test shall be made at the rated continuous current ( $I_{rd}$ ) of the switchgear and controlgear. The supply current shall be direct current with a ripple coefficient that does not exceed 5 %.

The test shall be made over a period of time sufficient for the temperature rise to reach a stable value. This condition is deemed to be obtained when the variation of temperature rise does not exceed 1 K in 1 h. This criterion will normally be met after test duration of five times the thermal time constant of the test object.

The time for the whole test may be shortened by preheating the circuit with a higher value of current, provided that sufficient test data is recorded to enable calculation of thermal time constant.

For the convenience of testing, alternating current may be used alternatively. In such a case, the RMS value of the alternating current shall be equal to the rated continuous current ( $I_{rd}$ ). Frequency of the test current shall be recorded in the test report. Alternating current test is applicable for devices except for semiconductor devices.

NOTE When using alternating current, the power losses during the entire test duration will be greater than the losses while tested with direct current. Measured temperature rise values by alternating current test is higher than these by direct current test caused by skin effect, by complex construction of switchgear and by material with iron component.

#### 7.4.3.2 Test of the auxiliary and control equipment

The test is made with the specified supply voltage (AC or DC), and for AC at its rated frequency (tolerance  $\begin{smallmatrix} +2 \\ -5 \end{smallmatrix}$  %).

The auxiliary equipment shall be tested at its rated supply voltage ( $U_a$ ) or at its rated continuous current. The AC supply voltage shall be practically sinusoidal.

Coils rated for continuous duty shall be tested over a period of time sufficient for the temperature rise to reach a constant value. This condition is usually obtained when the temperature variation does not exceed 1 K in 1 h.

For circuits energized only during operations, the tests shall be made under the following conditions.

- a) When the operating device has an automatic breaking device for interruption of the auxiliary circuit at the end of the operation, the circuit shall be energized 10 times, for either 1 s or until the automatic breaking device operates, the interval between the instant of each energizing being 10 s or, if the construction of the operating device does not permit this, the lowest interval possible.
- b) When the operating device has no automatic breaking device for interruption of the auxiliary circuit at the end of the operation, the test shall be made by energizing the circuit once for duration of 15 s.

#### **7.4.4 Temperature measurement during test**

##### **7.4.4.1 Ambient air temperature**

The ambient air temperature is the average temperature of the air surrounding the test object (for enclosed switchgear and controlgear, it is the air outside the enclosure). It shall be recorded during the tests by means of at least three thermometers, thermocouples or other temperature-measuring devices equally distributed around the test object at about the average height of its current-carrying parts and at a distance of about 1 m from the test object. The thermometers or thermocouples shall be protected against air currents and undue influence of heat.

In order to avoid indication errors because of rapid temperature changes, the thermometers or thermocouples maybe put into small bottles containing about 0,5 l of oil.

During the last quarter of the test period, the change of ambient air temperature shall not exceed 1 K in 1 h. If this is not possible because of unfavourable temperature conditions of the test room, the temperature of an identical switchgear and controlgear under the same conditions, but without current, may be taken as a substitute for the ambient air temperature. This additional switchgear and controlgear shall not be subjected to an undue amount of heat.

The ambient air temperature during tests shall be more than 10 °C but shall not exceed 40 °C without the consent of the manufacturer. No correction of the temperature-rise values shall be made for ambient air temperatures within this range and above.

##### **7.4.4.2 Temperature of test object**

Precautions shall be taken to reduce the variations and the errors due to the time lag between the temperature of the test object and the variations in the ambient air temperature.

For coils, the method of measuring the temperature rise by variation of resistance shall normally be used. Other methods are permitted only if it is impracticable to use the resistance method.

The temperature of the various parts other than coils for which limits are specified shall be measured with thermometers or thermocouples, or other sensitive devices of any suitable type, placed at the hottest accessible point.

The surface temperature of a component immersed in a dielectric liquid shall be measured only by thermocouples attached to the surface of this component. The temperature of the liquid dielectric itself shall be measured in the upper layer of the dielectric.

For measurement with thermometers or thermocouples, the following precautions shall be taken:

- a) the bulbs of the thermometers or thermocouples shall be protected against cooling from outside (dry clean wool, etc.). The protected area shall, however, be negligible compared with the cooling area of the apparatus under test;
- b) good heat conductivity between the thermometer or thermocouple and the surface of the part under test shall be ensured;

- c) when bulb thermometers are employed in places where there is any varying magnetic field, it is recommended to use alcohol thermometers in preference to mercury thermometers, as the latter are more liable to be influenced under these conditions.

Sufficient temperature measurements shall be made during the test, at time intervals not exceeding 30 min, in order to calculate the thermal time constant, and shall be recorded in the test document.

The temperatures at the terminals of the main circuit and at the temporary connections at a distance of 1 m from the terminals shall be measured. The difference in temperature rise shall not exceed 5 K.

However, if the temperature rise of the temporary connections at the distance of 1 m from the terminal of the main circuit exceeds by more than 5 K the temperature rise of the terminal, the test can be considered as valid if all criteria to pass the test defined in 7.4.6 are fulfilled.

#### **7.4.5 Resistance of the main circuit**

This subclause is only applicable for mechanical switching device.

A measurement of the resistance of the main circuit shall be made before the continuous current test, with the test object at the ambient air temperature according to the measurement procedure as defined in 7.3.4.

The resistance value measured before the continuous current tests is made for comparison between the switchgear and controlgear type tested for continuous current and all other switchgear and controlgear of the same type subjected to routine tests (see Clause 8).

#### **7.4.6 Criteria to pass test**

Insulators for DC GIS are considered electrical insulation system (EIS) according to IEC 60085:2007. The upper limit temperatures defined in IEC TS 62271-5 shall therefore be applicable for the EIS and not for the electrical insulation material (EIM).

For outdoor application, the manufacturer shall demonstrate that the temperature rise of the equipment will not exceed the limit acceptable under the service condition chosen in Clause 4.

NOTE 1 The effect of solar radiation can be taken into account. See IEEE C37.24 [17].

The temperature rise of components contained in the DC GIS which are subject to documents not covered by the scope of IEC TS 62271-5:2024 shall not exceed the temperature-rise limits permitted in the relevant document for those components.

NOTE 2 When applying a temperature rise equal to or higher than 65 K for parts of the enclosure not accessible to the operator, every precaution can be taken to ensure that no damage is caused to the surrounding insulating materials.

##### **7.4.6.1 General**

The test object has passed the test if the temperature rise of the parts of the test object for which limits are specified, has not exceeded the values specified in Table 10.

If the insulation of a coil is made of several different insulating materials, the permissible temperature rise of the coil shall be taken as that for the insulating material with the lowest limit of temperature rise.

If the test object is fitted with various equipment complying with particular standards (for example, rectifiers, motors, low-voltage switches, etc.), the temperature rise of such equipment shall not exceed the limits specified in the relevant standards.

In case alternating current is applied as a substitute of direct current, the test object is considered to pass the test if the temperature rise does not exceed the relevant temperature limit described in Table 10. Test results will be more severe when alternating current is used in comparison to direct current. If the test object fails to pass the test with an alternating current, the test may be repeated with a direct current; maintenance before repeating the test is allowed.

**Table 10 – Limits of temperature and temperature rise for various parts, materials and dielectrics of high-voltage switchgear and controlgear**

| Nature of the part, of the material and of the dielectric<br>(Refer to points 1, 2 and 3 in 7.4.6.2) (Refer to NOTE 1)                                                                                                                                                                                                                                                                                                   | Maximum value                                                               |                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                          | Temperature<br><br>°C                                                       | Temperature rise at<br>ambient air temperature<br>not exceeding 40 °C<br>(NOTE 2)<br><br>K |
| <b>1</b> Contacts (refer to point 4)<br>Bare-copper or bare-copper alloy<br>– in OG (refer to point 5)<br>– in NOG (refer to point 5)<br>– in oil<br>Silver-coated or nickel-coated (refer to point 6)<br>– in OG (refer to point 5)<br>– in NOG (refer to point 5)<br>– in oil<br>Tin-coated (refer to point 6)<br>– in OG (refer to point 5)<br>– in NOG (refer to point 5)<br>– in oil                                | <br><br>75<br>115<br>80<br><br>115<br>115<br>90<br><br>90<br>90<br>90       | <br><br>35<br>75<br>40<br><br>75<br>75<br>50<br><br>50<br>50<br>50                         |
| <b>2</b> Connection, bolted or the equivalent (refer to point 4)<br>Bare-copper, bare-copper alloy or bare-aluminium alloy<br>– in OG (refer to point 5)<br>– in NOG (refer to point 5)<br>– in oil<br>Silver-coated or nickel-coated (refer to point 6)<br>– in OG (refer to point 5)<br>– in NOG (refer to point 5)<br>– in oil<br>Tin-coated<br>– in OG (refer to point 5)<br>– in NOG (refer to point 5)<br>– in oil | <br><br>100<br>115<br>100<br><br>115<br>115<br>100<br><br>105<br>105<br>100 | <br><br>60<br>75<br>60<br><br>75<br>75<br>60<br><br>65<br>65<br>60                         |
| <b>3</b> All other contacts or connections made of bare metals or coated with other materials                                                                                                                                                                                                                                                                                                                            | (Refer to point 7)                                                          | (Refer to point 7)                                                                         |
| <b>4</b> Terminals for the connection to external conductors by screws or bolts (refer to points 8 and 14)<br>– bare<br>– silver or nickel coated<br>– tin-coated<br>– other coatings                                                                                                                                                                                                                                    | <br>100<br>115<br>105<br>(Refer to point 7)                                 | <br>60<br>75<br>65<br>(Refer to point 7)                                                   |
| <b>5</b> Oil for oil switching devices (refer to points 9 and 10)                                                                                                                                                                                                                                                                                                                                                        | 90                                                                          | 50                                                                                         |

| Nature of the part, of the material and of the dielectric<br>(Refer to points 1, 2 and 3 in 7.4.6.2) (Refer to NOTE 1)                                                                                                                       | Maximum value         |                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                              | Temperature<br><br>°C | Temperature rise at<br>ambient air temperature<br>not exceeding 40 °C<br>(NOTE 2)<br><br>K |
| 6 Metal parts acting as springs                                                                                                                                                                                                              | (Refer to point 11)   | (Refer to point 11)                                                                        |
| 7 Materials used as insulation and metal parts in contact with insulation of the following classes (refer to point 12)                                                                                                                       |                       |                                                                                            |
| – Y                                                                                                                                                                                                                                          | 90                    | 50                                                                                         |
| – A                                                                                                                                                                                                                                          | 105                   | 65                                                                                         |
| – E                                                                                                                                                                                                                                          | 120                   | 80                                                                                         |
| – B                                                                                                                                                                                                                                          | 130                   | 90                                                                                         |
| – F                                                                                                                                                                                                                                          | 155                   | 115                                                                                        |
| – Enamel: oil base                                                                                                                                                                                                                           | 100                   | 60                                                                                         |
| synthetic                                                                                                                                                                                                                                    | 120                   | 80                                                                                         |
| – H                                                                                                                                                                                                                                          | 180                   | 140                                                                                        |
| – C other insulating material                                                                                                                                                                                                                | (Refer to point 13)   | (Refer to point 13)                                                                        |
| 8 Any part of metal or of insulating material in contact with oil, except contacts                                                                                                                                                           | 100                   | 60                                                                                         |
| 9 Accessible surfaces                                                                                                                                                                                                                        | (Refer to point 15)   | (Refer to point 15)                                                                        |
| Surfaces of manual control components to be touched in normal operation:                                                                                                                                                                     |                       |                                                                                            |
| – Uncoated metal                                                                                                                                                                                                                             | 55                    | 15                                                                                         |
| – Coated metal                                                                                                                                                                                                                               | 55                    | 15                                                                                         |
| – Non metal                                                                                                                                                                                                                                  | 65                    | 25                                                                                         |
| Other surfaces to be touched in normal operation but not to be held continuously in the hand:                                                                                                                                                |                       |                                                                                            |
| – Uncoated metal                                                                                                                                                                                                                             | 65                    | 25                                                                                         |
| – Coated metal                                                                                                                                                                                                                               | 70                    | 30                                                                                         |
| – Non metal                                                                                                                                                                                                                                  | 80                    | 40                                                                                         |
| Surfaces not to be touched in normal operation:                                                                                                                                                                                              |                       |                                                                                            |
| – Uncoated metal                                                                                                                                                                                                                             | 80                    | 40                                                                                         |
| – Coated metal                                                                                                                                                                                                                               | 80                    | 40                                                                                         |
| – Non metal                                                                                                                                                                                                                                  | 90                    | 50                                                                                         |
| NOTE 1 The points referred to in this table are those in 7.4.6.2.                                                                                                                                                                            |                       |                                                                                            |
| NOTE 2 For switchgear and controlgear with special service conditions including a maximum temperature different from 40 °C, the maximum values of temperature applies and the maximum values of temperature rise are calculated accordingly. |                       |                                                                                            |

#### 7.4.6.2 Particular points of Table 10

The following points are referred to in Table 10 and complete it.

**Point 1** According to its function, the same part can belong to several categories as listed in Table 10.

In this case the permissible maximum values of temperature and temperature rise to be considered are the lowest among the relevant categories.

**Point 2** For vacuum switching devices, the values of temperature and temperature-rise limits do not apply to parts in vacuum. The remaining parts shall not exceed the values of temperature and temperature rise given in Table 10.

**Point 3** Care shall be taken to ensure that no damage is caused to the surrounding insulating materials.

**Point 4** When engaging parts have different coatings or one part is of bare material, the permissible temperatures and temperature rises shall be:

- a) for contacts, those of the surface material having the lowest value permitted in item 1 of Table 10;
- b) for connections, those of the surface material having the highest value permitted in item 2 of Table 10.

**Point 5** NOG (Not Oxidizing Gases), for the purposes of this document, are non-reactive gases that are considered as not accelerating ageing of contacts by corrosion or oxidation, due to their chemical characteristics and demonstrated operational records.

Recognized NOG are SF<sub>6</sub>, N<sub>2</sub>, CO<sub>2</sub>, CF<sub>4</sub>. They can be used pure or as a mixture of various NOG.

OG (Oxidizing Gases), for the purposes of this document, are reactive gases that can accelerate ageing of contacts either by corrosion phenomena (presence of humidity) or by oxidation phenomena (mostly due to ambient air medium like oxygen). Gases classified as OG are ambient air, "dry" air, any gas not classified as NOG and any mixture including part of OG.

NOTE Some gases considered as OG in the classification above could be re-classified as NOG, in future revision of this document.

For description of these corrosion and oxidation phenomena, refer to IEC TR 60943 [45].

Due to the absence of corrosion and oxidation in NOG, a harmonization of the limits of temperature for different contact and connection parts in the case of gas insulated switchgear appears appropriate.

The permissible temperature limits for bare copper and bare copper alloy parts are equal to the values for silver-coated or nickel-coated parts in the case of NOG atmospheres.

In the particular case of tin-coated parts, due to fretting corrosion effects, an increase of the permissible temperatures is not applicable, even under the corrosion and oxidation free conditions of NOG. Therefore, the values for tin-coated parts are lower.

**Point 6** The quality of the coated contacts shall be such that a continuous layer of coating material remains in the contact area:

- a) after the making and breaking test (if any);
- b) after the short-time withstand current test;
- c) after the mechanical endurance test.

According to the relevant standard for each equipment. Otherwise, the contacts shall be regarded as "bare".

- Point 7** When materials other than those given in Table 10 are used, their properties shall be considered, notably in order to determine the maximum permissible temperature rises.
- Point 8** The values of temperature and temperature rise are valid even if the conductor connected to the terminals is bare.
- Point 9** The temperature shall be measured at the upper part of the oil.
- Point 10** Special consideration should be given when low flash-point oil is used in regard to vaporization and oxidation.
- Point 11** The temperature shall not reach a value where the elasticity of the material is impaired.
- Point 12** Classes of insulating materials are those given in IEC 60085.
- Point 13** The temperature is limited only by the requirement not to cause any damage to surrounding parts.
- Point 14** These values do not take into account any influence on insulation of cable or cable termination.
- Point 15** For further details regarding temperature limits for hot surfaces to be touched, refer to IEC Guide 117 [67].

## **7.5 Short-time withstand current and peak withstand current tests**

### **7.5.1 General**

The tests apply to the main circuits and where applicable, to the earthing circuits of the test object to demonstrate their ability to carry their rated peak withstand current and their thermal withstand capability for their rated duration of short-circuit.

The test may be performed at any convenient ambient temperature.

### **7.5.2 Arrangement of the equipment and of the test circuit**

The test object shall be mounted on its own support(s) or on (an) equivalent support(s) and installed with its own operating device(s) as far as necessary to make the test representative for checking mechanical and thermal effects of the test currents. It shall be in the closed position, where relevant.

Each test shall be preceded by a no-load opening operation of the mechanical switching device(s) (if any) and, with the exception of earthing switches, by measurement of the resistance of the main circuit according to 7.3.4. The no-load opening operation shall be carried out at the rated value of the supply voltage in the case of power operated devices and the force/torque shall be measured in the case of dependent manually operated devices.

The distance between the terminals and the nearest supports of the conductors or the nearest clamping points of cable on both sides of the test object shall be in accordance with the instructions of the manufacturer.

The test arrangement shall be noted in the test report.

DC GIS with single-pole enclosures shall be tested in a single-pole circuit with return current or without return current in the enclosure.

The tests shall be made on a representative assembly which should include all types of connections of bolted, welded, plug-in or otherwise jointed sections to verify the integrity of DC GIS components are joined together. Assemblies shall be tested such that specimens of all components and sub-assemblies of the design are subjected to the test. Tests shall be made using configurations that provide the most severe conditions.

### 7.5.3 Test current and duration

The peak current shall be not less than the rated peak withstand current ( $I_{pd}$ ) and shall not exceed it by more than 5 % without the consent of the manufacture. The value of Joule integral  $\int I^2 dt$  of the test current shall not be less than the specified value calculated by the specified waveform, peak current and duration, and shall not exceed by more than 10 % without the consent of the manufacturer.

NOTE The value of the Joule integral can be calculated by the specified waveform, peak current, and duration by equations indicated in D.6.

The following deviations are permitted:

- a) if the decrement of the short-circuit of the test laboratory is such that the specified Joule integral value cannot be obtained for the specified duration without applying initially an excessively high current, the duration of the test may be increased appropriately to obtain the specified joule integral value, provided that the value of the peak current is not less than that specified and the duration is not extended to more than 5 s;
- b) if, in order to obtain the required peak current, the Joule integral value of the current is increased above the specified value, the duration of the test may be reduced accordingly;
- c) multi-part test such as separation of the peak withstand current test and the short-time withstand current test is permissible:
  - for the peak withstand current test, the time during which the short-circuit current is applied shall be not less than 0,3 s;
  - for the short-time withstand current test, the time during which the short-circuit current is applied shall be equal to the specified duration. However, deviation in time according to item a) is permitted;
  - for switching devices the test object shall be kept in closed position between the tests.

For the convenience of testing, AC test current may be used alternatively. In such case, the tests shall be made under the following conditions:

- a) AC peak current shall be not less than the rated peak withstand current ( $I_{pd}$ ) and shall not exceed it by more than 5 % without the consent of the manufacturer;
- b) The value of the Joule integral  $\int I^2 dt$  of AC current shall be not less than the specified value of DC Joule integral value and shall not exceed it by more than 10 % without consent of the manufacturer.

The following deviations are permitted:

- a) if the decrement of the short-circuit of the test laboratory is such that the specified Joule integral value cannot be obtained within the specified duration without applying initially an excessively high current, the RMS value of the test current may be permitted to fall below the specified value during the test and the duration of the test may be increased appropriately, provided that the value of the peak current is not less than that specified and the time is not extended to more than 5 s;
- b) if, in order to obtain the required peak current, the Joule integral value of the current is increased above the specified value, the duration of the test may be reduced accordingly;
- c) separation of the peak withstand current test and the short-time withstand current test is permissible:

- for the peak withstand current test, the time during which the short-circuit current is applied shall be not less than 0,3 s;
- for the short-time withstand current test, the time during which the short-circuit current is applied shall be equal to the specified duration. However, deviation in time according to item a) is permitted;
- for switching devices the test object shall be kept in closed position between the tests.

#### **7.5.4 Conditions of the test object after test**

After the test, the test object shall not show significant deterioration, shall be capable of operating normally and carrying its rated continuous current.

If the mechanical switching device has a rated making and/or breaking capacity, then the condition of the contacts shall not be such as to affect the performance materially at any making and/or breaking current up to its rated value.

The following steps are used to check these requirements:

- a) a no-load opening operation of the mechanical switching device shall be performed in the same conditions as stated in 7.5.2 immediately after the test, and the contacts shall open at the first attempt;
- b) except for earthing switches, the variation of the resistance of the main circuit shall be checked according to 7.3.4;
- c) visual inspection of the test object and the contacts (if not detrimental).

NOTE For semiconductor devices, reference is made to IEC 62501, 4.4.2 and 11 [64].

##### **7.5.101 Tests on the main circuits**

After the tests, the resistance measurement shall not increase more than 20 % with respect to its pre-test resistance measurement. Neither the components nor conductors within the enclosure shall show any deformation or damage, which can impair the intended operation.

Short connections to voltage measurement devices shall be considered as part of the main circuit, except for parts included in the voltage measurement device compartment.

##### **7.5.102 Tests on earthing circuits**

The manufacturer shall demonstrate by tests or calculations the capability of earthing circuits to withstand the rated short-time and peak withstand current of the system.

When verification tests are required by the user, earthing circuits of DC GIS which are factory assembled and comprise earthing conductors, earthing connections and earthing devices shall be tested as installed in the DC GIS with all associated components which can influence the performance or modify the short-circuit current.

After the test, the components or conductors within the enclosure shall not show deformation or damages, which can impair the intended operation of the main circuit. Some deformation and degradation of the earthing conductor, earthing connections or earthing devices is permissible, but the continuity of the earthing circuit shall be preserved.

#### **7.6 Verification of the protection**

##### **7.6.1 Verification of the IP coding**

In accordance with the requirements specified in Clauses 11, 12, 13 and 15 of IEC 60529:1989, IEC 60529:1989/AMD1:1999 and IEC 60529:1989/AMD2:2013, tests shall be performed, to demonstrate performances as required in 6.14, on the enclosures of switchgear and controlgear fully assembled as under service conditions. As real cable connections entering the enclosures

are not normally installed for type tests, corresponding filler pieces shall be used. Transport units of switchgear shall be closed for the tests by covers providing identical protection qualities as for the joints.

The tests shall, however, be made only if there are doubts regarding the compliance with these requirements, they shall be performed in each position of the relevant parts as deemed necessary.

When the supplementary letter W is used, test method given in Annex G (normative) shall be applied.

Verification of IP coding is not applicable to pressurized DC GIS enclosures.

Where supplementary letter W is specified, it shall be checked by inspection, that the design does not contain places where significant accumulation of water can be retained (to minimize corrosion).

## 7.6.2 Verification of the IK coding

The requirements specified in 6.14.4 shall be demonstrated according to IEC 62262:2002; tests shall be performed on the enclosures of switchgear and controlgear fully assembled as under service conditions.

After the test, the enclosure shall show no breaks and the deformation of the enclosure shall not affect the normal function of the equipment, reduce the insulating and/or creepage distances or reduce the specified degree of protection against access to hazardous parts below the permitted values. Superficial damage, such as removal of paint, breaking of cooling ribs or of similar parts, or depression of small dimension can be ignored.

The tests shall, however, be made only if there are doubts regarding the compliance with these requirements, they shall be performed in each position of the relevant parts deemed necessary.

Auxiliary equipment such as meters, relays etc., which can form part of the enclosure is exempted from receiving impacts in this test.

Verification of IK coding is not applicable to pressurized DC GIS enclosures.

## 7.7 Tightness tests

### 7.7.1 General

The purpose of tightness tests is to demonstrate that the absolute leakage rate  $F$  does not exceed the specified value of the permissible leakage rate  $F_p$  at standardized ambient temperature of 20 °C. Acceptable test condition is an ambient temperature in a range of 15 °C up to 30 °C.

If tightness tests at the temperature limits of the service condition are required in the relevant product standards, an increased leakage rate is permissible. The increased temporary leakage rate shall not exceed the values given in Table 11.

Tightness test shall be performed with the same fluid and under the same pressure (density) as used in service. If the fluid itself is not traceable additional traceable fluids may be added, for example helium. The leakage test method shall have sufficient sensitivity; reference is made to IEC TR 62271-306 [62].

Where possible, the tests should be performed on a complete system. If this is not practical, the tests may be performed on parts, components or subassemblies. In such cases, the leakage

rate of the total system shall be determined by summation of the component leakage rates using the tightness coordination chart (refer to IEC TR 62271-306 [62]). The possible leakages between subassemblies of different pressures shall also be taken into account.

The tightness test of switchgear and controlgear containing a mechanical switching device shall be performed both in the closed and open position of the device, unless the leakage rate is independent of the position of the main contacts.

Cumulative leakage measurement, which takes into account all the leaks from a given assembly to determine the leakage rate, shall be used in the calculation of leakage rates.

The type test report should include such information as:

- description of the object under test, including its internal volume and the nature of the filling gas or liquid;
- whether the object under test is in the closed or open position (if applicable);
- the pressures and temperatures recorded at the beginning and end of the test and the number of replenishments (if applicable);
- the value of the ambient temperature during the test.
- the cut-in and cut-off pressure settings of the pressure (or density) control or monitoring device;
- an indication of the calibration of the meters used to detect leakage rates;
- the results of the measurements;
- the test gas and if applicable the conversion factor to assess the results.

In general, for the application of an adequate test method, reference is made to IEC 60068-2-17:1994.

**Table 11 – Permissible leakage rates for gas systems**

| Temperature<br>°C                                                    | Permissible leakage rate |
|----------------------------------------------------------------------|--------------------------|
| Maximum service temperature ( $\geq 40$ °C)                          | $3F_p$                   |
| Standardized ambient temperature (20 °C)                             | $F_p$                    |
| Minimum service temperature (any value down to and including -40 °C) | $3F_p$                   |
| Minimum service temperature (any value below -40 °C)                 | $6F_p$                   |

The measurement of gas tightness shall be performed as a type test to show that the relative leakage rate complies with 6.16.101. The tightness test shall be performed at filling pressure  $p_{re}$ .

The type test shall be performed with representative types of DC GIS compartments comprising sealings and accessories (e.g. gas filling valves, density monitors, bursting discs, UHF monitors, viewing ports, etc.)

For switching devices and insulators the measurement of gas tightness shall be performed together with the tests of 7.102 and 7.106.

### 7.7.2 Controlled pressure systems for gas

Preferred method for checking the relative leakage rate  $F_{\text{rel}}$  is by measuring the pressure drop  $\Delta p$  over a time period  $t$  that is of sufficient duration to permit a determination of the pressure drop (within the filling and replenishing pressure range). A correction shall be made to take into account the variation of ambient air temperature during the course of the test. During this period the replenishment device shall be inoperative.

$$F_{\text{rel}} = \frac{\Delta p}{p_r} \times \frac{24}{t} \times 100 \text{ (\% per day)} \quad (1)$$

$$N = \frac{\Delta p}{p_r - p_m} \times \frac{24}{t} \quad (2)$$

where

$t$  is the test duration (h);

$p_r$  is the filling pressure (Pa);

$p_m$  is the replenishing pressure (Pa);

$\Delta p$  is the pressure drop after time  $t$  (Pa);

$N$  is the number of replenishments per day.

NOTE The linearity of the formula is considered to be maintained provided that  $\Delta p$  is of the same order of magnitude as  $p_r - p_m$ .

### 7.7.3 Closed pressure systems for gas

The test  $Q_m$  (Test method 1: cumulative test) described in IEC 60068-2-17:1994 is the preferred method to determine the relative leakage rate  $F_{\text{rel}}$  in gas systems and calculate the time between replenishments  $t_r$ . Detailed information about test procedure, sensitivity of measurement and example of calculation are also given in IEC TR 62271-306 [62].

Alternative methods of leak detection are also given in IEC TR 62271-306 [62] that may be used to measure the leakage rate, which allows in combination with the tightness coordination chart, the calculation of:

- the relative leakage rate;
- the time between replenishments (without considering extreme temperature conditions of number of operations).

The tightness test is considered to be successful when the measured leakage rate does not exceed the permissible leakage rate stated in Table 11 within the limits of +10 %. This inaccuracy of the measurement shall be taken into account when calculating the period of time between replenishments.

The measurement of gas tightness shall be performed by cumulative method ( $Q_m$  described in IEC 60068-2-17, test method 1).

### 7.7.4 Sealed pressure systems

Tightness tests on sealed pressure systems shall be as follows

- a) Switchgear using gas

The tests shall be performed according to the preferred method of 7.7.3.

b) Switchgear using vacuum interrupters

No specific tightness tests are required for vacuum interrupters since their tightness is verified during manufacturing process and because they are considered to have a zero leakage rate during their life. Nevertheless, instead of a tightness test, the vacuum integrity shall be verified where specific standards ask for a tightness test as condition check (for example mechanical test, low and high temperature tests, etc.).

The integrity of the vacuum can be verified by the dielectric condition check test, refer to 7.2.11.

### 7.7.5 Liquid tightness tests

The purpose of liquid tightness tests is to demonstrate that the total system leakage rate  $F_{liq}$  does not exceed the specified value  $F_{p(liq)}$ .

The object under test shall be as in service conditions with all its accessories and its normal fluid, mounted as close as possible as in service.

An increased leakage rate at extreme temperatures (if such tests are required in the relevant standards) and/or during operations is acceptable, provided that this rate resets to the initial value after the temperature is returned to normal ambient air temperature and/or after the operations are performed. The increased temporary leakage rate shall not impair the safe operation of the switchgear and controlgear.

The switchgear shall be observed over a period sufficient to determine a possible leak or the pressure drop  $\Delta p_{liq}$ . In this case, the calculations given in 7.7.2 are valid.

As an alternative, using liquids different from those in service or gas for the test is possible but requires justification by the manufacturer.

The test report shall include such information as:

- a general description of the object under test;
- the number of operations performed;
- the nature and pressure(s) of the liquid;
- the ambient air temperature during test;
- the results with the switchgear device in closed and in open position (where applicable).

## 7.8 Electromagnetic compatibility tests (EMC)

### 7.8.1 Emission tests

#### 7.8.1.1 Emission tests from the main circuits (radio interference voltage test, RIV)

Subclause 7.8.1.1 of IEC TS 62271-5:2024 applies only to bushings.

Radio interference voltage tests apply only to switchgear and controlgear having a rated direct voltage of 210 kV and above, when specified in the relevant product standard.

Test object shall be installed as stated in 7.2.4.

The test voltage shall be direct voltage and applied as follows.

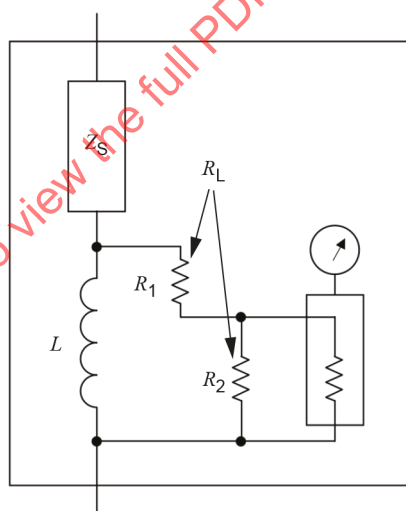
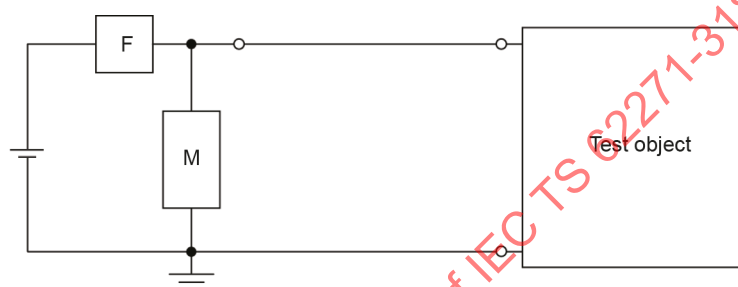
- a) in closed position, between the terminals and the earthed frame;

- b) in open position, if any, between one terminal and the other terminal connected to the earthed frame and then with the connections reversed if the switching device is not symmetrical.

The case, tank, frame and other normally earthed parts shall be connected to earth.

The test object shall be dry and clean and at approximately the same temperature as the room in which the test is made. During the tests the test object shall be equipped with all accessories such as grading elements, corona rings, high-voltage connectors, etc. which may influence the radio interference voltage.

The measuring circuit (refer to Figure 6) shall comply with CISPR TR 18-2. The measuring circuit shall preferably be tuned to a frequency within 10 % of 0,5 MHz, but other frequencies in the range 0,5 MHz to 2 MHz may be used, the measuring frequency being recorded. The results shall be expressed in  $\mu\text{V}$ .



Details of M

IEC

#### Key

- F Filter
- $R_L$  The equivalent resistance of  $R_1$  in series with the parallel combination of  $R_2$  and the equivalent resistance of the measuring set
- $Z_s$  Either a capacitor or a circuit composed of a capacitor and an inductor in series
- $L$  The inductance used to shunt harmonic currents and to compensate for stray capacitance at the measuring frequency

**Figure 6 – Diagram of a test circuit for the radio interference voltage test**

The preferred measuring impedances are those specified in CISPR publications. If measuring impedances different from those specified in CISPR publications are used as an alternative,

they shall be from 30  $\Omega$  up to 600  $\Omega$ ; in any case the phase angle shall not exceed 20°. The equivalent radio interference voltage referred to 300  $\Omega$  can be calculated, assuming the measured voltage to be directly proportional to the resistance, except for test pieces of large capacitance, for which a correction made on this basis can be inaccurate. Therefore, a 300  $\Omega$  resistance is recommended for switchgear and controlgear with bushings with earthed flanges (for example dead tank switchgear and controlgear).

The filter F shall have high impedance at the measuring frequency, so that the impedance between the high-voltage conductor and earth is not shunted as seen from the switchgear and controlgear under test.

NOTE 1 This filter also reduces circulating radiofrequency currents in the test circuit, generated by the high-voltage transformer or picked up from extraneous sources. A suitable value for its impedance has been found to be 10 000  $\Omega$  to 20 000  $\Omega$  at the measuring frequency.

It shall be ensured by suitable means that the radio interference background level (radio interference level caused by external field and by the high-voltage transformer when magnetized at the full test voltage) is at least 6 dB below the specified radio interference level of the test object. Calibration methods for the measuring instrument and for the measuring circuits are given in CISPR 16-1 (all parts) and CISPR TR 18-2 respectively.

The following test procedure shall be followed.

Unless otherwise specified by the relevant product standard, direct voltage of  $1,1 \times U_{rd}$ ,  $U_{rd}$  being the rated direct voltage of the switchgear and controlgear, shall be applied to the test object with both polarities and maintained for at least 5 min. A much longer test time than 5 min is also applicable by agreement between user and manufacturer.

NOTE 2 The test time of 5 min is based on IEC TS 63014-1. However, RIV behaviour and physical mechanisms (space charges, ozone generation, etc.) with a DC applied voltage can be slightly different from that with an AC applied voltage, especially for the polymeric insulated part subjected to direct voltage. In some cases, a long-time such as one hour or three hours test is possible.

As alternative method, RIV tests may be performed using an alternating voltage source as described in IEC 60437, instead of direct voltage. In this case, the RMS value of the alternating voltage shall be the direct test voltage divided by  $\sqrt{2}$ .

The test is passed, if the radio interference level does not exceed 2 500  $\mu\text{V}$ . In a long-time test, the test is passed if no more than 30 RIV pulses exceeding 2 500  $\mu\text{V}$  are recorded during any 30-min period of the test. RIV pulses that are proven to be external to the test object shall be disregarded.

As the radio interference level can be affected by fibres or dust settling on the insulators, it is permitted to wipe the insulators with a clean cloth before taking a measurement. The atmospheric conditions during the test shall be recorded. If the measured RIV value is above the limit and the relative humidity is above 80 %, the test is not conclusive and shall be repeated with a relative humidity lower than 80 %.

#### **7.8.1.2 Emission tests from the auxiliary and control circuits**

Auxiliary and control circuits of switchgear and controlgear shall be subjected to electromagnetic emission tests if they include electronic equipment or components. In other cases, no tests are required.

For auxiliary and control circuits of switchgear and controlgear, the EMC requirements and tests specified in this document have precedence over other EMC specifications.

The test shall be performed only on a representative auxiliary and control circuit, because the single components are tested according to their relevant standards, if any.

Electronic equipment, which is part of the auxiliary and control circuits, shall fulfil the requirements with regard to radiated emission, as defined in CISPR 11:2015 for group 1, class A equipment. No other tests are specified. A 10 m measuring distance may be used instead of 30 m, by increasing the limit values by 10 dB.

## **7.8.2 Immunity tests on auxiliary and control circuits**

### **7.8.2.1 General**

Auxiliary and control circuits of switchgear and controlgear shall be subjected to electromagnetic immunity tests if they include electronic equipment or components. In other cases no tests are required.

The tests shall be performed on a typical auxiliary and control circuit. Components shall comply with their relevant standards, if any.

The following immunity tests are specified:

- electric fast transient/burst test (refer to 7.8.2.2). The test simulates the conditions caused by switching in the auxiliary and control circuit;
- oscillatory wave immunity test (refer to 7.8.2.3). The test simulates the conditions caused by switching in the main circuit.

NOTE Other EMC immunity tests do exist, but are not specified in this case.

Electromagnetic immunity tests shall be made on complete auxiliary and control circuits or subassemblies. The tests can be made on

- the complete auxiliary and control circuits;
- subassemblies, such as central control cubicle, drive mechanism cubicle, etc.;
- subassemblies within a cubicle, such as metering or monitoring system.

Individual testing of subassemblies is strongly recommended in cases where long lengths of interconnections are required, or where significant interference voltages are expected between the subassemblies. Individual testing is mandatory for each interchangeable subassembly.

The test voltage shall be applied to the interface of the auxiliary and control circuits or tested subassembly.

The type test report shall clearly state what system or subassembly has been tested.

### **7.8.2.2 Electrical fast transient/burst test**

An electrical fast transient/burst test shall be performed in accordance with IEC 61000-4-4, with a repetition rate of 5 kHz. The ports and interfaces shall be chosen in accordance with IEC 61000-6-2. The test voltage and coupling shall be chosen according to Table 12.

**Table 12 – Application of voltages at the fast transient/burst test**

| Interface                                                                        | Relevance for equipment                                                                                                                                                                                            | Test voltage<br>kV | Coupling                              |
|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------------------------------|
| Power port                                                                       | AC and DC power lines                                                                                                                                                                                              | 2                  | CDN                                   |
| Cabinet earth port                                                               |                                                                                                                                                                                                                    | 2                  | CDN                                   |
| Signal port                                                                      | Shielded and unshielded lines, carrying analogue and/or digital signals<br>control lines<br>communication lines (for example data buses)<br>measuring lines (for example current transducers, voltage transducers) | 2                  | CCC<br>or equivalent coupling methods |
| <b>Key</b><br>CDN Coupling decoupling network.<br>CCC Capacitive coupling clamp. |                                                                                                                                                                                                                    |                    |                                       |

### 7.8.2.3 Oscillatory wave immunity test

An oscillatory wave immunity test shall be performed, with shape and duration of the test voltage in accordance with IEC 61000-4-18.

The ports and interfaces shall be chosen in accordance with IEC 61000-6-2.

Damped oscillatory wave tests shall be made at 100 kHz and 1 MHz, with a relative tolerance of  $\pm 30$  %.

Tests shall be made for both common and differential mode. The test voltage and coupling method shall be chosen according to Table 13.

**Table 13 – Application of voltage at the damped oscillatory wave test**

| Interface                                      | Relevance for equipment                                                                                                                                                                                             | Test voltage<br>kV                         | Coupling                                    |
|------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|---------------------------------------------|
| Power port                                     | AC and DC power lines                                                                                                                                                                                               | Differential mode: 1,0<br>Common mode: 2,5 | CDN<br>CDN                                  |
| Signal port                                    | Shielded and unshielded lines, carrying analogue and/or digital signals<br>control lines<br>communication lines (for example data buses)<br>measuring lines (for example: current transducers, voltage transducers) | Differential mode: 1,0<br>Common mode: 2,5 | CDN<br>CDN<br>Or equivalent coupling method |
| <b>Key</b><br>CDN Coupling decoupling network. |                                                                                                                                                                                                                     |                                            |                                             |

#### 7.8.2.4 Behaviour of the secondary equipment during and after tests

The auxiliary and control circuits shall withstand each of the tests specified in 7.8.2.2 and 7.8.2.3 without permanent damage. After the tests it shall still be fully operational. Temporary loss of parts of the functionality is permitted according to Table 14.

**Table 14 – Assessment criteria for transient disturbance immunity**

| Function                                                                                                                                                     | Criterion |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Protection, tele protection                                                                                                                                  | A         |
| Alarm                                                                                                                                                        | B         |
| Supervision                                                                                                                                                  | B         |
| Command and control                                                                                                                                          | A         |
| Measurement                                                                                                                                                  | B         |
| Counting                                                                                                                                                     | A         |
| Data processing<br>for high-speed protective system                                                                                                          | A         |
| for general use                                                                                                                                              | B         |
| Information                                                                                                                                                  | B         |
| Data storage                                                                                                                                                 | A         |
| Processing                                                                                                                                                   | B         |
| Monitoring                                                                                                                                                   | B         |
| Man-machine interface                                                                                                                                        | B         |
| Self-diagnostics                                                                                                                                             | B         |
| Processing, monitoring and self-diagnostic functions which are on-line connected, and are part of command and control circuits, shall fulfil criterion A.    |           |
| <b>Key</b><br>A Normal performance within the specification limits;<br>B Temporary degradation or loss of function or performance which is self-recoverable. |           |

#### 7.8.3 Additional EMC tests on auxiliary and control circuits

##### 7.8.3.1 General

The objective of the tests described below is to qualify the whole assembly without repeating individual test on components. Therefore, tests on components which comply with their relevant IEC standards and with relevant rated values do not need to be repeated.

##### 7.8.3.2 Ripple on DC input power port immunity test

This test shall be performed according to IEC 61000-4-17:1999. The test level shall be level 2, and the frequency of the ripple is equal to three times the rated frequency of auxiliary and control circuits.

The assessment criterion is: “normal performance within the specification limits” (criterion A).

##### 7.8.3.3 Voltage dips, short interruptions and voltage variations on input power port immunity tests

Voltage dips, short interruptions and voltage variations tests on AC power ports shall be performed according to IEC 61000-4-11 and on DC power ports according to IEC 61000-4-29.

The relevant acceptance criteria are present in 6.4.1.

## **7.9 Additional tests on auxiliary and control circuits**

### **7.9.1 General**

Tests on components, which comply with their relevant IEC standards and with relevant rated values, shall not be repeated.

### **7.9.2 Functional tests**

A functional test of all auxiliary and control circuits shall be made to verify the proper functioning of auxiliary and control circuits in conjunction with the other parts of the switchgear and controlgear. The test procedures depend on the nature and the complexity of the auxiliary and control circuits of the device. They shall be performed with the upper and lower value limits of the supply voltage defined in 6.4.1.

For auxiliary and control circuits, sub-assemblies and components, operation tests can be omitted if they have been fully performed during a test applied to the whole switchgear and controlgear or in relevant circumstances.

### **7.9.3 Verification of the operational characteristics of auxiliary contacts**

#### **7.9.3.1 General**

Auxiliary contacts, which are contacts included in auxiliary circuits, shall be submitted to the following tests unless the equipment has passed the whole type tests as a functional unit.

#### **7.9.3.2 Auxiliary contact rated continuous current**

This test verifies the rated value of current which a previously closed auxiliary contact is capable of carrying continuously.

The circuit shall be closed and opened by means independent from the contact under test. Test procedures are described in 7.4.3.2. The contact shall carry its class rated continuous current according to Table 4 without exceeding the temperature rise in Table 10 based on the contact material and the working environment.

#### **7.9.3.3 Auxiliary contact rated short-time withstand current**

This test verifies the value of current which a previously closed auxiliary contact is capable of carrying for a specified short period.

The circuit shall be closed and opened by means independent from the contact under test. The contact shall carry its class rated short-time withstand current according to Table 4 for 30 ms, with a resistive load. The current value to be obtained shall be reached within 5 ms after current

initiation. The tolerance on the test current amplitude is  $^{+5}_0$  % and the tolerance on the test

current duration is  $^{+10}_0$  %.

This test shall be repeated 20 times with a 1 min interval between each test. The contact resistance value shall be taken before and after the tests at 50 % of the rated continuous current in Table 4, with the contacts at ambient temperature for both measurements.

The test is passed:

- if the resistance increase is less than 20 %;

- or, when the increase exceeds 20 %, if the continuous current test according to 7.4.3.2 is performed successfully.

#### 7.9.3.4 Auxiliary contact breaking capacity

This test verifies the breaking capacity of an auxiliary contact.

The circuit shall be closed by means independent from the contact under test. The contact shall carry for 5 s and shall break the current associated with its class according to Table 4, with an inductive load. The tolerance on the test voltage is  $^{+10}_0$  % and the tolerance on the test current amplitude is  $^{+5}_0$  %.

For all classes, the circuit time constant shall be 20 ms with a tolerance of  $^{+20}_0$  %.

This test shall be repeated 20 times with a 1 min interval between each test. The recovery voltage shall be maintained during each 1 min interval and for  $300\text{ ms} \pm 30\text{ ms}$  after the last operation. The contact resistance value shall be taken before and after the tests at 50 % of the rated continuous current in Table 4, with the contacts at ambient temperature for both measurements. The resistance increase shall be less than 20 %. If the increase exceeds 20 % then the continuous current test according to 7.4.3.2 shall be performed.

#### 7.9.4 Environmental tests

##### 7.9.4.1 General

Heating elements, if any, shall be ready to operate except where otherwise stated.

The following tests are independent type tests.

Auxiliary and control circuits shall be energised and shall remain in the operating condition during and after the test until the functional checks have been performed. At the end of the test duration, except for the vibration response test, auxiliary and control circuits shall be checked to ascertain whether they are capable of functioning in accordance with their design intent.

If other environmental tests than indicated under 7.9.4 are requested, due to special environmental conditions, then these tests should be performed according to IEC 60068-2 (all parts) [13] where applicable.

##### 7.9.4.2 Cold test

A cold test shall be performed according to test Ad of IEC 60068-2-1:2007, under the service conditions specified in Clause 4. The test temperature shall be the minimum ambient air temperature and the test duration shall be 16 h.

##### 7.9.4.3 Dry heat test

A dry heat test shall be performed according to test Be of IEC 60068-2-2:2007 according to the configuration of auxiliary circuits, under the service conditions specified in Clause 4. The test temperature shall be the maximum ambient air temperature and the test duration shall be 16 h.

##### 7.9.4.4 Cyclic humidity test

A cyclic humidity test shall be performed according to test Db of IEC 60068-2-30:2005. The upper temperature shall be the maximum ambient air temperature specified in Clause 4 and the number of temperature cycles shall be two. Variant 2 may be used for the temperature fall

period and recovery shall take place under standard atmospheric conditions. No special precautions shall be taken regarding the removal of surface moisture.

#### **7.9.4.5 Vibration tests**

Vibrations due to operation of the associated switchgear or controlgear are checked as follows.

- A test is performed according to IEC 60255-21-1:1988. Vibration response test parameters are those corresponding to severity class 1;
- or the auxiliary and control equipment assembly is subjected to the relevant mechanical endurance tests in the complete switchgear and controlgear.

The auxiliary and control circuits shall withstand the vibration response test without permanent damage. After the test, it shall still be fully operational. Temporary loss of parts of the functionality is permitted during the test according to criteria stated in Table 13.

#### **7.9.4.6 Condition check**

The power-frequency voltage withstand tests according to 7.9.5 shall be performed after each type test, to confirm that there has been no reduction of performance during testing.

In the case the type tests of 7.9.4 are performed as test sequence on the same test object, this condition check may be performed only once at the end.

#### **7.9.5 Dielectric test**

Auxiliary and control circuits of switchgear and controlgear shall be subjected to short-duration power-frequency voltage withstand tests. Each test shall be performed:

- a) between the auxiliary and control circuits connected together as a whole and the frame of the switching device;
- b) if practicable, between each part of the auxiliary and control circuits, which in normal use can be insulated from the other parts, and the other parts connected together and to the frame.

The power frequency tests shall be performed according to IEC 61180. The test voltage shall be 2 kV with duration of 1 min.

A DC test is acceptable by agreement of the manufacturer, the test voltage shall be 2,8 kV, with a duration of 1 min.

The auxiliary and control circuits of switchgear and controlgear shall be considered to have passed the tests if no disruptive discharge occurs during each test.

If motors and other devices such as electronic equipment used in the auxiliary and control circuits have already been tested in accordance with their own specification, they shall be disconnected for these tests.

### **7.10 X-radiation test for vacuum interrupters**

#### **7.10.1 General requirements**

##### **7.10.1.1 Condition of interrupter to be tested**

Tests on the X-radiation emission levels shall be performed on new vacuum interrupters.

There is no requirement to test switchgear and controlgear for X-radiation emission, where the vacuum interrupter type has been successfully tested as a component.

### 7.10.1.2 Mounting of specimen

The interrupter shall be mounted in a test fixture, designed so that the open contact spacing can be set at the minimum distance when installed in the switchgear and controlgear. Interrupters designed for operation in an insulating medium other than air (such as oil or SF<sub>6</sub>) may be tested in such a medium, if necessary, to withstand the test voltage.

The container for the insulating medium shall be of an insulating material having radiation attenuation no greater than that afforded by 9,5 mm thick methyl methacrylate. The insulating medium between the interrupter and radiation survey instrument shall be the minimum required for dielectric purposes.

### 7.10.1.3 Radiation survey instrument

A radiofrequency shielded radiation survey instrument having the following minimum specifications shall be used.

- accuracy: capable of measuring from 5 µSv/h up to 150 µSv/h with an accuracy of ±25 % along this range and with a response time not to exceed 15 s;
- energy response range: at least 25 keV to 0,5 MeV.

NOTE The selection of the radiation survey measuring instrument is related to the test voltage and sensitivity of the detector across the specified energy response range.

### 7.10.1.4 Location of radiation survey instrument

The sensing element of the radiation survey instrument shall be positioned in the plane of the separable contacts and pointed at the contacts. The preferred distance between the measuring instrument and the wall of the vacuum interrupter is 1 m. However, any distance up to 15 m may be used in which case the instrument reading shall be adjusted by applying the inverse square law as follows:

$$R(1\text{ m}) = R(d) \times d^2 \quad (3)$$

where  $R(d)$  is the radiation level measured, at the distance  $d$  (in m) from the external surface of the vacuum interrupter.

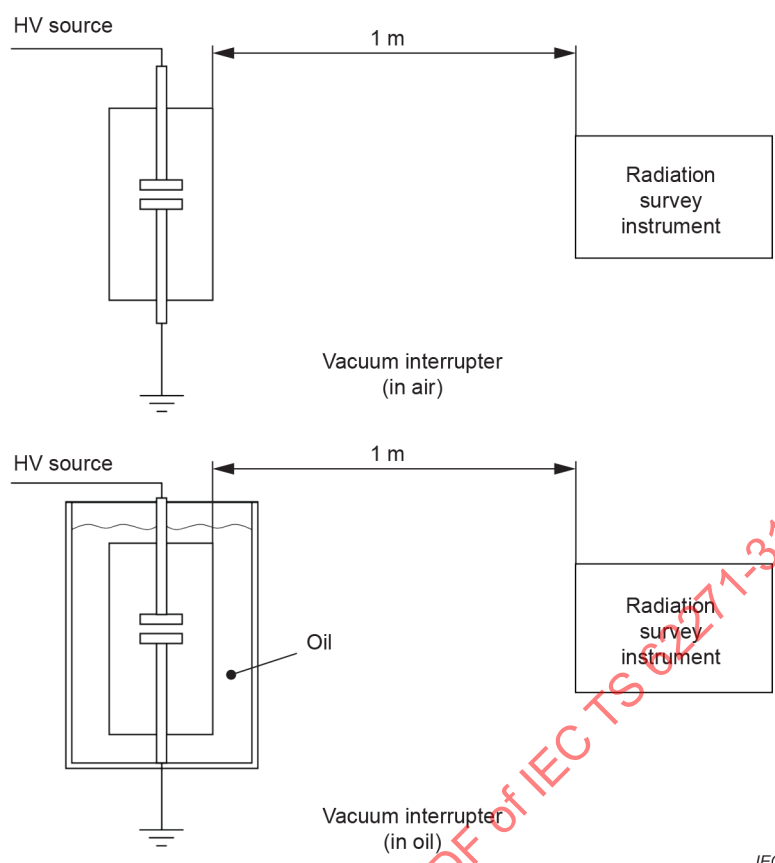


**Figure 7 – Test location of radiation survey instrument**

### 7.10.2 Test voltage and measurement procedure

With the interrupter mounted in a test fixture, with the contacts blocked open at the minimum contact spacing specified, and with the radiation survey instrument in place (refer to Figure 7), a voltage shall be applied across the interrupter contacts equal the rated direct voltage  $U_{rd}$  of the switchgear and controlgear. After a minimum of 15 s, the X-radiation level on the radiation survey instrument shall be according to 7.10.3.

Next, the voltage across the interrupter contacts shall be raised to a value equal to the rated direct withstand voltage  $U_{dd}$  shown in Table 1 as appropriate. After a minimum of 15 s, the X-radiation level on the radiation survey instrument shall be recorded in the test report.

### 7.10.3 Acceptance criteria

The X-radiation emitted from vacuum interrupters shall not exceed 5  $\mu\text{Sv/h}$  at 1 m distance at the rated direct voltage  $U_{rd}$ .

For vacuum interrupters used in switchgear and controlgear that have a rated direct withstand voltage less than or equal to 240 kV, the X-radiation emitted at the rated direct withstand voltage  $U_{dd}$  shall not exceed 150  $\mu\text{Sv/h}$  at 1 m distance.

For vacuum interrupters in switchgear and controlgear that have a rated direct withstand voltage greater than 240 kV, the X-radiation emitted at the rated direct withstand voltage  $U_{dd}$  shall be measured. If the measured value exceeds 150  $\mu\text{Sv/h}$  at 1 m distance, then the actual value shall be declared by the manufacturer.

NOTE 1 The declared value can be used to develop a safe working environment in accordance with local regulations when performing a power frequency withstand test across open contact gaps of vacuum interrupters.

NOTE 2 The test duration can be longer than the voltage applied time in actual use.

**7.101 Verification of making and breaking capacities**

Switching devices forming part of the main circuit of DC GIS shall be tested to verify their rated making and breaking capacities according to the relevant documents (IEC TS 62271-313, IEC TS 62271-314, IEC TS 62271-315) and under the proper conditions of installation and use, i.e. they shall be tested as normally installed in the DC GIS with all associated components, the arrangement of which can influence the performance, such as connections, supports, etc.

NOTE In determining which associated components are likely to influence the performance, special attention can be given to mechanical forces due to short-circuiting, to the possibility of disruptive discharges, etc. It is recognized that, in some cases, such influences can be quite negligible.

**7.102 Mechanical and environmental tests****7.102.1 General**

Switching devices of DC GIS shall be submitted to mechanical operation and environmental tests in accordance with their relevant documents (IEC TS 62271-313, IEC TS 62271-314, IEC TS 62271-315) and shall be tested in a representative assembly of all associated components, which can influence the performance, including auxiliary devices. All equipment shall withstand the stresses caused by the operation of switching devices.

**7.102.2 Mechanical operation test at ambient temperature**

Before and after the mechanical operation tests, the measurement of gas tightness according to 7.7 shall be performed to show that the leakage rate is not changed by influences caused by the mechanical type tests.

All switching devices fitted with interlocks shall be submitted to 5 operating cycles in order to check the operation of the associated interlocks. Before each operation the interlocks shall be set in the position intended to prevent the operation of the switching devices and one attempt shall then be made to operate each switching device. During these tests only normal operating forces shall be employed and no adjustment shall be made to the switching devices or interlocks.

**7.102.3 Low- and high-temperature test**

Operation tests at minimum and maximum temperature shall be performed in accordance with the relevant apparatus documents.

**7.103 Proof tests for enclosures****7.103.1 General**

Proof tests are made when the strength of the enclosure or parts thereof is not calculated. They are performed on individual enclosures before the internal parts are added with testing conditions based on the design pressure stresses.

Proof tests can take the form of either a destructive or a non-destructive pressure test, as appropriate to the material employed. For further information, see EN 50052 [5], EN 50064 [6], EN 50068 [7], EN 50069 [8].

**7.103.2 Burst test procedure**

The pressure rise shall not be greater than 400 kPa/min.

The pressure test requirements shall be at least as follows:

Cast aluminium and composite aluminium enclosures

- type test pressure =  $[ 3,5 / 0,7 ] \times \text{design pressure}$

NOTE The value 0,7 has been included to cover the possible variability of production castings. This factor can be increased to 1,0 if it can be justified by special material tests.

#### Welded aluminium and welded steel enclosures

- type test pressure =  $[(2,3 / \nu) \times (\sigma_t / \sigma_a)] \times \text{design pressure}$

where

$\nu$  is the welding coefficient (1 for ultrasonic or radiography inspection of 10 % of welded section and 0,75 for visual inspection);

$\sigma_t$  is the permissible design stress at test temperature;

$\sigma_a$  is the permissible design stress at design temperature.

These factors are based on the minimum certified properties of the material used.

Additional factors can be used taking into account the methods of construction.

Any enclosure remaining intact after these pressures have been reached shall not be used for normal operation.

#### 7.103.3 Strain measurement test

In the case of a non-destructive pressure test using a strain indication technique, the following procedure shall be applied:

Before the test, strain gauges capable of indicating strains to  $5 \times 10^{-5}$  mm/mm shall be affixed to the surface of the enclosure. The number of gauges, their position and their direction shall be chosen so that principal strains and stresses can be determined at all points of importance to the integrity of the enclosure.

Hydrostatic pressure shall be applied gradually in steps of approximately 10 % until the routine test pressure for the expected design pressure (see 8.101) is reached or significant yielding of any part of the enclosure occurs.

When either of these points is reached, the pressure shall not be increased further.

Strain readings shall be taken during the increase of pressure and repeated during pressure decrease.

Indication of localized permanent set can be disregarded provided there is no evidence of general distortion of the enclosure.

If the curve of the strain/pressure relationship show a non-linearity, the pressure can be re-applied not more than five times until the loading and unloading curves corresponding to two successive cycles substantially coincide. If coincidence is not attained, the design pressure and the test pressure shall be taken from the pressure range corresponding to the linear portion of the curve obtained during the final unloading.

If the routine test pressure is reached within the linear portion of the strain/pressure relationship, the expected design pressure shall be considered to be confirmed.

If the final test pressure or the pressure range corresponding to the linear portion of the strain/pressure relationship (see above) is less than the routine test pressure, the design pressure shall be calculated from the following equation:

$$p = \frac{1}{1,1k} \left( p_y \frac{\sigma_a}{\sigma_t} \right)$$

where

$p$  is the design pressure;

$p_y$  is the pressure at which significant yielding occurs or the pressure range corresponding to the linear portion of the strain/pressure relationship of the most highly strained part of the enclosure during final unloading (see above);

$k$  is the routine test pressure factor (see 8.101);

$\sigma_t$  is the permissible design stress at test temperature;

$\sigma_a$  is the permissible design stress at design temperature.

#### 7.104 Pressure test on partitions

The purpose of this test is to demonstrate the safety margin of the partition submitted to pressure in service condition. For further information see EN 50089 [18].

The partitions shall be installed as for the maintenance condition. The pressure shall rise at a rate of not more than 400 kPa/min.

The bursting pressure shall be three times the design pressure.

#### 7.105 Test under conditions of arcing due to an internal fault

Evidence of performance according to 6.103.2 shall be demonstrated by the manufacturer when required by the user.

Evidence can consist of a test or calculations based on test results performed on a similar arrangement or a combination of both.

If such a test is required, the procedure shall be in accordance with the methods described in Annex A.

NOTE Information about experience of internal arc tests and calculation principles are present in CIGRE Technical Brochure 602 [2], CIGRE Session 1998 – WG 21/23/33-03 [3] and RGE: 04/82 [4].

For the convenience of testing, alternating test current can be used alternatively. In such a case, the RMS value of the alternating current shall be not less than the rated short-time withstand direct current as defined in IEC TS 62271-5. The test duration can be one of the preferred values of short-circuit duration given in IEC TS 62271-5:2024, 5.5. The test duration can be reduced to 0,3 s by increasing the test current to reach the equivalent Joule integral value according to Table 2.

#### 7.106 Insulator tests

##### 7.106.1 General

Tests on insulators (partitions and support insulators) shall be performed as in 7.106.2 and 7.106.3.

### 7.106.2 Thermal performance

The thermal performance of each insulator design shall be verified by subjecting five insulators to ten thermal cycles each. Temperature values should be chosen according to Table 1.

The thermal cycle shall be as follows:

- a) 4 h at minimum ambient air temperature (for example  $-40\text{ }^{\circ}\text{C}$ );
- b) 2 h at room temperature;
- c) 4 h at limit of temperature according to Table 10 row 7 of IEC TS 62271-5:2024 (for example  $+105\text{ }^{\circ}\text{C}$ );
- d) 2 h at room temperature.

Insulators for DC GIS are considered electrical insulation system (EIS) according to IEC 60085:2007. The upper limit temperatures defined in IEC TS 62271-5 are therefore applicable for the EIS and not for the electrical insulation material (EIM).

The given thermal cycle times do not include the necessary transition times to reach the stable end temperatures of steps a), b), c) and d).

After the test sequence, all insulators shall be tested in accordance with routine tests 8.2, 8.6 and 8.104.

### 7.106.3 Tightness test for partitions

An overpressure withstand test shall be performed as described:

The design pressure of the partition shall be applied on one side of the partition while the adjacent compartment is under vacuum to verify the tightness of a partition. Alternatively, the pressure on one side of the partition shall be the design pressure of the partition plus 1 bar while the adjacent compartment is at 1 bar. The pressure in both compartments shall be measured over a period of 24 h.

Precautions shall be taken during test, as the test pressure across the partition is higher than the design pressure of the partition.

At the end of the test, no damage shall be observed on the partition. A gas tightness test shall be performed in accordance with 7.7. The relative leakage rate shall not be greater than the defined value prescribed in 6.16.

## 7.107 Corrosion test on earthing connections

### 7.107.1 General

For outdoor application, or on user's request, a corrosion proof test shall be performed in accordance with this subclause.

The tested sub-assemblies shall be representative of a DC GIS arrangement, including the devices providing electrical continuity and earthing of the enclosure, flanges of enclosures which can be part of the earthing system, the accessories (pressure monitoring device) and the secondary system as described in 15.7 of IEC TR 62271-306:2012 and IEC TR 62271-306:2012/AMD1:2018.

Testing of one representative earthing connection is considered to be sufficient.

**7.107.2 Test procedure**

The tested sub-assembly shall be submitted to environmental testing Ka (salt mist) according to IEC 60068-2-11. The duration of the test is 168 h.

In addition, for painted surfaces, the resistance to humid atmospheres containing sulphur dioxide shall be tested according to ISO 22479.

NOTE The CIGRE working group WG B3.57 is working on lifetime management of outdoor DC GIS [19]. The recommendations of this CIGRE guide can be considered.

**7.107.3 Criteria to pass the test**

The resistance of the earthing of the enclosure, measured according to 7.3.1, shall not increase more than 20 % after this test.

After the test, the dismantling of the assemblies shall not be affected. The degree of corrosion, if any, should be indicated in the test report. If the surfaces are painted, no trace of degradation shall be noticed.

**7.108 Corrosion tests on sealing systems of enclosures and auxiliary equipment****7.108.1 General**

On user's request, a corrosion proof test shall be performed in accordance with this subclause.

The tested sub-assemblies shall be representative of a DC GIS arrangement, including the enclosures, auxiliary equipment (gas filling valves, viewports, pressure monitoring device, pressure relief device, UHF sensor, etc.) and sealing systems (including dynamic sealings of switching devices) as described in 15.7 of IEC TR 62271-306:2012 and IEC TR 62271-306:2012/AMD1:2018.

**7.108.2 Test procedure**

The tested sub-assembly shall be submitted to environmental testing Ka (salt mist) according to IEC 60068-2-11. The duration of the test is 168 h.

After the corrosion tests a gas tightness test shall be performed in accordance with 7.7.

**7.108.3 Criteria to pass the test**

- The relative leakage rate in the gas tightness test shall not be greater than the defined value prescribed in 6.16.
- Visual inspection of flanges and sealing systems. If corrosion is observed, it shall be documented in the test report.
- The degree of corrosion, if any, should be indicated in the test report.

NOTE The CIGRE working group WG B3.57 is working on lifetime management of outdoor DC GIS [19]. The recommendations of this CIGRE guide can be considered.

**8 Routine tests****8.1 General**

The routine tests are for the purpose of revealing faults in material or construction. They do not impair the properties and reliability of a test object. The routine tests shall be made wherever reasonably practicable at the manufacturer's' works on each apparatus manufactured. By agreement, any routine test may be made on site.

The routine tests given in this document comprise:

- a) dielectric test on the main circuit in accordance with 8.2;
- b) tests on auxiliary and control circuits in accordance with 8.3;
- c) measurement of the resistance of the main circuit in accordance with 8.4;
- d) tightness test in accordance with 8.5;
- e) design and visual checks in accordance with 8.6.

Additional routine tests can be specified in the relevant IEC standards.

When switchgear and controlgear is not completely assembled before transport, separate tests shall be made on all transport units. In this event, the manufacturer shall demonstrate the validity of this test (for example, leakage rate, test voltage, resistance of part of the main circuit).

Test reports of the routine tests are not required unless otherwise agreed upon between the manufacturer and the user.

For routine tests technical grade SF<sub>6</sub> and its mixtures in accordance with IEC 60376 or used SF<sub>6</sub> and its mixtures in accordance with IEC 60480, can be used. See 6.2.

If the DC GIS is designed to use any other gas than SF<sub>6</sub>, the necessary technical grade and the characteristics of the gas / gas mixture used for the routine testing shall be defined and documented by the manufacturer of the DC GIS and documented in the routine test reports.

The routine tests shall be performed on all components of a DC gas-insulated metal-enclosed switchgear and its controlgear. Depending on the nature of tests, some tests can be performed on components, transport units or on the complete installation.

The following routine tests shall be carried out:

|                                                                                   | Subclause |
|-----------------------------------------------------------------------------------|-----------|
| a) Dielectric test on the main circuit                                            | 8.2       |
| b) Tests on auxiliary and control circuits                                        | 8.3       |
| c) Measurement of the resistance of the main circuit                              | 8.4       |
| d) Tightness test                                                                 | 8.5       |
| e) Design and visual checks                                                       | 8.6       |
| f) Pressure tests of enclosures                                                   | 8.101     |
| g) Mechanical operation tests                                                     | 8.102     |
| h) Tests on auxiliary circuits, equipment and interlocks in the control mechanism | 8.103     |
| i) Pressure test on partitions                                                    | 8.104     |

## 8.2 Dielectric test on the main circuit

It is preferred to carry out the test at short-duration AC power-frequency voltage. Alternatively, a dry, short-duration direct voltage test may be applied. The test duration shall be 1 min. The test procedure shall be according to IEC 60060-1 and to 7.2, except that each pole or transport unit shall be tested. For sealed pressure systems, the test shall be made at the filling pressure for insulation.

The test voltage shall be the rated direct withstand voltage divided by  $\sqrt{2}$  for AC power-frequency tests or the rated direct withstand voltage for DC tests. The rated direct withstand voltages are specified in column 3 of Table 1.

When the insulation of switchgear and controlgear is provided only by solid-core insulators and air at ambient pressure, the voltage withstand test may be omitted if the dimensions between the conductive parts – across open switching devices and between conductive parts and the frame – are checked by dimensional measurements.

Bases for the checking of dimensions are the dimensional (outline) drawings, which are part of the type test report (or are referred to in it) of the particular switchgear and controlgear. Therefore, in these drawings all information necessary for dimensional checking including the permissible tolerances shall be given.

The tests shall be performed at the minimum functional pressure for insulation  $p_{me}$ .

### **8.2.101 Alternating or direct voltage tests on the main circuit**

The alternating or direct voltage test of DC GIS shall be performed according to the requirements in 7.2.6.1 or 7.2.7.1 to earth, between poles (if applicable) and across the open switching devices. The voltage test across the open switching device can be carried out from one side of the switching device.

The test voltage shall be the rated direct withstand voltage divided by  $\sqrt{2}$  for alternating voltage test or the rated direct withstand voltage for direct voltage test. The rated direct withstand voltages are specified in column 3 of Table 1 in IEC TS 62271-5:2024.

The test voltage shall be raised for each test condition to the test value and maintained for 1 min.

### **8.2.102 Partial discharge measurement**

The measurement of partial discharges shall be performed to detect possible material and manufacturing defects.

Partial discharge tests shall be performed in accordance with 7.2.10.

The measurement of partial discharges shall be performed with dielectric tests after mechanical routine tests.

The test shall be carried out on all components of a switchgear and controlgear. It can be performed on the complete switchgear and controlgear, if applicable, or on transport units or on individual components. Tests on simple components containing no solid insulation can be excepted.

## **8.3 Tests on auxiliary and control circuits**

### **8.3.1 Inspection of auxiliary and control circuits, and verification of conformity to the circuit diagrams and wiring diagrams**

The nature of the materials, the quality of assembly, the finish and, if necessary, the protective coatings against corrosion shall be checked. A visual inspection is also necessary to check the satisfactory installation of the thermal insulation, if any.

A visual inspection of actuators, interlocks, locks, etc., shall be made.

Components for auxiliary and control circuits inside enclosures shall be checked for proper mounting. The location of the means provided for connecting external wiring shall be checked to ensure that there is sufficient wiring space for spreading of the cores of multi-core cables and for the proper connection of the conductors.

The conductors and cables shall be checked for proper routing. Special attention shall be given to ensure that no mechanical damage can occur to conductors and cables due to the proximity of sharp edges or heating elements, or to the movement of moving parts.

Furthermore, the identification of components and terminals and, if applicable, the identification of cables and wiring shall be verified. In addition, the conformity of auxiliary and control circuits to the circuit diagrams and wiring diagrams shall be checked.

### 8.3.2 Functional tests

Functional tests are specified, where relevant, in the relevant IEC product standards. When specified, they shall be made on all auxiliary and control circuits to verify the proper functioning of auxiliary and control circuits in conjunction with the other parts of the switchgear and controlgear. The test procedures depend on the nature and the complexity of the auxiliary and control circuits of the device.

Operation tests on auxiliary and control circuits, subassemblies and components may be omitted if they have been fully tested during a test applied to the whole switchgear and controlgear.

### 8.3.3 Verification of protection against electrical shock

Protection against direct contact with the main circuit and safe accessibility to the auxiliary and control equipment parts liable to be touched during normal operation shall be checked. The preferred method is by visual inspection.

Where visual inspection cannot provide confirmation of the electrical continuity of earthed metallic parts, the alternative procedure defined in 7.3.3 shall be applied.

### 8.3.4 Dielectric tests

Only power frequency tests shall be performed. This test shall be made under the same conditions as those detailed in 7.9.5.

The test voltage shall be 1 kV with duration of 1 s.

## 8.4 Measurement of the resistance of the main circuit

This subclause is only applicable for mechanical switch parts.

For the routine test, the direct voltage drop or resistance of the main circuit shall be measured under conditions as nearly as possible similar, with regard to ambient air temperature and points of measurement, to those under which the corresponding measurement before the continuous current test was made. The test current shall be within the range stated in 7.3.4.

The measured resistance shall not exceed  $1,2 \times R_u$ , where  $R_u$  is equal to the resistance measured before the continuous current test.

In the case of assemblies, it is possible to calculate the expected resistance based on relevant type tests.

Overall measurements are made on sub-assemblies or, on transport units in the factory. Overall measurements shall be made in such a way that comparison with measurement taken on-site after installation, during maintenance or repair of the installation is possible.

## 8.5 Tightness test

The tightness test shall be performed at filling pressure for insulation  $p_{re}$ , when the detection method is by sniffing device.

The maximum relative leakage rate  $F_{rel}$  of each compartment under the standardized ambient temperature of 20 °C shall be 0,5 % per year (independent on type of gas and size of gas compartment).

NOTE The commonly used test method for gas-filled systems tested in factory and on-site is the probing test using a sniffing device with the minimum sensitivity mentioned in IEC TS 62271-5:2024, 8.5.3. If a leak is detected, the test is considered failed, and the test object will be repaired, or the leak will be quantified by using a cumulative method. Leakage rate below 0,5 % per year per gas compartment are not always easily possible to verify using the probing test method.

### 8.5.1 General

Routine tests shall be performed to demonstrate the tightness criteria according to 6.16 at ambient temperature with the switchgear parts, components or subassemblies at or above the minimum functional pressure (or density) for insulation.

### 8.5.2 Controlled pressure systems for gas

The test procedure corresponds to 7.7.2.

### 8.5.3 Closed pressure systems for gas

The test may be performed at different stages of the manufacturing process or of assembling on site, on parts, components and subassemblies.

For parts or subassemblies tested in factory, the cumulative test is the preferred method.

For gas-filled systems tested in factory, the probing test using a sniffing device may be used. If any leak is detected, the test shall be considered to be failed or the leak shall be quantified by using a cumulative method.

For routine tests at site, the probing test using a sniffing device is the preferred method.

The sensitivity of the sniffing device shall be at least  $10^{-8} \text{ Pa} \times \text{m}^3/\text{s}$ .

### 8.5.4 Sealed pressure systems

Depending on the insulation medium two situations are considered:

#### a) Switchgear and controlgear using gas

The preferred test procedure corresponds to 7.7.4, item a).

An alternative test procedure corresponds to the sealing tracer gas test with mass spectrometer, refer to IEC 60068-2-17:1994.

#### b) Switchgear and controlgear using vacuum interrupters

The vacuum tightness shall be demonstrated by a dielectric test according to 7.2.11 carried out after the mechanical routine test specified in the relevant product standards.

### 8.5.5 Liquid tightness tests

Routine tests shall be performed at normal ambient air temperature with the completely assembled switchgear and controlgear device. Testing of subassemblies is also permissible. In this case, a final check shall be performed at site.

The test methods correspond to those of the type tests (refer to 7.7.5).

## 8.6 Design and visual checks

The switchgear and controlgear shall be checked to verify its compliance with the purchase specification, if any.

### 8.101 Pressure tests of enclosures

Pressure tests shall be made on enclosures after complete machining.

The standard test pressure shall be  $k$  times the design pressure, where the factor  $k$

- is 1,3 for welded aluminium and welded steel enclosure,
- is 2 for cast aluminium and composite aluminium enclosures.

The test pressure shall be maintained for at least 1 min.

No rupture or permanent deformation should occur during this test.

### 8.102 Mechanical operation tests

Operation tests are made to ensure that the switching devices comply with the prescribed operating conditions and that the mechanical interlocks work properly.

Switching devices of DC GIS shall be submitted to a mechanical routine test in accordance with their relevant documents. The mechanical routine tests can be made before or after assembly of transport units.

In addition, all switching devices fitted with mechanical interlocks shall be submitted to five operating cycles in order to check the operation of the associated interlocks. Before each operation one attempt shall be made to operate each switching device as specified in 7.102.

NOTE Mechanical interlocks can be checked on-site depending on the size of delivered transport components.

During these tests, which are performed without voltage on, or current in, the main circuits, it shall be verified in particular that the switching devices open and close correctly within the specified limits of the supply voltage and pressure of their operating devices.

### 8.103 Tests on auxiliary circuits, equipment and interlocks in the control mechanism

All auxiliary equipment shall be tested either by a functional operation or by verification of the continuity of wiring. Settings relays or sensors shall be checked.

The electrical, pneumatic and other interlocks, together with control devices having a predetermined sequence of operations, shall be tested five times in succession in the intended conditions of use and operation and with the most unfavourable limit values of auxiliary supply. During the test, no adjustment shall be made.

The tests are considered to be satisfactory if the auxiliary devices have operated properly, if no effect on the entire operating unit can be visually determined after the tests and if the force to operate the switching device is practically the same before and after the tests.

### 8.104 Pressure test on partitions

Each partition shall be subjected to a pressure test at twice the design pressure for 1 min.

For the pressure test the partition shall be secured in exactly the same manner as in service.

The partition shall not show any sign of overstress or leakage.

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

### 9.1 General

Clause 9 gives general guidance on the appropriate selection of ratings and parameters depending on the application to be covered by high-voltage switchgear and controlgear. A summary of the considerations for specifying the ratings of switchgear and controlgear is provided in Annex L (informative).

Annex D provides a summary of the considerations for specifying ratings of switchgear and controlgear.

NOTE IEEE C37.122.1 [20] and CIGRE Technical Brochure 125 [21] describe the general guideline for the selection of a AC gas-insulated metal-enclosed switchgear above 52 kV and of 72,5 kV and above, respectively. Some of them can also be referred to a DC GIS.

### 9.2 Selection of rated values

The rated values should be chosen in accordance with this document having regard for the characteristics of the system as well as its anticipated future system development. A list of ratings is given in Clause 5.

For most of the rated voltages, several rated insulation levels exist to allow for application of different performance criteria or overvoltage patterns. The choice should be made considering the degree of exposure to fast-front and slow-front overvoltage, the type of earthing of the system and the type of overvoltage limiting devices. Other parameters, such as local atmospheric and climatic conditions and the use at altitudes exceeding 1 000 m, should also be considered.

The duty imposed by fault conditions should be determined by calculating the fault currents at the place where the switchgear and controlgear is located in the system.

The rated values should be chosen in accordance with Clause 5 of this document.

### 9.3 Cable-interface considerations

For connection to cables, the maximum temperature at the terminals at full continuous current should be below the temperature limits of the cable insulation and cable termination.

### 9.4 Continuous or temporary overload due to changed service conditions

Equipment could be required to carry a load current above its rated continuous current during a short period of time or when ambient temperatures are favourable to do it provided the temperature does not exceed the maximum temperature value specified in Table 10; reference is made to IEC TR 62271-306 [62].

NOTE For certain switching devices the temporary overload could result in a load current that exceeds their switching capability.

### 9.5 Environmental aspects

#### 9.5.1 Service conditions

Selected switchgear and controlgear and its associated operating devices and auxiliary equipment should be designed and validated to comply with at least the specific service conditions required by the user or appropriate arrangements should be made.

### 9.5.2 Clearances affected by service conditions

Where clearances can be compromised by environmental related changes in the service access level (for example accumulation of snow, sand, etc.) the use of increased clearances should be considered.

### 9.5.3 High humidity

For the normal service conditions present in 4.1.2 e), condensation can occasionally occur on, or in, indoor switchgear and controlgear.

To withstand the effects of high humidity and condensation, such as breakdown of insulation or corrosion of metallic parts, switchgear designed for such conditions should be used.

Condensation can be prevented by special design of the building or housing, by suitable ventilation and heating of the station or by the use of dehumidifying equipment. Other options include heaters with thermostats/humidistat inside the switchgear.

High humidity can also be due to ground level rainwater or for cable-connected applications of underground network applications from incoming cable raceways connected to switchgear.

### 9.5.4 Solar radiation

Under certain levels of solar radiation, appropriate measures, for example roofing, forced ventilation etc., should be taken, or derating can be used, in order not to exceed the specified temperature and pressure rise limits. Tests with simulated solar gain can be used to demonstrate if measures or derating are required.

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

### 10.1 General

The intention of this clause is to define information, which is necessary to enable the user to make an appropriate enquiry for equipment and to enable the supplier to give an adequate tender.

Furthermore, it enables the user to make a comparison and evaluation of offers from different suppliers.

NOTE The supplier can either be a manufacturer or a contractor.

When enquiring about or ordering an installation of switchgear and controlgear the following information as a minimum should be supplied by the enquirer.

Annex L (informative) provides similar information items in a tabular form for ease of use.

Annex D defines, in tabular format, technical information to be exchanged between user and supplier.

### 10.2 Information with enquiries and orders

The following information listed below, if applicable, should be given by the enquirer / user.

a) Particulars of the system as defined in Clause 3:

Nominal and highest voltage, normal current and maximum fault current. Unusual characteristics of the system in which the equipment to be installed should be noted;

b) Service conditions if different from normal (refer to Clause 4):

Any condition deviating from the normal service conditions or affecting the satisfactory operation of the equipment.

In this case high-voltage switchgear and controlgear and associated operating devices and auxiliary equipment should be designed and validated to comply with any special service conditions required by the user, or appropriate arrangements should be made.

c) Particulars of the installation and its components:

- 1) indoor or outdoor installation;
- 2) unidirectional or bidirectional;
- 3) number of busbars, as shown in the single-line diagram;
- 4) rated direct voltage;
- 5) rated insulation level ( $U_{dd}$ ,  $U_p$ ,  $U_s$  when applicable);
- 6) rated continuous currents of busbars and feeder circuits;
- 7) rated short-time withstand direct current ( $I_{kd}$ );
- 8) rated peak withstand current ( $I_{pd}$ );
- 9) rated duration of short-circuit ( $t_{kd}$ ) (if different from the preferred values given in 5.5.4);
- 10) rated values of components (e.g. for DCVTs or DCCTs in an assembly, for individual functional units of an assembly.);
- 11) degree of protection for the enclosure and partitions;
- 12) circuit diagrams.

d) Particulars of the operating devices:

- 1) type of operating devices;
- 2) rated supply voltage (if any);
- 3) rated supply frequency (if any);
- 4) rated supply pressure (if any);
- 5) special interlocking requirements;
- 6) number of available auxiliary contacts required (the user should state the contact performance required).

In addition to these items the enquirer should indicate every condition which might influence the tender or the order; for example special mounting or installation conditions, the location of the external high-voltage connections or any specific rules for pressure vessels, requirements for cable testing and, if applicable, whether functionality shall be maintained after a seismic event or during and after a seismic event.

Information should be supplied if type test reports or any other conformity assessment related document are requested.

### 10.3 Information with tenders

The following information listed below, if applicable, should be given by the manufacturer with descriptive material and drawings.

a) Rated values and characteristics as enumerated in item c) of 10.2.

b) Constructional features, for example:

- 1) mass of the heaviest transport unit;
- 2) overall dimensions of the installation;
- 3) arrangement of the external connections;
- 4) future extensions if applicable;
- 5) facilities for transport and mounting;

- 6) mounting provisions;
  - 7) accessible sides;
  - 8) instructions for installation, operation and maintenance;
  - 9) type of gas-pressure or liquid-pressure system;
  - 10) filling level /pressure and minimum functional level / pressure;
  - 11) volume or mass of fluid for the different compartments;
  - 12) specification of fluid;
  - 13) number of units in series, or, in parallel;
  - 14) minimum clearance in air and safety boundaries in operation;
  - 15) any special arrangements (cooling system, for example) to maintain the rated characteristics of the equipment at the required temperatures of the ambient air.
- c) Particulars of the operating devices:
- 1) types and rated values as enumerated in item d) of 10.2;
  - 2) current or power for operation;
  - 3) operating times.
- d) List of recommended spare parts that should be procured by the user.
- e) Any other document or information requested in the enquiry.
- f) list of recommended tools that should be procured by the user.

## **11 Transport, storage, installation, operating instructions and maintenance**

### **11.1 General**

It is essential that the transport, storage and installation of switchgear and controlgear, as well as their operation and maintenance in service, is performed in accordance with instructions given by the manufacturer.

Consequently, the manufacturer shall provide the appropriate version of the instruction manual for the transport, storage, installation, operation and maintenance of switchgear and controlgear. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, operation and maintenance should be given by the time of delivery at the latest. It is preferable that the operation manual be a separate document from the installation and maintenance manual.

It is impossible, here, to cover in detail the complete rules for the installation, operation and maintenance of each one of the different types of apparatus manufactured, but the following information is given relative to the most important points to be considered for the instructions provided by the manufacturer.

### **11.2 Conditions during transport, storage and installation**

A special agreement should be made between manufacturer and user if the service conditions of temperature and humidity defined in the order cannot be guaranteed during transport, storage and installation. Special precautions can be essential for the protection of insulation during transport, storage and installation, and prior to energizing, to prevent moisture absorption due, for instance, to rain, snow or condensation. Vibrations during transport should be considered. Appropriate instructions should be given by the manufacturer.

Special packaging should be proposed by the manufacturer for long term storage of parts for maintenance needs according to customer specifications.

### **11.3 Installation**

#### **11.3.1 General**

For each type of switchgear and controlgear the instructions provided by the manufacturer shall include at least the items listed below.

#### **11.3.2 Unpacking and lifting**

Each complete equipment shall be provided with adequate lifting facilities and labelled (externally) to show the correct method of lifting. The equipment shall be labelled (externally) to indicate its maximum mass, in kg, when fully equipped. Special lifting devices shall be capable of lifting the mass of each transport unit and special precautions shall be detailed in the installation manual (for example lifting brackets/bolts that are not intended to be left outdoors shall be removed at site).

Required information for unpacking should be given.

#### **11.3.3 Assembly**

When the switchgear and controlgear is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the switchgear and controlgear.

#### **11.3.4 Mounting**

Instructions for the mounting of switchgear and controlgear, operating device and auxiliary equipment should include sufficient details of locations and foundations to enable site preparation to be completed.

These instructions should also indicate:

- the total mass of the apparatus inclusive of extinguishing or insulating fluids;
- the mass of extinguishing or insulating fluids;
- the mass of each unit to be lifted separately.

#### **11.3.5 Connections**

Instructions should include information on:

- connection of conductors, comprising the necessary advice to prevent overheating and unnecessary strain on the switchgear and controlgear and to provide adequate clearance distances;
- connection of auxiliary circuits;
- connection of liquid or gas systems, if any, including size and arrangement of piping;
- connection for earthing;
- auxiliary contacts available to the user.

#### **11.3.6 Information about gas and gas mixtures for controlled and closed pressure systems**

For controlled and closed pressure systems filled with gas mixture, the percentage of the different gases and their associated tolerances shall be defined by the manufacturer taking into account handling and uncertainty of measurement. Appropriate gas filling procedures are defined in IEC 62271-4.

During commissioning or maintenance, the maximum allowable humidity content within gas-filled switchgear and controlgear filled with gas at the filling pressure (density) for insulation shall be checked by dew point measurement. Appropriate correction factors shall be used for

measurements performed at temperatures other than 20 °C according to the manufacturer's instruction manual.

The maximum allowable humidity content for equipment filled or re-filled with new or used gas should be such that the dew point inside the switchgear compartment is not higher than

- -10 °C for equipment with adsorber material;
- -15 °C for equipment without adsorber material.

during commissioning or after maintenance for a measurement at filling pressure (density) for insulation and at 20 °C.

NOTE 1 These dew point values during commissioning are expected to give a dew point value lower than -5 °C during service life, for a measurement at 20 °C.

NOTE 2 The measurement of the dew point is specified at a given temperature due to the possible exchange of water between gas and solid materials when the temperature changes, which could change the measured value.

NOTE 3 An example of measurement and determination of the dew point is given in IEEE C37.122.5 [70].

### 11.3.7 Final installation inspection

Instructions should be provided for inspection and tests which should be made after the switchgear and controlgear has been installed and all connections have been completed.

These instructions should include:

- a schedule of recommended site tests to establish correct operation;
- procedures for carrying out any adjustment that can be necessary to obtain correct operation;
- recommendations for any relevant measurements that should be made and recorded to help with future maintenance decisions;
- a procedure for qualitative gas tightness test at site (sniffing test) on all field assembled connections for closed pressure systems, reference is made to 8.5.3;
- instructions for final inspection and putting into service.

Guidance for electromagnetic compatibility site measurements is given in Annex M (informative).

### 11.3.8 Basic input data by the user

These data should include:

- a) access limitations to the local site;
- b) local working conditions and any restrictions that can apply (for example, safety equipment, normal working hours, union requirements for supervisor, manufacturer's and local installation crew, etc.);
- c) availability and capacity of lifting and handling equipment;
- d) availability, number and experience of local personnel;
- e) specific pressure vessel rules and procedures that can apply during installation and commissioning tests;
- f) interface requirements for high-voltage cables and transformers;
- g) in the case of extensions to existing switchgear and controlgear:
  - 1) provisions for the extension available within existing primary and secondary equipment;
  - 2) in-service conditions or operating restrictions that apply;
  - 3) safety regulations that locally apply.

### 11.3.9 Basic input data by the manufacturer

These data should include:

- a) space necessary for installation and assembly;
- b) size and weight of components and testing equipment;
- c) site conditions regarding cleanliness and temperature for clean installation and preparation area;
- d) number and experience of local personnel required for installation;
- e) time and activity schedules for installation and commissioning;
- f) electric power, lighting, water and other needs for installation and commissioning;
- g) proposed training of installation and service personnel;
- h) in case of extension to existing switchgear and controlgear:
  - 1) out-of-service requirements of existing components related to the installation schedule;
  - 2) safety precautions.
- i) gas filling procedure (mixed gases) and dew point verification, if necessary.

### 11.4 Operating instructions

The operating instructions given by the manufacturer shall contain the following information:

- a general description of the equipment with particular attention to the technical description of its characteristics and operation so that the user has an adequate understanding of the main principles involved;
- a description of the safety features of the equipment and the operation of the interlocks and padlocking facilities;
- as relevant, a description of the action to be taken to manipulate the equipment for operation isolation, earthing, maintenance, and testing;
- as relevant, measures against corrosion should be given.

### 11.5 Maintenance

In case of leakage which cannot be easily repaired, temporary solutions for limiting or stopping this leakage and allowing continuity of service should be recommended by the manufacturer and agreed by the user until a repair is scheduled.

NOTE The direct voltage stress can cause charge accumulation on the surface of the insulating material of the bushings. This can lead to increased dirt accumulation. The maintenance of bushings is described in IEC/IEEE 65700-19-03:2014, 11.6. The subclause shows special precautions which need to be observed related to cleanliness of the surface.

#### 11.5.1 General

The effectiveness of maintenance depends mainly on the way instructions are prepared by the manufacturer and implemented by the user.

#### 11.5.2 Information about fluids and gas to be included in maintenance manual

Where applicable, the following information shall be provided by the manufacturer:

- a) type and required quantity and quality of liquid to be used in switchgear and controlgear;
- b) type and required quantity and quality of gas to be used in switchgear and controlgear.

### 11.5.3 Recommendations for the manufacturer

The manufacturer should be responsible for ensuring the continued availability of spare parts required for maintenance for a period of not less than 10 years from the date of final manufacture of the switchgear and controlgear.

The manufacturer should inform the purchasers of a particular type of switchgear and controlgear about corrective actions required by systematic defects and failures detected in service.

The manufacturer's maintenance manual should include the following information listed below.

- a) Extent and frequency of maintenance. For this purpose, the following factors should be considered:
    - 1) switching operations (current and number);
    - 2) total number of operations;
    - 3) time in service (periodic intervals);
    - 4) environmental conditions;
    - 5) activity after a seismic event (if applicable);
    - 6) measurements and diagnostic tests, (if any).
  - b) Detailed description of the maintenance work:
    - 1) recommended place for the maintenance work (indoor, outdoor, in factory, on site, etc.);
    - 2) procedures for inspection, diagnostic tests, examination, overhaul;
    - 3) reference to drawings;
    - 4) reference to part numbers;
    - 5) use of special equipment or tools;
    - 6) precautions to be observed (for example cleanliness and possible effects of harmful arcing by-products);
    - 7) lubrication procedures.
  - c) Comprehensive drawings of the details of the switchgear and controlgear important for maintenance, with clear identification (part number and description) of assemblies, subassemblies and significant parts.
- NOTE Expanded detail drawings which indicate the relative position of components in assemblies and subassemblies are a common illustration method.
- d) Limits of values, which can be measured during operation or routine maintenance and tolerances which, when exceeded, make corrective action necessary, for example:
    - 1) pressures, density levels, gas mixtures tolerance;
    - 2) insulating liquid or gas characteristics;
    - 3) quantities and quality of liquid or gas (see IEC 60480 and IEC 62271-4 for SF<sub>6</sub>);
    - 4) dew point inside gas-filled switchgear compartment according to 11.3.6;
    - 5) resistance and/or capacitance (of the main circuit);
    - 6) operating times;
    - 7) permissible erosion of parts subject to wear;
    - 8) torques;
    - 9) important dimensions.
  - e) Specifications for auxiliary maintenance materials, including warning of known non-compatibility of materials:
    - 1) grease;

- 2) oil;
  - 3) fluid;
  - 4) cleaning and degreasing agents.
- f) List of special tools, lifting and access equipment.
  - g) Tests after the maintenance work.
  - h) List of the recommended spare parts (description, reference number, quantities) and advice for storage.
  - i) Estimate of active scheduled maintenance time, carried out in accordance with an established time schedule.
  - j) How to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.

#### **11.5.4 Recommendations for the user**

If the user wishes to perform maintenance, the maintenance manual of the manufacturer should be followed.

The user should record the following information:

- the serial number and the type of the switchgear and controlgear;
- the date when the switchgear and controlgear is put in service;
- the results of all measurements and tests including diagnostic tests carried out during the life of the switchgear and controlgear;
- dates and extent of the maintenance work carried out;
- the history of service, periodical records of the operation counters and other indications (for example short-circuit operations);
- references to any failure report.

In case of failures and defects, the user should make a failure report and should inform the manufacturer by stating the special circumstances and measures taken. Depending upon the nature of the failure, an analysis of the failure should be made in collaboration with the manufacturer.

#### **11.5.5 Failure report**

The purpose of the failure report is to standardize the recording of the switchgear and controlgear failures with the following objectives:

- to describe the failure using a common terminology;
- to provide data for the user statistics;
- to provide a meaningful feedback to the manufacturer.

The following gives guidance on how to make a failure report.

A failure report should include the points listed below.

- a) Identification of the switchgear which failed:
  - 1) substation name;
  - 2) identification of the switchgear (manufacturer, type, serial number, ratings);
  - 3) switchgear technology (mechanical switching device, power electronic DC circuit-breaker, hybrid DC circuit-breaker, vacuum, SF<sub>6</sub>, gas mixture, etc.);
  - 4) location (indoor, outdoor);
  - 5) enclosure;

- 6) drive mechanism, if applicable (hydraulic, spring, motor, manual).
- b) History of the switchgear:
  - 1) date of commissioning of the equipment;
  - 2) date of failure/defect;
  - 3) total number of operating cycles, if applicable;
  - 4) date of last maintenance;
  - 5) details of any changes made to the equipment since manufacture;
  - 6) total number of operating cycles since last maintenance;
  - 7) condition of the switchgear when the failure/defect was discovered (in service, maintenance, etc.).
- c) Identification of the subassembly/component responsible for the primary failure/defect:
  - 1) high-voltage stressed components;
  - 2) electrical control and auxiliary circuits;
  - 3) drive mechanism, if applicable;
  - 4) other components.
- d) Stresses presumed to contribute to the failure/defect:
  - 1) operation mistake or misuse of the equipment;
  - 2) environmental conditions (temperature, wind, rain, snow, ice, pollution, lightning, etc.).
- e) Classification of the failure/defect:
  - 1) major failure;
  - 2) minor failure;
  - 3) defect.
- f) Origin and cause of the failure/defect:
  - 1) origin (mechanical, electrical, tightness if applicable);
  - 2) cause (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.);
  - 3) operation mistake or misuse.
- g) Consequences of the failure or defect:
  - 1) switchgear down-time, which is time interval during which an item is in a down state;
  - 2) time consumption for repair;
  - 3) labour cost;
  - 4) cost of spare parts.

A failure report can include the following information:

- drawings, sketches;
- photographs of defective components;
- single-line station diagram;
- operation and timing sequences;
- records or plots;
- references to maintenance or operating manuals.

**11.101 Tests after installation on-site****11.101.1 General**

After installation, and before being put into service, the DC GIS shall be tested in order to check the correct operation and the dielectric integrity of the equipment.

These tests and verifications comprise:

|                                                      | Subclause |
|------------------------------------------------------|-----------|
| a) dielectric tests on the main circuits             | 11.101.2  |
| b) dielectric tests on auxiliary circuits            | 11.101.3  |
| c) measurement of the resistance of the main circuit | 11.101.4  |
| d) gas tightness tests                               | 11.101.5  |
| e) checks and verifications                          | 11.101.6  |
| f) gas quality verifications                         | 11.101.7  |

To ensure minimum disturbance, and to reduce the risk of humidity and dust entering enclosures and thus preventing correct operation of the switchgear, no obligatory periodic inspections or pressure tests concerning the enclosures are specified or recommended when the DC GIS is in service. Reference shall be made, in any case, to the manufacturer's installation, operation and maintenance manuals.

The manufacturer and user should agree on a commissioning test plan for tests on-site.

**11.101.2 Dielectric tests on the main circuits****11.101.2.1 General**

Since it is especially important for DC GIS, the dielectric integrity shall be checked in order to eliminate fortuitous causes (wrong fastening, damage during handling, transportation, storage and installation, presence of foreign bodies, etc.) which might in the future give rise to an internal fault.

Because of their different purpose, these tests shall not replace the type tests or the routine tests carried out on the transport units and, as far as possible, in the factory. They are supplementary to the dielectric routine tests with the aim of checking the dielectric integrity of the completed installation and of detecting irregularities as mentioned above. Normally the dielectric test shall be made after the DC GIS has been fully installed and gas-filled at the filling density preferably at the end of all site tests, when newly installed. Such a dielectric test is also recommended to be performed after major dismantling for maintenance or reconditioning of compartments. These tests shall be distinguished by their progressive voltage increase, performed in order to achieve some form of electrical conditioning of the equipment before commissioning.

The execution of such site tests is not always practicable and deviations from the standard tests can be accepted. The aim of these tests is to offer a final check before energizing. It is very important that the chosen test procedure does not jeopardize sound parts of the DC GIS, see Clause B.3.

In choosing an appropriate test method for each individual case, a special agreement can be made in the interest of practicability and economy, considering the electrical power requirements and the dimensions and weight of the test equipment.

A detailed test programme for the dielectric tests on-site shall be agreed between manufacturer and user.

### 11.101.2.2 Test procedure

The DC GIS shall be installed completely and gas-filled at its filling density.

Some parts can be disconnected for the test, either because of their high charging current or because of their effect on voltage limitation, such as

- high voltage cables and overhead lines;
- main transformer,
- voltage transducers, and
- surge arresters.

NOTE In determining the parts which can be disconnected, attention is drawn to the fact that the reconnection can introduce faults after the tests are completed.

Every newly installed part of a DC GIS shall be subjected to a dielectric test on-site.

In the case of extensions, in general, the adjacent existing part of the DC GIS shall be de-energized and earthed during the dielectric test, unless special measures are taken to prevent disruptive discharges in the extension affecting the energized part of the existing DC GIS.

Application of the test voltage may be necessary after repair or maintenance of major parts or after installation of extensions. The test voltage can then be applied to existing parts in order to test all sections involved. In those cases, the same procedure should be followed as for newly installed DC GIS.

One of the following test procedures shall be chosen:

#### a) Procedure A (recommended for all voltage levels):

- Alternating voltage test for a duration of 1 min at the value of  $\hat{U}_{\text{pre-stress AC}} = 1,5 \times U_{\text{rd}}$ ; and
- partial discharge measurements according to Table 4, however with  $\hat{U}_{\text{pd-test AC}} = 1,2 \times U_{\text{rd}}$ .

In addition to the before mentioned tests, a direct voltage test at  $1,2 \times U_{\text{rd}}$  (column 2 in Table 6) for 1 h in the same polarity as used in service is recommended. If both polarities can occur in service, each polarity shall be tested for 1 h.

A PD measurement at  $U_{\text{rd}}$  is also recommended since this measurement can be helpful in determining the need for maintenance of the equipment after a period of service. For practical application of PD measurements, see Annex B.

#### b) Procedure B (alternative to procedure A):

- Alternating voltage test for a duration of 1 min at the value of  $\hat{U}_{\text{pre-stress AC}} = 1,5 \times U_{\text{rd}}$ ; and
- Partial discharge measurements according to Table 4, however with  $\hat{U}_{\text{pd-test AC}} = 1,2 \times U_{\text{rd}}$
- Lightning impulse tests with three impulses of each polarity and with the value specified in Table 6, column (4).

In addition to the before mentioned tests, a direct voltage test at  $1,2 \times U_{\text{dds}}$  (Column (2) in Table 6) for 1 h in the same polarity as used in service is recommended. If both polarities can occur in service, each polarity shall be tested for 1 h.

A PD measurement at  $U_{rd}$  is also recommended since this measurement can be helpful in determining the need for maintenance of the equipment after a period of service. For practical application of PD measurements, see Annex B.

### 11.101.2.3 Test voltages

Considering that

- transport units have normally been subjected to routine test,
- the probability of disruptive discharges is higher for the complete installation than for individual functional units,
- disruptive discharges in correctly installed equipment shall be avoided,

the test voltage for dielectric tests on-site shall be as shown in Table 6.

**Table 6 – On-site test voltages**

| Rated voltage for equipment<br>$U_{rd}$<br>kV | On-site short-duration direct withstand voltage<br>$U_{dds}$<br>kV | On-site short-duration alternating withstand voltage<br>$U_{ds}$<br>kV (RMS value) | On-site lightning impulse withstand voltage<br>$U_{ps}$<br>kV (peak value) |
|-----------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| (1)                                           | (2)                                                                | (3)                                                                                | (4)                                                                        |
| 105                                           | 130                                                                | 115                                                                                | 305                                                                        |
| 160                                           | 195                                                                | 170                                                                                | 360                                                                        |
| 210                                           | 255                                                                | 225                                                                                | 440                                                                        |
| 265                                           | 320                                                                | 285                                                                                | 600                                                                        |
| 340                                           | 410                                                                | 365                                                                                | 760                                                                        |
| 420                                           | 505                                                                | 450                                                                                | 940                                                                        |
| 525 <sup>a</sup>                              | 635                                                                | 560                                                                                | 1 140                                                                      |
| 630                                           | 760                                                                | 670                                                                                | 1 240                                                                      |
| 840                                           | 1 010                                                              | 895                                                                                | 1 560                                                                      |

NOTE 1 The on-site test voltages have been calculated as follows:

$$U_{dds} \text{ (on-site test value)} = U_{dd} \times 0,8 \quad (\text{column (2)})$$

$$U_{ds} \text{ (on-site test value)} = U_{dd} / \sqrt{2} \quad (\text{column (3)})$$

$$U_{ps} \text{ (on-site test value)} = U_p \times 0,8 \quad (\text{column (4)})$$

All values have been rounded up to the next higher modulus 5 kV.

NOTE 2 If other insulation levels than the rated values of Table 1 in IEC TS 62271-5:2024 are specified, then the on-site test voltage is calculated according to Note 1.

<sup>a</sup> Instead of  $U_{rd} = 525$  kV rated direct voltage,  $U_{rd} = 550$  kV can also be applicable.

In certain circumstances, for technical or practical reasons, dielectric tests on-site can be carried out with reduced voltage values. Details are given in B.3.

### 11.101.2.4 Voltage waveforms

For the choice of an appropriate voltage waveform, IEC 60060-1 should be taken into consideration; however, similar waveforms are also permissible. An ideal voltage waveform covering all requirements does not exist. Permissible deviations are indicated below. Information concerning the generation of test voltages is given in B.1.

#### **a) Alternating voltage tests**

Alternating voltage tests are especially sensitive in detecting contaminations (e.g. free moving conducting particles), and are, in most cases, also sufficient in detecting abnormal field configurations.

The existing experience refers to test frequencies from 10 Hz to 300 Hz.

#### **b) Impulse voltage tests**

Tests with lightning impulse voltages are especially sensitive in detecting abnormal field configurations (e.g. damaged electrodes).

Based on the existing experience, lightning impulse voltages with a front time extended up to 8  $\mu$ s are acceptable. When using oscillating lightning impulse voltages, the front time can be extended to approximately 15  $\mu$ s.

NOTE Reflections due to steep front waves in large installations can be taken into account.

#### **c) Direct voltage tests**

Direct voltage tests are less sensitive in detecting. Nevertheless, to minimize the risk of a dielectric breakdown after applying DC system voltage (at service), beforehand a test with direct voltage stress is also required.

The existing experience refers to ripple factor lower than or equal to 3 %.

### **11.101.2.5 Voltage application**

The test voltage source can be connected to any convenient point of the conductor under test.

It is often convenient to divide the whole installation of DC GIS into sections by opening disconnectors for at least one of the following reasons:

- to limit the capacitive load on the test voltage source;
- to facilitate the location of disruptive discharges;
- to limit the discharged energy if a disruptive discharge occurs.

The sections which, in such cases, are not being tested, and which are isolated by a disconnector from the section under test, shall be earthed. Unless dismantled after routine test or during maintenance, no dielectric test across the open switching devices shall be carried out on-site.

### **11.101.2.6 Assessment of the test**

The switchgear shall be considered to have passed the test if each section has withstood the specified test voltage without any disruptive discharge.

In the event of a disruptive discharge occurring during dielectric tests on-site, the tests shall be repeated.

Guidelines on repetition tests are given in B.6.

If partial discharges are measured with the conventional method according to IEC 60270, the maximum permissible intensity of partial discharge shall be 10 pC. The limit of 10 pC only applies when the test is carried out with alternating voltage.

NOTE 1 It can be difficult to have noise level below 5 pC on-site. Special care with the test circuit is needed to achieve a good measurement. If the noise level is higher than 5 pC, the test is still valid for detecting major defects but not suitable for detection of fixed conducting particles since this kind of defect will cause a very low level of partial discharges and they will be completely masked by the noise. In such circumstances, the test is acceptable if no discharges are detected above the noise level.

NOTE 2 It can also be possible to isolate the component that is causing the noise level higher than 5 pC. Test procedure considers this possibility in the test sequence and is agreed between user and manufacturer.

NOTE 3 If VHF/UHF or acoustic partial discharge measuring methods are used, a calibration is not possible. Instead, a sensitivity check according to B.7.5, IEC TS 62478 [33] and CIGRE Technical Brochure 654 [22] can be performed.

#### **11.101.3 Dielectric tests on auxiliary circuits**

Subclause 8.3 of IEC TS 62271-5:2024 is applicable with the following addition:

Dielectric tests should be carried out on new wiring. If wiring shall be taken off or if electronic devices are in circuits, these circuits shall not be tested.

#### **11.101.4 Measurement of the resistance of the main circuit**

Overall measurements shall be made on the complete installation, under conditions as similar as possible to those of the routine test on transport units.

The resistance measured shall not exceed the maximum values permitted for the routine tests on transport units (see 8.4), taking into account the differences of the two test arrangements (number of devices, contacts and connections, length of conductors, etc.).

Resistance values between earthing switches shall be verified during on-site assembly and documented in the project documentation.

#### **11.101.5 Gas tightness tests**

Subclause 8.5 of IEC TS 62271-5:2024 is also applicable for on-site gas tightness tests. A qualitative gas tightness test shall be carried out on all field assembled connections.

A leakage detector can be used. See appendixes of IEC 62271-4.

#### **11.101.6 Checks and verifications**

The following shall be verified:

- a) conformity of the assembly with the manufacturer's drawings and instructions;
- b) sealing of all pipe junctions, and the tightness of bolts and connections;
- c) conformity of the wiring with the diagrams;
- d) proper function of the electrical, pneumatic and other interlocks;
- e) proper function of the control, measuring, protective and regulating equipment including heating and lighting.

The mechanical operation checks and tests shall be carried out according to the relevant documents. If verification is not specified, the manufacturer shall specify them in the commissioning test plan.

#### **11.101.7 Gas quality verifications**

In order to get a reliable measurement, the humidity content shall be checked at least 5 days after final filling of gas. The humidity content shall not exceed the limit defined in 6.2 of IEC TS 62271-5:2024.

For checking the condition of the gas during service, reference is made to IEC 60480 for SF<sub>6</sub> and its mixtures and to manufacturer recommendations and IEC 62271-4 for other gases.

For handling precautions, reference is made to IEC 62271-4 for SF<sub>6</sub> and manufacturer recommendations for other gases.

## 12 Safety

Working on gas compartments with adjacent compartments under full pressure according to manufacturer safety procedures can require applying safety measures for workers. Local regulations can apply.

### 12.1 General

High-voltage switchgear and controlgear, complying with the applicable IEC standards, can be considered safe when installed in accordance with the relevant installation rules including instructions provided by the manufacturers and used and maintained in accordance with the manufacturer's instructions (see Clause 11).

High-voltage switchgear and controlgear is normally only accessible by instructed persons. Performing operations and maintenance is only allowed to skilled persons. When unrestricted access is available to switchgear and controlgear, additional safety features should be required.

High-voltage switchgear and controlgear in accordance with IEC offers a high level of safety with regard to external effects that might harm personnel, mainly because the high-voltage parts can be surrounded by an enclosure. Nevertheless, high power equipment, can comprise some potential risks, some examples are:

- the enclosures, if any, can be pressurized with gas;
- pressure-relief devices can open due to exceptional conditions, e.g. resulting from an internal arc. In extreme circumstances, the arc can burn through the enclosures. Both result in the sudden release of hot gas;
- sudden events, which are in themselves with low risk to humans, can alarm personnel and lead to accidents (for example, a fall);
- commissioning, maintenance and extension activities can require special attention due to the complexity of the equipment and its internal parts which are mostly not visible.

Experience has shown that human error is a factor that shall be considered (for example, closing an earthing switch on an energized conductor).

### 12.2 Precautions by manufacturers

The following list provides examples of precautions usually implemented by manufacturers.

- design and test pressurized enclosures, pressure relief devices and relevant switchgear elements to international established standards;
- provide adequate and easy means to check interlocking systems (the most reasonable way to avoid human error);
- explain safe operation of the switchgear and controlgear clearly in instruction manuals. Explain precautions to prevent improper operation and the consequences of improper operation;
- provide the user and/or contractor with appropriate information related to design of the surrounding area, possibly ventilation and gas detection information, to minimize personnel risks in case a failure occurs;
- provide safe procedures for dismantling and disposal.

### 12.3 Precautions by users

The following list provides examples of precautions that can be taken by users:

- limit access to the installation to people who are trained and authorized;
- keep operators and other personnel instructed regarding risks and safety requirements including local regulations;

- keep switchgear and controlgear maintained and up to date in terms of technical standards, especially interlocking and protection devices;
- use remote control and have the interlocking system working as intended;
- select equipment that minimizes the risk to personnel from improper operation (for example earthing switches with short-circuit making capacity on lines, motor actuators to allow remote operation);
- coordinate the protection system with product properties (for example, do not reclose on internal faults);
- prepare earthing procedures considering the difficulty of referring to and understanding the complex arrangement and operation of the switchgear and controlgear. Depending on the configuration of the DC system, monopolar or bipolar, and type of switch, one or both of the terminals of the switchgear and controlgear can be connected to one pole or neutral conductor of the system. For reliable protection of personnel and equipment, the protective earthing of the switchgear and controlgear shall be achieved through connecting the earthing point provided by the switchgear and controlgear to the system earth (see 6.3 for earthing point);
- label equipment clearly for easy identification of individual devices and gas compartments.

Especially during maintenance, repair or extension work:

- ensure that maintenance, repair and extension work is carried out only by qualified and trained personnel;
- prepare a safety and protection plan for the work. Indicate who is responsible for planning, implementing and enforcing safety and protection measures;
- check interlocking and protection devices before starting;
- pay special attention to manual operations, especially when the switchgear and controlgear is energized;
- inform personnel who can be near the switchgear and controlgear before operating the equipment (for example, a horn or flashing light);
- mark emergency exits and keep passages clear of obstructions;
- instruct the people involved how to work safely in a switchgear and controlgear environment and what to do in an emergency.

### 13 Influence of the product on the environment

Documentation shall include the following relevant information about the environmental impact of the switchgear:

- a) When fluids are used in switchgear and controlgear, instructions shall be provided in order to allow the user to:
  - 1) minimize the leakage rate as far as is practicable;
  - 2) control the handling of the new and used fluids. IEC 62271-4 is referred to gases for insulation and/or switching.
- b) Instructions concerning disassembly and end-of-life procedures for the different materials of the equipment and indicate the possibility to recycle.

Local regulations can apply for handling releases during manufacturing, installation, on-site tests, repair, maintenance and end-of-life, see IEC 62271-4.

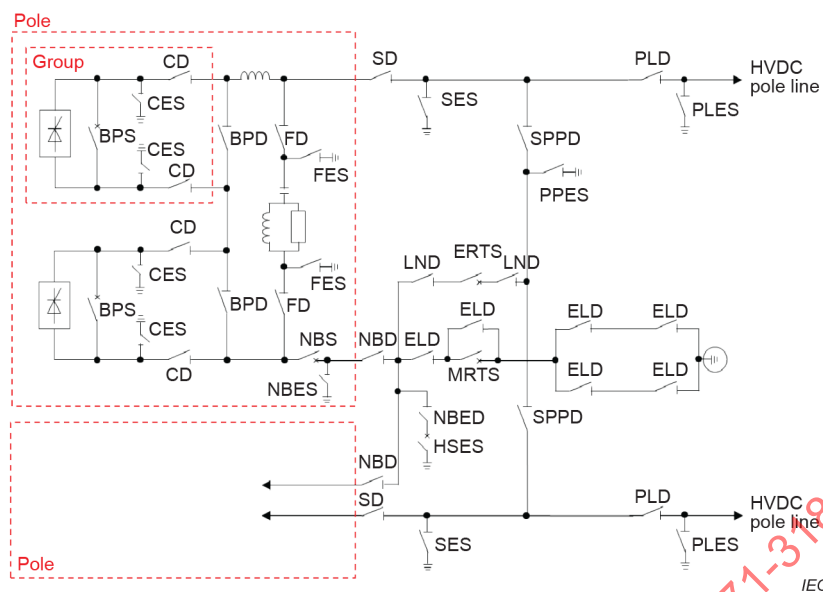
For environmental aspects of gases and gas mixtures see CIGRE Technical Brochure 802 [13].

## **Annex A** (informative)

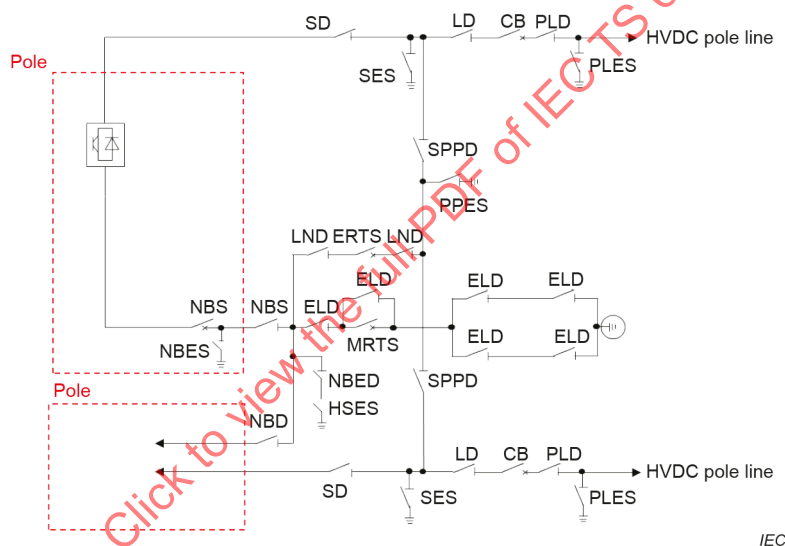
### **Examples of HVDC side switchgear arrangement for one pole in an HVDC substation**

This annex provides examples of HVDC side switchgear arrangement for one pole in an HVDC substation. The upper side of Figure A.1 shows an example for LCC, whereas the bottom side shows that for VSC. The purpose of these examples are to introduce many various types of switching devices which are used in HVDC substations and they do not represent the real configuration. In addition to the switching devices shown in Figure A.1, there is a switching device called paralleling switch used for multiterminal HVDC systems. For the details of the purpose or usage of each switch, references can be made to CIGRE Technical Brochure 683 [72], IEC 60633 and IEC TS 63014-1 [66].

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### Line Commutated Converter (LCC)



### Voltage Sourced Converter (VSC)

#### Key

|      |                                          |      |                                  |
|------|------------------------------------------|------|----------------------------------|
| CD   | Converter Disconnector                   | NBES | Neutral Bus Earthing Switch      |
| BPD  | Bypass Disconnector                      | FES  | Filter Earthing Switch           |
| FD   | Filter Disconnector                      | CES  | Converter Earthing Switch        |
| SD   | Substation Disconnector                  | SES  | Substation Earthing Switch       |
| LD   | Line Disconnector                        | PPES | Pole Paralleling Earthing Switch |
| PLD  | Pole Line Disconnector                   | NBS  | Neutral Bus Switch               |
| LND  | Line to Neutral Disconnector             | MRTS | Metallic Return Transfer Switch  |
| NBD  | Neutral Bus Disconnector                 | ERTS | Earth Return Transfer Switch     |
| NBED | Neutral Bus Earthing Disconnector        | BPS  | Bypass Switch                    |
| ELD  | Electrode Line Disconnector              | HSES | High Speed Earthing Switch       |
| SPPD | Substation Pole Paralleling Disconnector | CB   | Circuit Breaker                  |
| PLES | Pole Line Earthing Switch                |      |                                  |

**Figure A.1 – Example of HVDC side switchgear arrangement for one pole in an HVDC substation**

## **Annex B** (informative)

### **Exposure to pollution**

#### **B.1 General**

The quality of ambient air with respect to pollution by dust, smoke, corrosive and/or flammable gases, vapours, or salt is a consideration under normal and special service conditions (refer to Clause 4). This annex defines recommendations for the minimum specific creepage distance across external insulation.

The approach for DC insulator design and selection with respect to pollution is different to that used for AC. In particular no discrete site severity classes are used, but instead a direct transfer from corrected site pollution severity to necessary USCD is employed. Reference is made to IEC 60815-4.

#### **B.2 Minimum requirements for switchgear in normal service condition**

In outdoor normal service condition RUSCDDC of 60 mm/kV is often used for non-HTM insulators and 45 mm/kV is often used for HTM insulators. In indoor normal service condition with uncontrolled environment (for example in indoor DC yard) RUSCDDC between 20 mm/kV and 30 mm/kV satisfies the performance. Reference is made to IEC 60071-11:2022.

IEC TS 60815-4:2016 gives information how to calculate USCD and to check the profile parameters.

#### **B.3 Minimum requirements for switchgear in special service condition**

In indoor clean and controlled (valve hall) environment with humidity control RUSCDDC of 14 mm/kV is widely used. Reference is made to IEC 60071-11:2022.

For the other cases of special service condition (for example outdoor offshore and coastal area installation), IEC TS 60815-4:2016 gives information on how to determine RUSCDDC.

IEC TS 60815-4:2016 gives information on how to calculate USCD and to check the profile parameters.

## Annex C (informative)

### Preferred insulation levels for rated voltages lower than 105 kV

For possible future development of this document, and due to the lack of applications or products, the following preferred insulation levels for rated voltages lower than 105 kV are given as an indication. These values have been derived from pilot projects, products and values from CIGRE Technical Brochure 793 [74].

**Table C.1 – Preferred insulation levels for rated voltages lower than 105 kV**

| Typical System direct voltage<br>$U_{typ,d}$<br>kV | Rated direct voltage<br>$U_{rd}$<br>kV<br>(NOTE 1) | Rated direct withstand voltage<br>$U_{dd}$<br>kV                                  | Rated lightning impulse withstand voltage<br>$U_p$<br>kV   |                                            |
|----------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------|--------------------------------------------|
|                                                    |                                                    | Pole-to-earth, Across open switching device and/or isolating distance<br>(NOTE 2) | Pole-to-earth and across open switching device<br>(NOTE 3) | Across the isolating distance <sup>a</sup> |
| (1)                                                | (2)                                                | (3)                                                                               | (4)                                                        | (5)                                        |
| 6                                                  | 6,3                                                | 15                                                                                | 40                                                         | 40(+6,3)                                   |
| 12                                                 | 12,5                                               | 25                                                                                | 75                                                         | 75(+12,5)                                  |
| 20                                                 | 21                                                 | 40                                                                                | 125                                                        | 125(+21)                                   |
| 30                                                 | 31,5                                               | 55                                                                                | 185                                                        | 185(+31,5)                                 |
| 50                                                 | 52,5                                               | 90                                                                                | 250                                                        | 250(+52,5)                                 |
| 70                                                 | 73,5                                               | 125                                                                               | 325                                                        | 325(+73,5)                                 |

NOTE 1 The rated direct voltage  $U_{rd}$  takes into account 5 % of ripples and harmonics to the typical system direct voltage, based on that the ripples and harmonics are in the range of 2 % to 5 % of the typical system direct voltage. Reference is made to CIGRE Technical Brochure 684 [73] and the nominal voltage is referred to IEC 60071-11:2022.

NOTE 2 For MVDC systems, the pole-to-earth over-voltage are limited to 1,7 times the rated voltage of the MVDC system, reference is made to CIGRE Technical Brochure 793 [74].

NOTE 3 The values for AC switchgear in IEC 62271-1 are referred to due to lack of sufficient data for DC switchgear.

<sup>a</sup> In column (5), values in brackets are the rated direct voltage applied to the opposite terminal (combined voltage). For multiterminal systems, where the full direct voltage can occur at the opposite terminal, the 100 % rated direct voltage shall be applied. For two-terminal systems, where no higher values can occur at the opposite terminal, the value of 10 % of rated direct voltage is chosen.

Withstand values given in Table C.1 cover the application of switchgear and controlgear under normal service conditions defined in 4.1 including altitudes from sea level up to 1 000 m. However, for testing purposes to verify a rating or capability, they shall be considered as insulation values at the standardized reference atmosphere temperature (20 °C), pressure (101,3 kPa) and humidity (11 g/m<sup>3</sup>) specified in 5.9.2 of IEC 60071-1:2019. For special service conditions, refer to IEC TR 62271-306 [62].

NOTE 1 The normal environmental conditions and the standard reference atmospheric conditions are currently not stated in IEC 60071-11:2022. In terms of these conditions 5.9.1 and 5.9.2 of IEC 60071-1:2019 are applied in this document.

NOTE 2 The insulation levels in Table C.1 are considered being applicable in the temperature range of -40 °C up to 40 °C for DC systems. Reference is made to IEC 60071-1:2019, 5.9.1 for AC systems,

## Annex D (informative)

### Short-circuit current in HVDC systems

#### D.1 VSC HVDC

Figure D.1a) shows considered 2-terminal VSC HVDC under DC fault, and Figure D.1b) shows the diode bridge discharge circuit once AC CB opens. It is assumed that the fault is cleared by AC back-up protection. The worst case DC fault current occurs for DC fault at zero cable length.

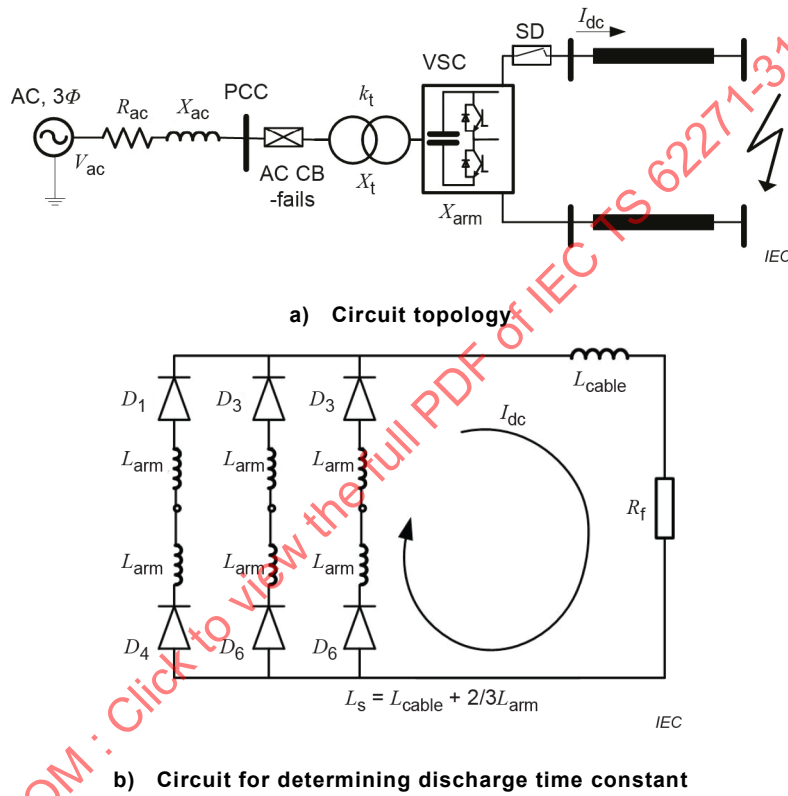


**Figure D.1 – VSC HVDC under worst-case, pole-pole DC fault**

The diode bridge current feed is supplied from AC system with RMS line voltage  $V_{ac}$ , through equivalent AC grid impedance of resistance  $R_{ac}$  and reactance  $X_{ac}$ , ( $X_{ac} = 2\pi f L_{ac}$ ) transformer of stepping ratio  $k_t$  and reactance  $X_t$ , VSC as diode bridge and DC fault path. Neglecting circuit resistance, and assuming the DC voltage under fault is 0,05-0,1 pu, the DC fault current can be approximated as (see [77]):

$$I_f = \frac{6V_{ac}/(k_t\sqrt{3})}{\pi\sqrt{(R_{ac})^2 + (X_{ac} + X_t + k_t^2 X_{arm}/2)^2}} \quad (D.1)$$

The impact of AC system frequency  $f$  is reflected in  $X_{ac}$ .

The rated duration of short circuit ( $t_{kd}$ ) is expressed as:

$$t_{kd} = t_k + \frac{L_s}{R_f} \quad (D.2)$$

Where  $t_k$  is the duration of diode bridge current feed that is the interval of time from the fault until AC CB opens, which is determined by back-up protection and typical value is  $t_k = 0,5$  s.  $L_s$  and  $R_f$  are the impedance and resistance, respectively in the DC fault current path after AC CB opens.

## D.2 LCC HVDC

Figure D.2 shows the considered LCC HVDC under a DC fault. Normally LCC converter responds rapidly to DC fault using one of redundant LCC converter controllers (see Table 9 of [76]). The LCC converter responds to nearby DC fault in the station by blocking and bypassing. This results in rapid LCC converter DC voltage reduction and application of negative DC voltage that leads to DC fault current extinction in 10 ms to 20 ms. A thyristor failure does not affect LCC converter operation because, they fail in short circuit and there is a number of redundant thyristors in each valve.

In Figure 2b) the LCC converter responds to nearby DC fault in the station by blocking and bypassing. This is self-protection LCC mechanism for extreme DC currents.

The rated duration of short circuit ( $t_{kd}$ ) is expressed as:

$$t_{kd} = \frac{L_s}{R_f} \quad (D.3)$$

Where  $L_s$  and  $R_f$  are the impedance and resistance, respectively, in the DC fault current path after LCC bypass, which resembles the circuit in Figure D.1b).

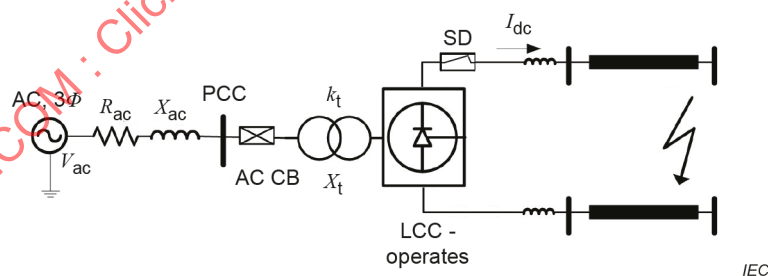


Figure D.2 – LCC HVDC under worst-case, pole-pole DC fault

## D.3 Special case of LCC HVDC DC faults – LCC as diode bridge

Figure D.3 shows the special case DC fault with LCC HVDC that can give much higher DC fault current. This case is based on the following assumptions:

- DC fault occurs on the valve-side of DC smoothing inductor, like for example inadvertent operation of bypass switch.
- The LCC converter is forced to operate as a diode bridge, to reduce semiconductor voltage stresses. This is self-protection LCC operating mode for extreme DC currents.

The diode bridge current feed is determined as:

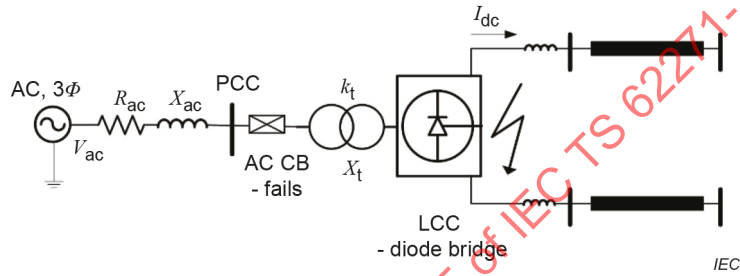
$$I_f = \frac{6V_{ac}/(k_t\sqrt{3})}{\pi\sqrt{(R_{ac})^2 + (X_{ac} + X_t)^2}} \quad (D.4)$$

The preferred value for the rated peak withstand current is  $10I_{rd}$ .

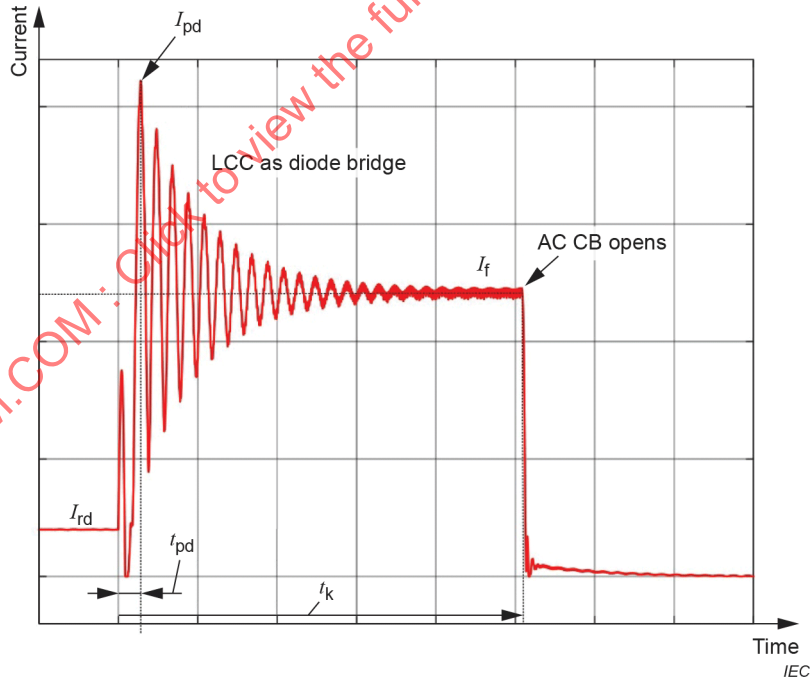
The preferred value for rated duration of short circuit is 0,5 s.

The time to peak short circuit current is 0,01 s.

An alternative value higher than above may be chosen.



a) Circuit diagram



b) Typical DC fault current  $I_{dc}$  response

Figure D.3 – Special case LCC HVDC under worst-case, pole-pole DC fault

#### D.4 HVDC systems with DC circuit-breakers

Figure D.4 shows the considered DC system with Line Disconnector (LD) under short-time DC fault current. The Station Disconnector (SD) shall be considered under the circuit in Figure D.1. It is assumed that the fault is cleared by back-up protection (DC CB on adjacent DC lines and AC CBs). The typical value for operating time of AC CB is  $t_k = 0,05$  s in this case. Figure D.5 shows the assumed simplified DC CB model (see [77]).

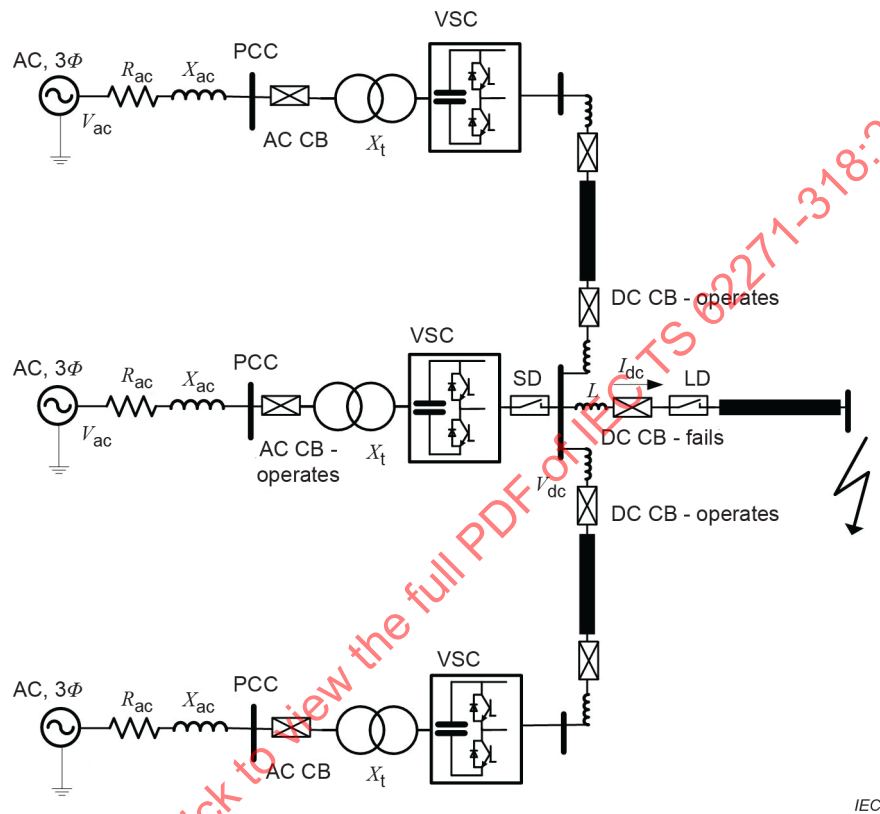


Figure D.4 – HVDC system with DC circuit-breaker under worst-case, pole-pole DC fault

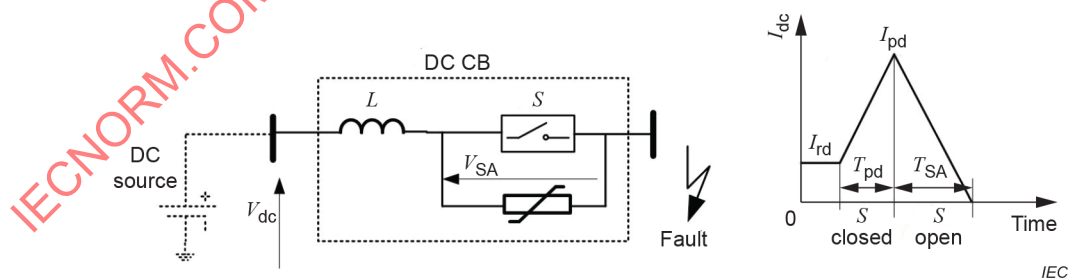


Figure D.5 – DC circuit-breaker simple model

The slope of DC line current rise will be the sum of currents slopes on each DC line:

$$S_L = (S_{p1} + S_{p2} + S_{p3}) \quad (D.5)$$

Where  $S_{p1}$ ,  $S_{p2}$  and  $S_{p3}$  are slopes of current rise on each of the 3 DC lines.

Assuming that  $I_{rd} = 0$ , and  $V_{dc} = \text{constant}$ , the fault path resistance is zero, and the total impedance in the fault path is  $L$ , the positive slope is defined, using the above DC CB model, the base value for positive slope ( $S_p$ ) is  $V_{dc}/L$ . The slope  $S_{p2}$  will be the largest as only one inductor ( $L$ ) is placed in the current path. Because of voltage drop during the current rise interval, and considering back-up protection time, typical value for slope of the local current is

$$0,1 \frac{V_{DC}}{L} < S_{p2} < 0,5 \frac{V_{DC}}{L} \quad (D.6)$$

Whereas the slope on remaining DC lines will be lower:

$$0,05 \frac{V_{DC}}{L} < S_{p1} < 0,3 \frac{V_{DC}}{L} \quad (D.7)$$

The rated duration of short circuit ( $t_{kd}$ ) is expressed as:

$$t_{kd} = \frac{L + L_s}{R_f} \quad (D.8)$$

Where  $L+L_s$  and  $R_f$  are the impedance and resistance, respectively, in the fault current path, after AC circuit-breaker opens, and  $L_s$  is defined as in Figure D.1b).

## D.5 Calculation of the rated short-time withstand direct current

The value of the rated short-time withstand direct current ( $I_{kd}$ ) is obtained by the following formula.

$$I_{kd} = \sqrt{E_f / t_{kd}} \quad (D.9)$$

Where  $E_f$  is Joule integral value as calculated in D.6. This means that  $I_{kd}$  is the equivalent RMS value of the short-circuit current in Figure 2, as shown in Figure D.6.

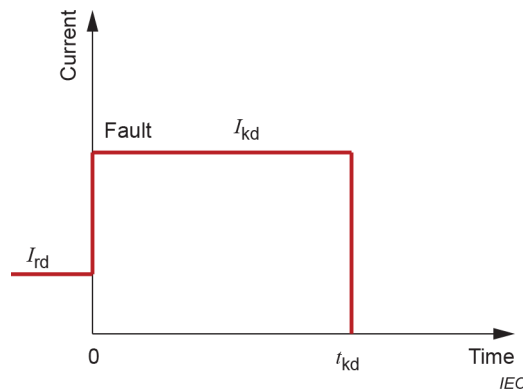


**Figure D.6 – Equivalent fault current for calculation of rated short time withstand direct current**

## D.6 Calculation of Joule integral value ( $E_j$ )

Joule integral value is obtained by calculation as  $E_j = \int I^2 dt$  based on relevant waveform indicated in Figure 2a), 2b), 2c). Based on the simplification of the waveforms in Figure 2, the following values for Joule integral are recommended:

- For the circuit in Figure 2a),  $E_j = I_f^2 t_k + I_f^2 \frac{t_{kd} - t_k}{3}$

where the preferred value of duration of the diode bridge current feed ( $t_k$ ) is 0,5 s;

- For the circuit in Figure 2b),  $E_j = I_{pd}^2 \frac{t_{kd}}{3}$ ,

where the preferred value of the duration of time to peak short-circuit current ( $t_{pd}$ ) is 0,07 s;

- For the circuit in Figure 2c),  $E_j = I_f^2 t_k + I_{pd}^2 \frac{t_{kd}}{3}$

- For the LCC special case circuit,  $E_j = I_f^2 t_k$

where the duration of time to peak short-circuit current ( $t_{pd}$ ) ranges typically from 0,002 s to 0,01 s, depending on the operating time of DC CB and protection (or back-up protection) time. For the purpose of calculation of the necessary thermal withstand capability of the switchgear or controlgear, it should be 0,01 s, considering time to back-up protection.

## Annex E (informative)

### References for auxiliary and control circuit components

Table E.1 is provided as a quick reference to many of the component standards. The latest editions should be used.

**Table E.1 – List of reference documents for auxiliary and control circuit components**

| Device                                                                                         |                                                                                                                                                                 | IEC standard               |
|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| Cables and wiring                                                                              | Insulation of PVC wiring                                                                                                                                        | IEC 60227 (all parts) [19] |
|                                                                                                | Size and area of conductors                                                                                                                                     | IEC 60228 [20]             |
|                                                                                                | Insulation of rubber cable                                                                                                                                      | IEC 60245 (all parts) [21] |
|                                                                                                | Identification                                                                                                                                                  | IEC 60445 [28]             |
| Terminals                                                                                      | Terminal blocks for round wire                                                                                                                                  | IEC 60947-7-1 [51]         |
|                                                                                                | Protective terminal blocks for round wire                                                                                                                       | IEC 60947-7-2 [52]         |
|                                                                                                | Identification                                                                                                                                                  | IEC 60445 [28]             |
| Relays                                                                                         | All-or-nothing relays                                                                                                                                           | IEC 61810 (all parts) [54] |
|                                                                                                | Voltage ratings and operating range of all-or-nothing relays                                                                                                    | IEC 61810-1 [55]           |
|                                                                                                | Performance of relay contacts                                                                                                                                   | IEC 61810-2 [56]           |
| Contactors and motor starters                                                                  | Electromechanical contactors for closing and opening electrical circuit                                                                                         | IEC 60947-4-1 [48]         |
|                                                                                                | Electromechanical contactors combined with relay for short-circuit protection                                                                                   | IEC 60947-2 [46]           |
|                                                                                                | Motor starters (AC)                                                                                                                                             | IEC 60947-4-1 [48]         |
|                                                                                                | AC semiconductor motor controllers                                                                                                                              | IEC 60947-4-2 [49]         |
|                                                                                                | Motor protective overload relays                                                                                                                                | IEC 60947-4-1 [48]         |
| Low-voltage switches                                                                           | Low-voltage switches for motor circuits and distribution circuits                                                                                               | IEC 60947-3 [47]           |
|                                                                                                | Manual control switches and push-buttons                                                                                                                        | IEC 60947-5-1 [50]         |
|                                                                                                | Pilot switches: pressure, temperature switches etc.                                                                                                             | IEC 60947-5-1 [50]         |
|                                                                                                | Household humidity sensing controls                                                                                                                             | IEC 60730-2-13 [43]        |
|                                                                                                | Household switches                                                                                                                                              | IEC 60669-1 [32]           |
|                                                                                                | Household thermostats                                                                                                                                           | IEC 60730-2-9 [42]         |
|                                                                                                | Lever (toggle) switch                                                                                                                                           | IEC 61020-1 [53]           |
|                                                                                                | Graphical symbols for manual switches                                                                                                                           | IEC 60417 [27]             |
|                                                                                                | Colours of lights for manual switches                                                                                                                           | IEC 60073 [14]             |
| Low-voltage circuit-breakers and low-voltage circuit-breakers with residual current protection | Requirements                                                                                                                                                    | IEC 60947-2 [46]           |
| Low-voltage fuses                                                                              | General requirements                                                                                                                                            | IEC 60269-1 [22]           |
|                                                                                                | Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) – Examples of standardized systems of fuses A to K | IEC 60269-2 [23]           |

| Device                                                                                                                           |                                                                                       | IEC standard               |
|----------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|----------------------------|
| Low-voltage disconnectors                                                                                                        | Requirements                                                                          | IEC 60947-3 [47]           |
| Motors                                                                                                                           | Requirements                                                                          | IEC 60034-1 [6]            |
| Meters                                                                                                                           | Analogue meters                                                                       | IEC 60051-1 [7]            |
|                                                                                                                                  | Ammeters and voltmeters                                                               | IEC 60051-2 [8]            |
|                                                                                                                                  | Frequency meters                                                                      | IEC 60051-4 [9]            |
|                                                                                                                                  | Phase-angle and power-factor meters                                                   | IEC 60051-5 [10]           |
| Lamp used as an indicator                                                                                                        | Requirements                                                                          | IEC 60947-5-1 [50]         |
|                                                                                                                                  | Graphical symbols                                                                     | IEC 60417 [27]             |
|                                                                                                                                  | Colour lights                                                                         | IEC 60073 [14]             |
| Plugs, socket-outlets, and couplers                                                                                              | Requirements for plugs, sockets-outlet, industrial cable couplers, appliance couplers | IEC 60309-1 [24]           |
|                                                                                                                                  | Dimensional and interchangeability                                                    | IEC 60309-2 [25]           |
|                                                                                                                                  | Household plugs, socket-outlets and couplers                                          | IEC TR 60083 [16]          |
|                                                                                                                                  | Other couplers and plugs                                                              | IEC 60130 (all parts) [18] |
| Printed circuit-boards                                                                                                           | Requirements                                                                          | IEC 62326-1 [63]           |
| Resistors                                                                                                                        | Potentiometers                                                                        | IEC 60393-1 [26]           |
|                                                                                                                                  | Resistors 1 W to 1 000 W                                                              | IEC 60115-4 [17]           |
| Illumination                                                                                                                     | Illumination fluorescents                                                             | IEC 60081 [15]             |
|                                                                                                                                  | Illumination for LED                                                                  | IEC 62612 [65]             |
|                                                                                                                                  | Tungsten filament lamps                                                               | IEC 60064 [12]             |
| NOTE For electronic components used in auxiliary and control equipment additional information can be found in IEC TR 62063 [60]. |                                                                                       |                            |

## Annex F (informative)

### List of symbols

| Description                                                                               | Symbol               | Subclause |
|-------------------------------------------------------------------------------------------|----------------------|-----------|
| Absolute leakage rate                                                                     | $F$                  | 3.6.6.4   |
| Absolute leakage rate                                                                     | $F_{liq}$            | 3.6.7.1   |
| Alarm pressure (or density) for insulation and/or switching                               | $p_{ae} (\rho_{ae})$ | 3.6.5.3   |
| Alarm pressure (or density) for operation                                                 | $p_{am} (\rho_{am})$ | 3.6.5.4   |
| Diode bridge current feed                                                                 | $I_f$                | 5.5.3     |
| Duration of polarity reversal tests                                                       | $t_1, t_2$           | 7.2.7.6   |
| Filling pressure                                                                          | $p_r$                | 7.7.2     |
| Filling pressure (or density) for insulation and/or switching                             | $p_{re} (\rho_{re})$ | 3.6.5.1   |
| Filling pressure (or density) for operation                                               | $p_{rm} (\rho_{rm})$ | 3.6.5.2   |
| Highest voltage for equipment                                                             | $U_m$                | 3.7.3     |
| Joule integral value                                                                      | $E_j$                | D.6       |
| Main circuit resistance measured before continuous current test                           | $R_u$                | 8.4       |
| Mass of switchgear and controlgear (including any fluid)                                  | $M$                  | 6.11.2    |
| Replenishing pressure                                                                     | $p_m$                | 7.7.2     |
| Minimum functional pressure (or density) for insulation and/or switching                  | $p_{me} (\rho_{me})$ | 3.6.5.5   |
| Minimum functional pressure (or density) for operation                                    | $p_{mm} (\rho_{mm})$ | 3.6.5.6   |
| Number of replenishments per day                                                          | $N$                  | 3.6.6.8   |
| Number of replenishments per day                                                          | $N_{liq}$            | 3.6.7.3   |
| Permissible leakage rate                                                                  | $F_p$                | 3.6.6.5   |
| Permissible leakage rate                                                                  | $F_{p(liq)}$         | 3.6.7.2   |
| Positive slope                                                                            | $S_p$                | 5.5.1     |
| Pressure drop                                                                             | $\Delta p$           | 3.6.6.9   |
| Pressure drop                                                                             | $\Delta p_{liq}$     | 3.6.7.4   |
| Rated continuous current                                                                  | $I_{rd}$             | 5.4       |
| Rated direct withstand voltage                                                            | $U_{dd}$             | 5.3       |
| Rated duration of short-circuit                                                           | $t_{kd}$             | 5.5.4     |
| Rated lightning impulse withstand voltage                                                 | $U_p$                | 5.3       |
| Rated peak withstand current                                                              | $I_{pd}$             | 5.5.3     |
| Rated short-time withstand direct current                                                 | $I_{kd}$             | 5.5.2     |
| Rated supply voltage                                                                      | $U_a$                | 5.6.2     |
| Rated supply voltage of closing and opening devices and of auxiliary and control circuits | $U_a$                | 5.6       |
| Rated switching impulse withstand voltage                                                 | $U_s$                | 5.3       |
| Rated direct voltage                                                                      | $U_{rd}$             | 5.2       |
| Relative leakage rate                                                                     | $F_{rel}$            | 3.6.6.6   |

| Description                                           | Symbol      | Subclause |
|-------------------------------------------------------|-------------|-----------|
| Time between replenishments                           | $t_r$       | 3.6.6.7   |
| Time to peak short-circuit current                    | $t_{pd}$    | 5.5.3     |
| Type and mass of fluid (liquid or gas) for insulation | $M_f$       | 6.11.2    |
| Typical system direct voltage                         | $U_{typ,d}$ | 5.2.1     |

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## **Annex G** (normative)

### **Method for the weatherproofing test for outdoor switchgear and controlgear**

The switchgear and controlgear to be tested shall be fully equipped and complete with all covers, screens, bushings, etc., and placed in the area to be subjected to with artificial precipitation. For switchgear and controlgear comprising several functional units a minimum of two units shall be used to test the joints between them.

The artificial precipitation shall be supplied by a sufficient number of nozzles to produce a uniform spray over the surfaces under test. The various parts of the switchgear and controlgear may be tested separately, provided that a uniform spray is simultaneously applied also to both of the following:

- a) the top surfaces from nozzles located at a suitable height;
- b) the floor outside the equipment for a distance of 1 m in front of the parts under test with the equipment located at the minimum height above the floor level specified by the manufacturer.

Where the width of the equipment exceeds 3 m, the spray may be applied to 3 m wide sections in turn. Pressurized enclosures do not need to be submitted to artificial precipitation.

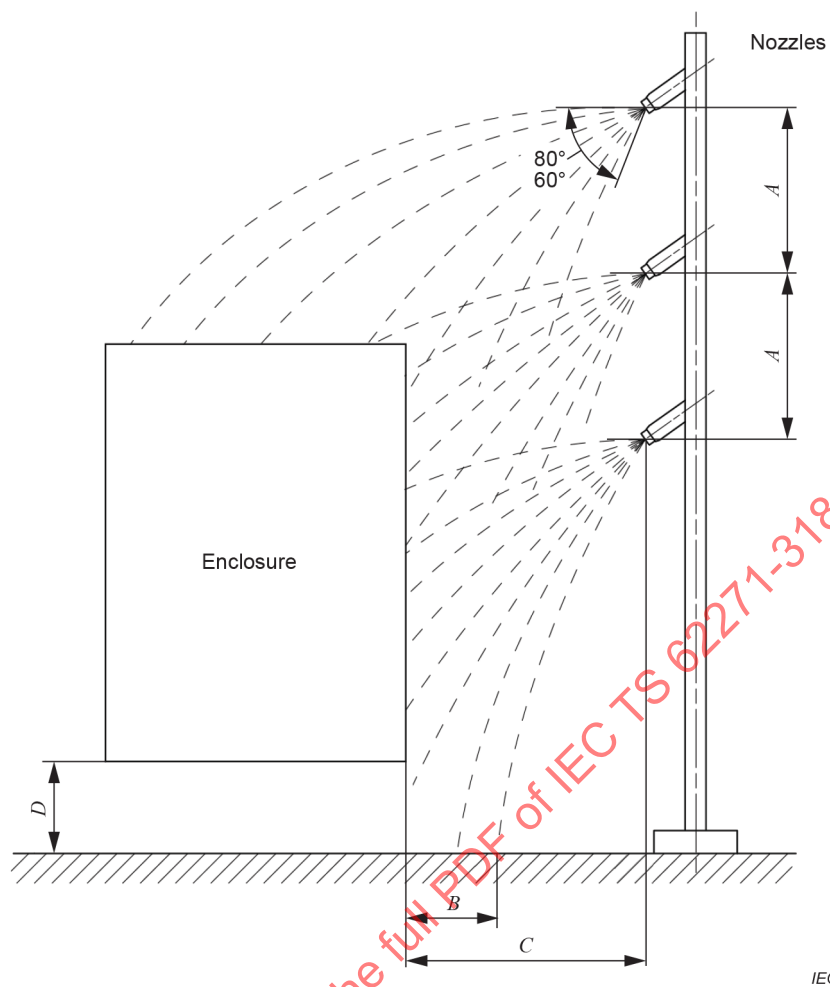
Each nozzle used for this test shall deliver a square-shaped spray pattern with uniform spray distribution and shall have a capacity of  $30 \text{ l/min} \pm 3 \text{ l/min}$  at a pressure of  $460 \text{ kPa} \pm 46 \text{ kPa}$  and a spray angle of  $60^\circ$  to  $80^\circ$ . The centre lines of the nozzles shall be inclined downwards so that the top of the spray is horizontal as it is directed towards the surfaces being tested. It is convenient to arrange the nozzles on a vertical stand-pipe and to space them about 2 m apart (refer to test arrangement in Figure G.1).

The pressure in the feed pipe of the nozzles shall be  $460 \text{ kPa} \pm 46 \text{ kPa}$  under flow conditions. The rate at which water is applied to each surface under test shall be about 5 mm/min, and each surface so tested shall receive this rate of artificial precipitation for duration of 5 min. The spray nozzles shall be at a distance between 2,5 m and 3 m from the nearest vertical surface under test.

NOTE When a nozzle in accordance with Figure G.2 is used, the quantity of water is considered to be in accordance with this document when the pressure is  $460 \text{ kPa} \pm 10 \%$ .

After the test is completed, the equipment shall be inspected promptly to determine whether the following requirements have been met:

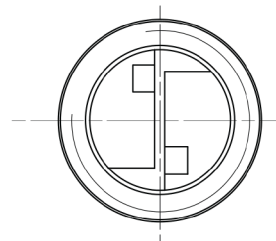
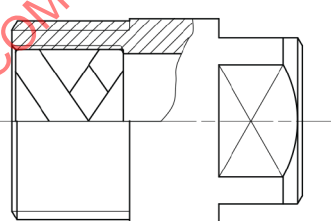
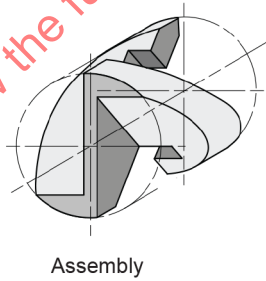
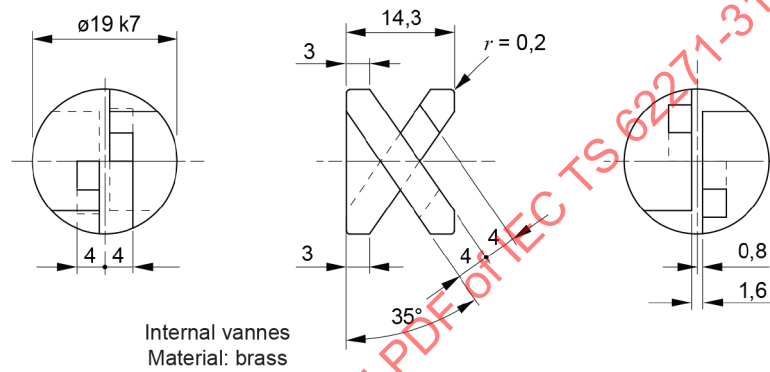
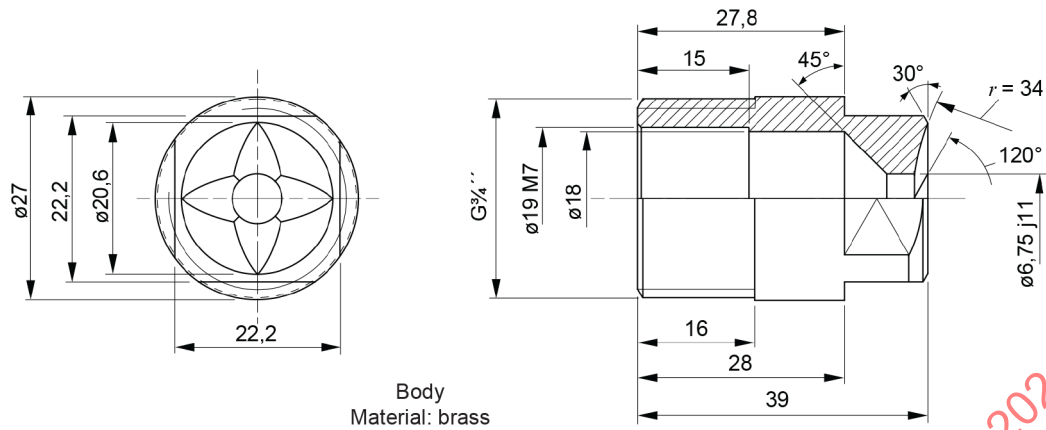
- a) no water shall be visible on the insulation of the main and auxiliary circuits;
- b) no water shall be visible on any internal electrical components and drive mechanisms of the equipment;
- c) no significant accumulation of water shall be retained by the structure or other non-insulating parts (to minimize corrosion).



|     |                            |
|-----|----------------------------|
| $A$ | About 2 m                  |
| $B$ | 1 m                        |
| $C$ | 2,5 m to 3 m               |
| $D$ | Minimum height above floor |

**Figure G.1 – Arrangement for weatherproofing test**

Dimensions in millimetres



Scale 1:1

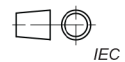


Figure G.2 – Nozzle for weatherproofing test

## Annex H (normative)

### Tolerances on test quantities during tests

During type tests, the following types of tolerances can normally be distinguished:

- tolerances on test quantities which directly determine the stress of the test object;
- tolerances concerning features or the behaviour of the test object before and after the test;
- tolerances on test conditions;
- tolerances concerning parameters of measurement devices to be applied.

A tolerance is defined as the range of the test value specified in the standard within which the measured test value shall lie for a test to be valid. In certain cases, the test may remain valid even if the measured value falls outside the range: this is the case when it results in a more severe test condition.

Any deviation between the measured test value and the true test value caused by the uncertainty of the measurement are not taken into account in this respect.

The basic rules for application of tolerances on test quantities during type tests are as follows:

- a) testing stations shall aim wherever possible for the test value specified;
- b) the tolerances on test quantities specified shall be observed by the testing station. Higher stresses exceeding those tolerances are permitted only with the consent of the manufacturer;
- c) where, for any test quantity, no tolerance is given within this document, or the standard to be applied, the type test shall be not less severe than specified. The upper stress limits are subject to the consent of the manufacturer.

**Table H.1 – Tolerances on test quantities for type test**

| Subclause          | Description of the test         | Test quantity      | Specified test value                      | Test tolerances / limits of test values | Reference to |
|--------------------|---------------------------------|--------------------|-------------------------------------------|-----------------------------------------|--------------|
| 7.2 up to 7.2.11   | Dielectric tests                |                    |                                           |                                         |              |
| 7.2.7.2 and 7.2.11 | Direct voltage tests            | Test voltage       | Rated direct withstand voltage            | ±1 %                                    | IEC 60060-1  |
| 7.2.7.3            | Switching impulse voltage tests | Peak value         | Rated switching impulse withstand voltage | ±3 %                                    | IEC 60060-1  |
|                    |                                 | Front time         | 250 µs                                    | ±20 %                                   |              |
|                    |                                 | Time to half-value | 2 500 µs                                  | ±60 %                                   |              |
| 7.2.7.4            | Lightning impulse voltage tests | Peak value         | Rated lightning impulse withstand voltage | ±3 %                                    | IEC 60060-1  |
|                    |                                 | Front time         | 1,2 µs                                    | ±30 %                                   |              |
|                    |                                 | Time to half-value | 50 µs                                     | ±20 %                                   |              |

| Subclause | Description of the test                                       | Test quantity                            | Specified test value                                                                   | Test tolerances / limits of test values                                                | Reference to   |
|-----------|---------------------------------------------------------------|------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------|
| 7.2.7.5   | Superimposed impulse voltage tests                            | Test voltage (direct voltage)            | Rated direct voltage                                                                   | ±1 %                                                                                   | IEC 60060-1    |
|           |                                                               | Test voltage (Lightning impulse voltage) | Rated lightning impulse withstand voltage                                              | Referred to lightning impulse voltage tests                                            |                |
|           |                                                               | Test voltage (Switching impulse voltage) | Rated switching impulse withstand voltage                                              | Referred to switching impulse voltage tests                                            |                |
| 7.2.7.6   | Polarity reversal tests                                       | Test voltage                             |                                                                                        | ±1 %                                                                                   |                |
| 7.2.11    | AC power-frequency voltage test                               | Test voltage (RMS value)                 | Rated short-duration power frequency withstand voltage                                 | ±1 %                                                                                   | IEC 60060-1    |
|           |                                                               | Frequency                                | –                                                                                      | 45 Hz to 65 Hz                                                                         |                |
|           |                                                               | Wave shape                               | Peak value / RMS value = $\sqrt{2}$                                                    | ±5 %                                                                                   |                |
| 7.3.4     | Measurement of the resistance of circuits                     | DC test current, $I_{DC}$                | –                                                                                      | 50 A < $I_{DC}$ ≤ rated continuous current, or –20 %, +0 % of $I_r$ ≤ 50 A             |                |
| 7.4       | Continuous current tests                                      | Ambient air velocity                     | –                                                                                      | ≤ 0,5 m/s                                                                              |                |
|           |                                                               | Test current                             | Rated continuous current                                                               | –0 %, +2 %<br>These limits shall be kept only for the last two hours of testing period |                |
|           |                                                               | Ambient air temperature $T_a$            | --                                                                                     | 10 °C < $T_a$ ≤ 40 °C                                                                  |                |
| 7.5       | Short-time withstand current and peak withstand current tests | Peak current                             | Rated peak withstand current                                                           | –0 %, +5 %                                                                             |                |
|           |                                                               | Value of Joule integral $\int I^2 dt$    | Value of Joule integral $\int I^2 dt$<br>Derived from the prospective current waveform | –0 %, +10 %                                                                            |                |
|           |                                                               | Short-circuit current duration           | Rated short-circuit duration                                                           | Maximum 5 s                                                                            |                |
| 7.8.1.1   | Radio interference voltage tests                              | Test voltage                             |                                                                                        | ±1 %                                                                                   |                |
|           |                                                               | Tune frequency of measurement circuit    |                                                                                        | Within +10 % of 0,5 MHz or between 0,5 MHz to 2 MHz                                    |                |
| 7.8.2.3   | Oscillatory wave immunity test                                | Damped oscillatory wave tests            | Test frequency 100 kHz, 1 MHz                                                          | ±30 %                                                                                  | IEC 61000-4-18 |
| 7.9.3.3   | Auxiliary contact rated short-time withstand current          | Test current amplitude                   |                                                                                        | –0 %, +5 %                                                                             |                |
|           |                                                               | Test current duration                    |                                                                                        | –0 %, +10 %                                                                            |                |

| Subclause | Description of the test               | Test quantity                                            | Specified test value                                   | Test tolerances / limits of test values | Reference to         |
|-----------|---------------------------------------|----------------------------------------------------------|--------------------------------------------------------|-----------------------------------------|----------------------|
| 7.9.3.4   | Auxiliary contact breaking capability | Test voltage amplitude                                   |                                                        | −0 %, +10 %                             |                      |
|           |                                       | Test current amplitude                                   |                                                        | −0 %, +5 %                              |                      |
|           |                                       | Circuit time constant                                    |                                                        | −0 %, +20 %                             |                      |
| 7.9.4.2   | Cold tests                            | Minimum and maximum ambient air temperature during tests | –                                                      | ±3 K                                    | IEC 60068-2-1: 2007  |
| 7.9.4.3   | Dry heat test                         | Minimum and maximum ambient air temperature during tests | –                                                      | ±3 K                                    | IEC 60068-2-2: 2007  |
| 7.9.4.4   | Cyclic humidity test                  | Minimum temperature of cycle                             |                                                        | ±3 K                                    | IEC 60068-2-30: 2005 |
|           |                                       | Maximum temperature of cycle                             |                                                        | ±2 K                                    |                      |
| 7.9.4.5   | Vibration response and seismic tests  |                                                          |                                                        |                                         | IEC 60255-21-1: 1988 |
| 7.9.5     | Power-frequency voltage test          | Test voltage (RMS value)                                 | Rated short-duration power frequency withstand voltage | ±1 %                                    | IEC 60060-1          |
|           |                                       | Frequency                                                | –                                                      | 45 Hz to 65 Hz                          |                      |
|           |                                       | Waveshape                                                | Peak value / RMS value<br>$= \sqrt{2}$                 | ±5 %                                    |                      |
| 7.10.1.3  | Radiation instrument                  | Accuracy measurement of radiation                        |                                                        | ±25 %                                   |                      |
|           | Energy response                       | Accuracy measurement of energy                           |                                                        | ±15 %                                   |                      |

## **Annex I** (informative)

### **Extension of validity of type tests**

#### **I.1 General**

An individual type test does not need to be repeated in some situations e.g.:

- for a change of construction detail, if the manufacturer can establish that this change does not influence the result of that individual type test;
- for a change in the installation instructions, provided that the test conditions are not invalidated by the new instructions (e.g. see I.2);
- for covering other values of ratings for the same switchgear and controlgear, if these new ratings are covered by the tests already performed (e.g. see I.3 or when lower performances are requested).

Particular examples where extension of a type test may be used to validate design changes or other similar equipment, without repeating type tests, are given in the following subclauses. It should be noted that supporting evidence should be provided to validate such extensions of type tests.

#### **I.2 Dielectric tests**

For non-enclosed conductors, the dielectric tests performed cover other dispositions having equal or higher clearances to surroundings (e.g. height above ground) and between conductors, if the insulating materials and shapes of conductors and insulators are the same.

#### **I.3 Short-time withstand current and peak withstand current tests**

A test performed in worst condition for instance with a rated short-time withstand direct current ( $I_{kd}$ ), rated peak withstand current ( $I_{pd}$ ) and rated duration of short-circuit ( $t_{kd}$ ) covers equal or less values independently from which of the three waveforms, indicated in 5.5.1, has been used.

#### **I.4 Electromagnetic immunity test on auxiliary and control circuits**

Subassemblies may be positioned in different places within the auxiliary and control circuits, without invalidating the type test of the complete system, provided that the overall wiring length and the number of individual wires connecting the subassembly to the auxiliary and control circuits is not greater than in the tested system.

Interchangeable subassemblies may be replaced by similar subassemblies, without invalidating the original type test, provided that:

- rules for design and installation given in IEC 61000-6-5 are followed;
- type tests have been performed on the most complete subassembly applicable to the type of switchgear and controlgear;
- manufacturer's design rules are the same as for the type-tested subassembly.

#### **I.5 Environmental tests on auxiliary and control circuits**

Environmental tests on auxiliary and control circuits do not need to be repeated if performance requirements are validated during environmental tests on a whole switchgear and controlgear.

Parts, or pieces of equipment, of auxiliary and control circuits validated in a given arrangement are validated also when used in a different arrangement of auxiliary and control circuits belonging to the same range of switchgear and controlgear equipment.

Tests performed with a given supply voltage for auxiliary and control circuit cover similar auxiliary and control circuits designed for lower supply voltages.

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## Annex J (normative)

### Identification of test objects

#### J.1 General

For identification of a test object, the following topics shall be covered.

#### J.2 Data

- Manufacturer's name;
- Type designation, ratings and serial number of apparatus;
- Outline description of apparatus (including interlocking system, busbar system, earthing system, and the arc extinguishing process);
- Make, type, serial numbers, ratings of essential parts, where applicable (for example, drive mechanisms, interrupters, shunt impedances, relays, fuse links, insulators);
- Rated characteristics of fuse links and protective devices;
- Whether the apparatus is intended for operation in the vertical and horizontal plane.

#### J.3 Drawings

**Table J.1 Drawing list and contents**

| Drawings to be submitted                                                                                                             | Drawing content (as applicable)                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Single-line diagram of main circuit                                                                                                  | Type designation of principal components                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| General layout<br><br>For an assembly it can be necessary to provide drawings of the complete assembly and of each switching device. | Overall dimensions<br>Supporting structure and mounting points<br>Enclosure(s)<br>Pressure-relief devices<br>Conducting parts of the main circuit<br>Earthing conductors and earthing connections<br>Electrical clearances:<br>– to earth;<br>– between open contacts<br>Location of earthed metallic screens, shutters or partitions in relation to live parts<br>Location and type designation of insulators<br>Location and type designation of instrument transformers |
| Detailed drawings of insulators                                                                                                      | Material<br>Dimensions (including profile and creepage distances)                                                                                                                                                                                                                                                                                                                                                                                                          |
| Arrangement drawings of cable boxes                                                                                                  | Electrical clearances<br>Principal dimensions<br>Terminals<br>Level or quantity and specifications of insulant in filled boxes<br>Cable termination details                                                                                                                                                                                                                                                                                                                |

| Drawings to be submitted                                                  | Drawing content (as applicable)                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Detailed drawings of parts of the main circuit and associated components  | Dimensions and material of principal parts<br>Cross-sectional view through the axis of main and arcing contacts<br>Travel of moving contacts<br>Electrical clearance between open contacts<br>Distance between point of contact separation and end of travel<br>Assembly of fixed and moving contacts<br>Details of terminals (dimensions, materials)<br>Identity of springs<br>Material and creepage distances of insulating parts |
| Detailed drawings of mechanisms (including coupling and drive mechanisms) | Arrangement and identity of main components of the kinematic chains to: <ul style="list-style-type: none"> <li>– main contacts;</li> <li>– auxiliary switches;</li> <li>– pilot switches;</li> <li>– position indication.</li> </ul> Latching device<br>Assembly of drive mechanism<br>Interlocking devices<br>Identity of springs<br>Control and auxiliary devices                                                                 |
| Electrical diagram of auxiliary and control circuits (if applicable)      | Type designation of all components                                                                                                                                                                                                                                                                                                                                                                                                  |

## Annex K (informative)

### Test circuit for superimposed impulse voltage tests

#### K.1 General

The superposition of an impulse wave on a direct voltage is obtained by using a blocking capacitor or a sphere gap and a current limiting resistor. The results according to both procedures are considered equivalent (see CIGRE Technical Brochure 842 [75]).

#### K.2 Test circuit using blocking capacitor

The choice of the blocking elements for the direct voltage has an influence on the protection effect and the waveform. Using blocking capacitors, the blocking capacitor and the test object form a capacitive voltage divider as shown in Figure K.1. Therefore, the rated direct voltage  $U_{rd}$  and the impulse voltage generator output can be added to receive approximately the amplitude of the superimposed voltage.

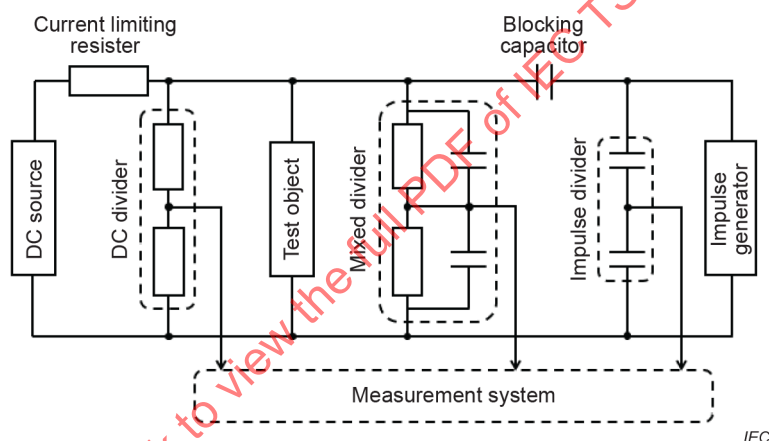


Figure K.1 – Test circuit for superimposed impulse tests using blocking capacitor

#### K.3 Test circuit using sphere gap

By ignition of the sphere gap (see Figure K.2), the test object is directly connected to the impulse voltage generator. Therefore, the amplitude of the composite voltage is equal to the impulse generator output voltage in this case. On the other hand, the impulse voltage waveshape can be different from the standard LI or SI waveshape. In any case, attention shall be paid to the design of the test circuits, and particularly the coupling elements.

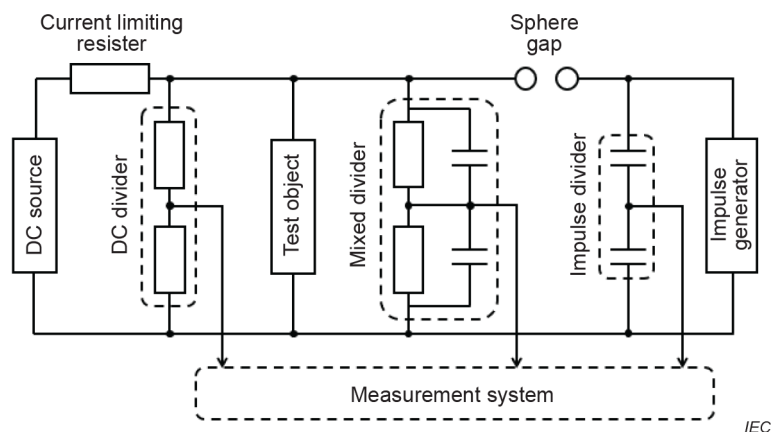


**Figure K.2 – Test circuit for superimposed impulse tests using sphere gap**

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## Annex L (informative)

### Information and technical requirements to be given with enquiries, tenders and orders

#### L.1 General

This annex provides a list of useful technical information items in a tabular form to be considered for possible exchange between user and supplier during contracting stage.

When in the table "supplier information" is mentioned, this means that only the supplier should deliver this information.

Attention should be paid to the fact that such table should be complemented with information and characteristics relevant for the type of switchgear and controlgear considered; see product standards.

#### L.2 Normal and special service conditions (refer to Clause 4)

|                                                                       |                   | User requirements | Supplier proposals |
|-----------------------------------------------------------------------|-------------------|-------------------|--------------------|
| Service condition                                                     | Indoor or outdoor |                   |                    |
| Ambient air temperature:                                              |                   |                   |                    |
| Minimum                                                               | °C                |                   |                    |
| Maximum                                                               | °C                |                   |                    |
| Solar radiation                                                       | W/m <sup>2</sup>  |                   |                    |
| Altitude                                                              | m                 |                   |                    |
| RUSCD for pollution                                                   | mm/kV             |                   |                    |
| Excessive dust or salt                                                |                   |                   |                    |
| Ice coating                                                           | mm                |                   |                    |
| Wind                                                                  | m/s               |                   |                    |
| Humidity                                                              | %                 |                   |                    |
| Condensation or precipitation                                         |                   |                   |                    |
| Vibration                                                             | Class             |                   |                    |
| Induced electromagnetic disturbance in auxiliary and control circuits | kV                |                   |                    |

**L.3 Ratings (refer to Clause 5)**

|                                                                                                     |    | User requirements | Supplier proposals |
|-----------------------------------------------------------------------------------------------------|----|-------------------|--------------------|
| Rated direct voltage for equipment ( $U_{rd}$ )                                                     | kV |                   |                    |
| Rated insulation levels pole to earth                                                               |    |                   |                    |
| Rated direct withstand voltage ( $U_{dd}$ )                                                         | kV |                   |                    |
| Rated switching impulse withstand voltage ( $U_s$ )                                                 | kV |                   |                    |
| Rated lightning impulse withstand voltage ( $U_p$ )                                                 | kV |                   |                    |
| Rated continuous current ( $I_{rd}$ )                                                               | A  |                   |                    |
| Rated short-time withstand direct current ( $I_{kd}$ )                                              | kA |                   |                    |
| Rated peak withstand current ( $I_{pd}$ )                                                           | kA |                   |                    |
| Rated duration of short-circuit ( $t_{kd}$ )                                                        | s  |                   |                    |
| Rated supply voltage of closing and opening devices and of auxiliary and control circuits ( $U_a$ ) | V  |                   |                    |
| Rated supply frequency of closing and opening devices and of auxiliary circuits                     | Hz | DC or 50 or 60    |                    |

**L.4 Design and construction (refer to Clause 6)**

To be complemented with information provided by the relevant product standards.

|                                                                          |  | User requirements | Supplier proposals |
|--------------------------------------------------------------------------|--|-------------------|--------------------|
| Number of units in series, or, in parallel                               |  |                   |                    |
| Mass of the heaviest transport unit                                      |  |                   |                    |
| Mounting provisions                                                      |  |                   |                    |
| Type of gas-pressure or liquid-pressure system                           |  |                   |                    |
| Overall dimensions of the installation                                   |  |                   |                    |
| Description by name and category of the various compartments             |  |                   |                    |
| Rated filling level and minimum functional level                         |  |                   |                    |
| Low- and high-pressure interlocking and monitoring devices               |  |                   |                    |
| Interlocking devices                                                     |  |                   |                    |
| Degrees of protection                                                    |  |                   |                    |
| Arrangement of the external connections                                  |  |                   |                    |
| Accessible sides                                                         |  |                   |                    |
| Volume of liquid or mass of gas or liquid for the different compartments |  |                   |                    |
| Facilities for transport and mounting                                    |  |                   |                    |
| Instructions for operation and maintenance                               |  |                   |                    |
| Specification of gas or liquid condition                                 |  |                   |                    |

## L.5 System information

|                           |    | User information |
|---------------------------|----|------------------|
| Nominal voltage of system | kV |                  |
| Highest voltage of system | kV |                  |

## L.6 Documentation for enquiries and tenders

|                                                                                                               | User requirements    | Supplier proposals |
|---------------------------------------------------------------------------------------------------------------|----------------------|--------------------|
| Scope of supply (training, technical and layout studies and requirements for co-operation with other parties) |                      |                    |
| Single-line diagram                                                                                           |                      |                    |
| General arrangement drawings of substation layout                                                             |                      |                    |
| Provisions for transport and mounting to be given by the user                                                 |                      |                    |
| Foundation loading                                                                                            | Supplier information |                    |
| Gas schematic diagrams                                                                                        | Supplier information |                    |
| List of type test reports                                                                                     | Supplier information |                    |
| List of recommended spare parts                                                                               | Supplier information |                    |

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## **Annex M** (informative)

### **Electromagnetic compatibility on site**

EMC site measurements are not type tests but can be performed in special situations:

- where it is deemed applicable to verify that actual stresses are covered by the EMC severity class of the auxiliary and control circuits;
- in order to evaluate the electromagnetic environment;
- in order to apply proper mitigation methods, if applicable;
- to record the electromagnetically induced voltages in auxiliary and control circuits, due to switching operations both in the main circuit and in the auxiliary and control circuits. It is not considered useful to test all auxiliary and control circuits in a substation under consideration. A typical configuration should be chosen.

Measurement of the induced voltages should be made at representative ports in the interface between the auxiliary and control circuits and the surrounding network, for example, at the input terminals of control cubicles, without disconnection of the system. Instrumentation for recording induced voltages should be connected as outlined in IEC TR 60816 [44].

Switching operations should be carried out at normal operating voltage, both in the main circuit and in the auxiliary and control circuits. Induced voltages will vary statistically and thus a representative number of both making and breaking operations should be chosen, with random operating instants.

The switching operations in the main circuit shall be made under no-load conditions. The tests will thus include the switching of parts of the substation but no switching of load currents and no fault currents.

The making operations in the main circuit should be performed with trapped charge on the load side corresponding to normal operating voltage. This condition can be difficult to obtain at testing, and, as an alternative, the test procedure can be as follows:

- discharge the load side before the making operation, to assure that the trapped charge is zero;
- multiply recorded voltage values at the making operation by 2, in order to simulate the case with trapped charge on the load side.

The switching device in the primary system shall preferably be operated at rated pressure and auxiliary voltage.

NOTE 1 The most severe cases, with regard to induced voltages, normally occur when only a small part of a substation is switched.

NOTE 2 The most severe electromagnetic disturbances are expected to occur at disconnector switching, especially for GIS installations.

The recorded or calculated peak value of induced common-mode voltage, due to switching in the main circuit, should not exceed 1,6 kV for interfaces of the auxiliary and control circuits.

## **Annex N** (informative)

### **Standardization activities of HVDC**

There are over 200 HVDC projects installed worldwide, and a number of projects is in planning stage. The applications of HVDC have been increasing in recent years, driven by the need to integrate remote renewable sources, to strengthen network, and to facilitate controllable power interchange between countries and regions. There is growing demand to reduce equipment cost, and size/weight, especially in the offshore HVDC terminals. The first HVDC grid was installed in 2021, and it is projected that demands for multiterminal HVDC and HVDC grids will increase.

HVDC applications today and in future are seen in many different cases in the network. The need of controllable power flow is increasing due to the requirements of the integration of renewable and fluctuating power generation. The goals of today to reach CO<sub>2</sub> neutral electric power generation within the next decades will require more controllable power flow in the network. HVDC will offer practical solutions. Space requirements for the HVDC converter station including the substation are not easy to fulfil on land and have high cost impact for converter stations to connect offshore wind farms.

DC power transmission systems use today voltage sourced converter technology (VSC) and line commutated converter technology (LCC) depending on their application in the network. VSC technology becoming the mainstream for applications in the network while LCC technology is used for very high voltages (up to 1 100 kV) and very high currents (up to 6 000 A). Along with this, plans for multiple terminals are in progress.

DC switching devices (AIS and GIS) and DC assemblies (GIS) are now under standardization works in SC 17A and SC 17C. This work in TC 17 will provide common specifications for devices and assemblies of high-voltage application.

In addition to standardization for HV switchgear of TC 17 IEC documents of DC equipment and systems are being promoted by other TCs.

The need for standardization of HV DC switchgear was discussed at the plenary meeting of the switchgear technical committee TC 17 and ad-hoc group Ahg 37 was established to investigate the standardization requirements and a report was published in 2018.

At the 2018 Korea-Busan plenary meeting, it was decided by TC 17, SC 17A and SC 17C to start standardization work of DC common requirements in TC 17, DC switchgear devices in SC 17A and DC switchgear assemblies in SC 17C.

Based on this, in TC 17 a questionnaire was distributed (17/1052/Q) and the NP proposal was approved by P-member voting in May 2019. Then the dedicated WG was established in TC 17 to prepare common specifications for DC switchgear.

Regarding the DC standard voltages, TC 8 provides the horizontal standard requirements for DC networks, TC 99 defines the requirements for DC substations and TC 115 for DC transmission systems. This Technical Specification provides rated and test voltage values for insulation coordination as recommendations from the view of air and gas insulated switchgear technology.

HVDC switchgear equipment today is designed following project specific requirements. In future with more HVDC projects the requirement for standardized requirements will be more important to gain from cost reductions coming with standard switchgear devices and assemblies. In addition to cost reduction with standardization of equipment reliability, performance, and delivery time will improve. Standardization will bring benefits to the market, manufacturers, and testing laboratories.

## Annex A (normative)

### Methods for alternating current testing of DC gas-insulated metal-enclosed switchgear under conditions of arcing due to an internal fault

#### A.1 General

The occurrence of an arc inside DC GIS due to an internal fault is accompanied by various physical phenomena.

For example, the energy resulting from an arc developing in the enclosure will cause internal overpressure and local overheating, which will result in mechanical and thermal stressing of the switchgear. Moreover, the materials involved can produce hot decomposition products which can be discharged into the atmosphere.

This annex takes into account the internal overpressure acting on the enclosure and the thermal effects of the arc or its root on the enclosure. It does not cover all the effects which can constitute a risk, such as toxic gases and their by-products (see annexes of IEC 62271-4 for further information).

#### A.2 Short-circuit current arcing test

##### A.2.1 Test arrangements

When choosing the object to be tested, reference shall be made to the design documents for the DC GIS. The compartments which appear to have the least likelihood of withstanding the pressure and temperature rise in the event of arcing shall be selected.

In any case, the following points shall be observed:

- a) each test can be carried out on a test object not previously subjected to arcing tests. Test objects that have already undergone arcing tests shall be restored so that the conditions for further arcing tests are neither aggravated nor eased;
- b) the test object shall be fully equipped and arranged to include any protection device, such as pressure reliefs, short-circuiting devices, etc. provided by the manufacturer for the limitation of the effects of the arc.
- c) the test object shall be filled with normal insulating gas at filling pressure  $p_{re}$ .

##### A.2.2 Current and voltage applied

###### A.2.2.1 General

Single-pole enclosures shall be tested single-pole.

###### A.2.2.2 Voltage

The test can be made with an applied voltage lower than the rated voltage for equipment of the test object if the following conditions are met:

- a) the arc current shall be practically sinusoidal;
- b) the arc shall not extinguish prematurely.

### **A.2.2.3 Current**

#### **a) AC component**

The AC component at the beginning of the test shall lie within a +10 %, -0 % tolerance. The current shall not fall below 80 % of the specified value, provided that the average AC component is not less than the stated short-circuit current.

NOTE If the test plant does not permit this, the test duration can be extended by not more than 20 % with an appropriate adjustment to the times at which assessments are made.

#### **b) DC component**

The instant of short-circuit making shall be chosen to ensure that the first loop of the arc-current has a peak value according to IEC TS 62271-5.

### **A.2.2.4 Duration of the test**

The current duration shall be such as to cover the back-up protection chosen on the basis of the expected duration as determined by the protection devices. See 6.103.2.

## **A.2.3 Test procedure**

### **A.2.3.1 Test connections**

The point of current infeed to be chosen is the one likely to result in the most onerous condition.

Care shall be taken to ensure that the connections do not ease the test conditions. Generally, the enclosure is earthed on the same side of the test object into which the current is fed.

### **A.2.3.2 Arc initiation**

The arc shall be initiated by means of a metal wire of suitable diameter.

The point of initiation to be chosen is where the arc is likely to set up the rated stresses in the test object. Generally, this will be achieved when the arc is initiated in the vicinity of a partition furthest from the point of infeed and furthest from the pressure relief device, if fitted.

NOTE The arc cannot be initiated by perforating the solid insulation.

### **A.2.3.3 Measurement and recording of the test performance**

The following parameters shall be plotted and recorded

- the current and its duration
- the arc voltage;
- the pressure on one or more points of the test object and in each compartment, if the test object comprises more than one;

and, when applicable

- the instant of pressure relief (either by operation of the pressure relief device or perforation of the enclosure).

Phenomena such as pressure relief, enclosure perforation and external effects shall be observed and recorded by appropriate means, e.g. cameras, luminosity detectors.

## **A.2.4 Criteria to pass the test**

The switchgear is considered adequate if, during the test, no external effect other than the operation of suitable pressure relief devices occurs within the Joule integral value specified in 6.103.2, and if gases or vapours escaping under pressure are directed so as to minimize the danger to an operator performing his normal operating duties.

Projections of small parts, up to an individual mass of 60 g are accepted.

No fragmentation of the enclosure shall occur.

#### **A.2.5 Test report**

The following information shall be given in the test report:

- rating and description of the test object, the materials of the enclosure and the conductors, together with a drawing showing the main dimensions and the arrangement of pressure relief devices;
- arrangement of the test connections, the point of initiation of the arc and the position of the transducers for pressure measurements;
- current, voltage, energy, pressure and times derived from the oscillograms;
- precise description of the test results and observations;
- other relevant remarks;
- photographs of the conditions before and after the test.

#### **A.2.6 Extension of the test results**

The test results can be extended to other enclosures of similar design but of different size and shape and/or to other test parameters by calculations.

### **A.3 Composite verification by calculation and separate tests**

The manufacturer is responsible for demonstrating the validity of extrapolation of test results for other currents and other sizes of enclosures. The manufacturer shall provide all necessary information with the calculation.

NOTE Information about experience of internal arc tests and calculation principles are present in CIGRE Technical Brochure 602 [2], CIGRE Session 1998 – WG 21/23/33-03 [3] and RGE: 04/82 [4].

## **Annex B** (informative)

### **Technical and practical considerations of site testing**

#### **B.1 Test voltage generators**

DC GIS installations have a relatively high load capacitance. This means that:

- alternating voltage tests, especially at higher  $U_{rd}$ , require a high reactive power,
- impulse testing with standardized double exponential waveforms can be inefficient due to the poor voltage utilization of the impulse generator.

The following voltage-generating equipment can be used:

##### **a) Alternating voltage sources**

The alternating voltage can be produced by:

- test sets with a test transformer,
- test sets with a variable resonant reactor for constant frequency,
- test sets with a constant resonant reactor for variable frequency,
- power or voltage transformers by energization from the low-voltage side (entails no dismantling after testing).

NOTE The thermal stresses of the voltage source can be taken into account especially when using voltage transformers

##### **b) Impulse voltage sources**

For large installations and especially for high voltages for equipment, impulse generators for double exponential waves are unwieldy. Oscillating impulses can be produced with an impulse generator and a high-voltage coil connected to the switchgear to be tested to form a damped series resonant circuit. Oscillating switching impulses can be produced by discharging a capacitor into the low-voltage side of a power, voltage or test transformer.

##### **c) Direct voltage sources**

A direct voltage test generator should be used. Discharging current should be limited by protecting elements to avoid damages of the test object and test equipment.

#### **B.2 Locating discharges**

There are different phenomena caused by discharges which can be helpful in locating them. Some of the possible means which can be tried are as follows:

- detection of light emission;
- measurement of audible noise and vibrations;
- recording and evaluation of electromagnetic transients following discharge;
- detection of decomposition products of the gas.

#### **B.3 Special test procedures**

##### **B.3.1 General**

In general, it is recommended that all testing should be performed at the specified test voltage and filling density. However, in certain circumstances special test procedures have been established which are not in general use but are worth mentioning for technical and/or practical reasons.

For extensions the user should be responsible for any flashovers in the existing DC GIS and the manufacturer of the extension equipment should be responsible for any flashovers in the extension equipment.

### **B.3.2 Testing at reduced voltage**

In accordance with the practice in some countries, DC gas-insulated metal-enclosed switchgear, or at least one bay or an equivalent part of the DC GIS installation, can be assembled completely at the factory and tested there at its full rated withstand voltages. If the tested units are transported without dismantling or if dismantling is limited to very simple connections, and subject to agreement between manufacturer and user, the site test can be carried out with reduced voltages.

Direct voltage test with  $1,1 \times U_{rd}$ ; with a 10 min voltage application.

### **B.3.3 Testing at reduced gas density**

Tests with reduced gas density are not generally advisable.

## **B.4 Partial discharge measurements**

Partial discharge measurements can be helpful in detecting certain kinds of faults during site tests and in determining the need for maintenance of the equipment after a period in service. They are therefore a useful complement to dielectric tests on-site but are often difficult to perform because of ambient disturbances.

If such a test is possible and agreed upon, then the requirements given in 11.101.2.6 should be applied as far as possible.

If VHF/UHF partial discharge measuring methods are specified by the user, internal PD sensors are recommended.

## **B.5 Electrical conditioning**

The term "electrical conditioning" means a progressive application of an alternating or direct voltage either by steps or continuously. It can be performed by the manufacturer as part of the gas-filling process on-site in order to move possible particles towards areas with a low field strength, where they become harmless.

Electrical conditioning is not a requirement and does not replace the alternating or direct voltage test, unless the test voltage is increased up to the specified value. Nevertheless, a disruptive discharge should be reported to the user as it can result in a weakening of the insulation.

## **B.6 Repetition tests**

### **B.6.1 General**

The procedure to be implemented following a disruptive discharge during dielectric tests on-site can depend on several factors which include:

- the type of disruptive discharge (breakdown in self-restoring or non-self-restoring insulation) if it can be identified (see Clause B.2);
- magnitude of the arc energy dissipated during the discharge;
- shape and material of the solid insulation;
- strategic importance of the installation.

Consideration of these and any other relevant factors should allow a procedure to be established and agreed between the manufacturer and user. A recommended procedure is given below but should be treated only as a guide. Variations can be acceptable, depending on the significance of the factors involved.

## **B.6.2 Recommended procedure**

### **B.6.2.1 Procedure a)**

If the disruptive discharge occurs along the surface of a solid insulation, it is recommended that the compartment should be opened and the insulation carefully inspected for impairments. After taking any necessary remedial action, the compartment should then be subjected to the complete specified dielectric test once more.

### **B.6.2.2 Procedure b)**

A disruptive discharge in the gas can be due to contamination or a surface imperfection which can be burned away during the discharge. It can be acceptable, therefore, that the test can be repeated at the specified test voltage. Another test voltage can be agreed between manufacturer and user before the site tests have been started.

NOTE 1 It is assumed that the manufacturer can satisfy the user that the gaseous insulation can be regarded as self-restoring for the arc energy dissipated in the discharge.

NOTE 2 In the event of a disruptive discharge occurring during dielectric tests on-site, secondary discharges can occur in other parts of the test section.

If the repetition test fails, again Procedure a) should be followed.

## **B.7 Partial discharge detection method**

### **B.7.1 General**

For partial discharge detection on-site, the electrical VHF/UHF and the acoustic method can be used in DC GIS in addition to the conventional method, according to IEC 60270. These two methods are less sensitive to noise than the conventional measurement and can also be used for partial discharge monitoring in service. However, for these new methods the sensitivity depends on the distance between the defect (signal source) and the sensor. Suitable procedures for using the VHF/UHF and acoustic method are available. They ensure that defects causing an apparent charge of around a few pC can be found by such equipment. The proposed sensitivity verification can be easily performed on-site. The advantage of the two additional methods is that the location of the defects can be detected. The methods and the interpretation of the results can only be used by experienced personnel. The methods are still under investigation and are not yet standardized.

### **B.7.2 Conventional method according to IEC 60270**

Electromagnetic interference from radio transmitters and other sources is picked up by open-air bushings and lead to a PD measurement sensitivity of some tens of pC. For noise rejection, analogue and digital filtering methods are available. Nevertheless, the use of such filtering tools requires trained personnel and is a limitation in this procedure. In actual site conditions, a noise level below 5 pC is hard to achieve. Therefore, a totally encapsulated test circuit with a shielded coupling capacitor directly connected to the DC GIS is preferable. In such a case, a sensitivity below 5 pC is achievable for DC GIS with cable terminations and for DC GIS sections which are separated by an open disconnector from open-air bushings.

### **B.7.3 VHF/UHF method**

The discharge currents at the defects of DC GIS have rise times that can be less than 100 ps. These defects cause electromagnetic transients with frequency content to above 2 GHz. The resulting signals propagate within a DC GIS with the speed of light as electromagnetic waves.

Reflections occur at the numerous discontinuities in the arrangement. Due to the finite conductivity of the metallic conductors and losses at the dielectric surfaces, the propagating signals are damped. The result is a complex resonance pattern of electromagnetic waves within each compartment.

The partial discharge signals in the VHF/UHF range (e.g. 100 MHz to 2 GHz) can be detected in the time domain or the frequency domain by means of couplers, which are usually of similar design to capacitive couplers. As consequence of VHF/UHF signal attenuation, many couplers can need to be installed in a DC GIS. The maximum distance between two adjacent couplers is approximately some tens of metres. The VHF/UHF signal is best taken from internal couplers, but when these are not available, it is sometimes possible to use external couplers on windows or partition and support insulator.

Due to the complexity of the resonance patterns, the magnitude of the detected PD signal depends strongly on the location and, to a minor degree, on the orientation of the defect and the coupler. The VHF/UHF method can therefore not be calibrated as in, for example, the measuring circuit of IEC 60270. Instead, the sensitivity check in B.7.5 can be performed.

The signal-to-noise-ratio and therefore, the sensitivity of the VHF/UHF measuring device can be improved by using suitable couplers, amplifiers and filters. The VHF/UHF method has proved to be at least as sensitive in detecting defects as the conventional method, and this is mainly due to the low external noise level. Tests in laboratories and on-site have shown that small critical defects and even non-critical defects can be detected.

An accurate location of the defect can be obtained by using a broadband oscilloscope to measure the time interval between the signals arriving at adjacent couplers.

#### **B.7.4 Acoustic method**

Acoustic signals (mechanical waves) are emitted from defects in a DC GIS mainly in two primary mechanisms: moving particles excite a mechanical wave in the enclosure when they impinge on it, whereas discharges from fixed defects create a pressure wave in the gas, which is then transferred to the enclosure. The resulting signal will depend on the source and on the propagating path. As the enclosures normally are made of aluminium or steel, the damping of the signals is quite small. However, there is a loss of energy when the signals are transmitted from one part to another across a flange. Acoustic signals can be picked up by means of externally mounted sensors. Normally, either accelerometers or acoustic emission sensors are used and the test procedure consists of measuring between all flanges.

The location of a defect can be found by searching for the acoustic signal with the highest amplitude or by time travel measurements with two sensors. Separation between different kinds of defects is possible by analysing the shape of the acoustic signal.

The signal from a bouncing particle is broadband (i.e. >1 MHz) and has a high amplitude compared with signals emitted from pre-discharges at fixed defects. The particle type signal will be spatially attenuated as it moves away from the source point. In general, two parameters of the acoustic signal are important for this type of defect: amplitude and flight time (this being the time between two consecutive impacts of the particle). These parameters are essential not only for recognition of defect type but also for risk assessment.

Predischage type signals from protrusions will be very wideband close to the source, but because the gas acts as a low pass filter, the high frequencies are attenuated as the signal propagates away from the source towards the enclosure. Normally, detected signals from predischage sources are limited to the frequency range below 100 kHz. The signal level is found to be fairly constant within the same sections, and to drop some 8 dB once a flange is crossed.

Bouncing particles producing apparent discharges in the 5 pC range can be detected with a high signal-to-noise ratio. The detection limit for corona discharges is in the 2 pC range.

Sensitivity decreases with distance because the acoustic signals are absorbed and attenuated as they propagate in the DC GIS. However, no direct correspondence between apparent PD-level and acoustic signal level has been established. Acoustic measurement is immune to electromagnetic noise in the substation. The acoustic sensitivity to bouncing particles is usually much higher than the sensitivity of any other diagnostic method, when the sensor is placed close to the defect. The acoustic method is therefore good for detecting the location of such defects.

#### **B.7.5 Sensitivity verification of acoustic and UHF method**

For the acoustic and the UHF method, the same technical principle is applied for the sensitivity verification of partial discharge detection. First, an artificial acoustic or electrical pulse is determined which emits a signal similar to that from a real defect that causes a defined level of apparent charge (e.g. 5 pC or more) according to IEC 60270. Secondly, this artificial pulse is injected during the commissioning test or operating conditions into the DC GIS in order to verify the detection sensitivity for the DC GIS and the associated measuring equipment. If the stimulated signal can be measured at the adjacent sensor, the sensitivity verification has been successful for the DC GIS section between these sensors.

For further information, see IEC TS 62478 [33] and CIGRE Technical Brochure 654 [22].

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## Annex C (informative)

### Calculation of pressure rise due to an internal fault

The pressure rise in a closed compartment filled with gas due to an internal fault can be calculated according to (C.1):

$$\Delta p = C_{\text{equipment}} \times \frac{I_{\text{arc}} \times t_{\text{arc}}}{V_{\text{compartment}}} \quad (\text{C.1})$$

where

- $\Delta p$  is the pressure rise (MPa);
- $I_{\text{arc}}$  is the arc fault current (kA<sub>RMS</sub>);
- $V_{\text{compartment}}$  is the volume of the compartment (l);
- $t_{\text{arc}}$  is the arc duration (ms);
- $C_{\text{equipment}}$  is the equipment factor.

The value of the equipment factor  $C_{\text{equipment}}$  shall be demonstrated by the manufacturer by tests on similar equipment.

Formula (C.1) can be used to verify that the pressure will not exceed the type test pressure of the enclosures in case of an internal fault in a gas compartment without a pressure relief device. This is verified if the maximum arc current and arc duration (based on the performance of the protective system) does not cause a pressure rise which exceeds the type test pressure of the enclosures.

**NOTE** For direct currents, the equivalent current according to the value of Joule integral is used.

## Annex D (informative)

### Information to be given with enquiries, tenders and orders

#### D.1 General

This annex defines, in tabular format, the technical information to be exchanged between user and supplier.

Reference to “supplier information” means that only the supplier provides this information.

#### D.2 Normal and special service conditions

See Clause 4. Table D.1 shows the technical information to be given regarding normal and service conditions.

**Table D.1 – Normal and special service conditions**

|                                                         |                   | User requirements<br>(see Table 1) | Supplier proposals |
|---------------------------------------------------------|-------------------|------------------------------------|--------------------|
| Service condition                                       | Indoor or outdoor |                                    |                    |
| Ambient air temperature:                                |                   |                                    |                    |
| Minimum                                                 | °C                |                                    |                    |
| Maximum                                                 | °C                |                                    |                    |
| Solar radiation                                         | W/m <sup>2</sup>  |                                    |                    |
| Altitude                                                | m                 |                                    |                    |
| Pollution (RUSCDdc)                                     | mm/kV             |                                    |                    |
| Ice coating                                             | mm                |                                    |                    |
| Wind                                                    | m/s               |                                    |                    |
| Humidity                                                | %                 |                                    |                    |
| Condensation or precipitation                           |                   |                                    |                    |
| Vibration                                               | Class             |                                    |                    |
| Induced electromagnetic disturbance in secondary system | kV                |                                    |                    |

### D.3 Ratings

See Clause 5. Table D.2 shows the technical information to be given regarding ratings.

**Table D.2 – Ratings**

|                                                                                                     |    | User requirements                | Supplier proposals |
|-----------------------------------------------------------------------------------------------------|----|----------------------------------|--------------------|
| Nominal voltage of system                                                                           | kV |                                  |                    |
| Rated voltage for equipment ( $U_{rd}$ )                                                            | kV |                                  |                    |
| Rated insulation levels pole-to-earth                                                               |    |                                  |                    |
| Rated direct withstand voltage ( $U_{dd}$ )                                                         | kV |                                  |                    |
| Rated switching impulse withstand voltage ( $U_s$ )                                                 | kV |                                  |                    |
| Rated lightning impulse withstand voltage ( $U_p$ )                                                 | kV |                                  |                    |
| Rated continuous current ( $I_{rd}$ )                                                               | A  | According to single-line diagram |                    |
| Rated short-time withstand direct current ( $I_{kd}$ )                                              | kA |                                  |                    |
| Rated peak withstand current ( $I_{pd}$ )                                                           | kA |                                  |                    |
| Rated duration of short-circuit ( $t_{kd}$ )                                                        | s  |                                  |                    |
| Rated supply voltage of closing and opening devices and of auxiliary and control circuits ( $U_a$ ) | V  |                                  |                    |
| Rated supply frequency of closing and opening devices and of auxiliary circuits                     | Hz | DC or 50 Hz or 60 Hz             |                    |

## D.4 Design and construction

See Clause 6. Table D.3 shows the technical information to be given regarding design and construction.

**Table D.3 – Design and construction**

|                                                                                     |                      | User requirements    | Supplier proposals |
|-------------------------------------------------------------------------------------|----------------------|----------------------|--------------------|
| Gas or gas mixture                                                                  |                      | Supplier information |                    |
| Maximum relative gas leakage rate                                                   | % / year             |                      |                    |
| Filling pressure $p_{re}$                                                           | MPa                  | Supplier information |                    |
| Alarm pressure $p_{ae}$                                                             | MPa                  | Supplier information |                    |
| Minimum functional pressure $p_{me}$                                                | MPa                  | Supplier information |                    |
| Design pressure of enclosures                                                       | MPa                  | Supplier information |                    |
| Type test pressure of enclosures                                                    | MPa                  | Supplier information |                    |
| Routine test pressure of enclosures                                                 | MPa                  | Supplier information |                    |
| Operating pressure of pressure relief device                                        | MPa                  | Supplier information |                    |
| Internal arc fault<br>Joule integral value ( $Ej$ )                                 | (kA) <sup>2</sup> ·s |                      |                    |
| Quantity of gas of complete DC GIS at filling pressure $p_{re}$                     | kg                   | Supplier information |                    |
| Quantity of gas of the largest compartment at filling pressure $p_{re}$             | kg                   | Supplier information |                    |
| Maximum permissible gas dew point                                                   | °C                   | Supplier information |                    |
| Recommendation for dew point measurement and adequate correction                    |                      |                      |                    |
| Number of gas compartments                                                          |                      | Supplier information |                    |
| Length of longest section for transportation                                        | m                    |                      |                    |
| Weight of the heaviest piece of equipment to be handled during installation on-site | kg                   |                      |                    |
| Noise                                                                               |                      |                      |                    |

## D.5 Bus ducts

Table D.4 shows the technical information to be given for bus ducts.

**Table D.4 – Bus ducts**

|                                  |      | User requirements    | Supplier proposals |
|----------------------------------|------|----------------------|--------------------|
| Inductance                       | H/m  | Supplier information |                    |
| Capacitance                      | pF/m | Supplier information |                    |
| Resistance of enclosure at $f_r$ | Ω/m  | Supplier information |                    |
| Resistance of conductor at $f_r$ | Ω/m  | Supplier information |                    |
| Surge impedance                  | Ω    | Supplier information |                    |

## D.6 Disconnecter and earthing switch

Clause 10 of IEC TS 62271-314:2024 is applicable.

## D.7 Bushing

Clause 6 of IEC 60137:2017 is tentatively applicable with the following additions and refer to IEC/IEEE 65700-19-03 in terms of bushings for DC application. Table D.5 shows the technical information to be given for bushings.

**Table D.5 – Bushing**

| Outdoor-immersed bushing<br>(see IEC 60137:2017, 3.20) |       | User requirements                        | Supplier proposals |
|--------------------------------------------------------|-------|------------------------------------------|--------------------|
| Type of internal insulation                            |       | Gas-insulated or resin-impregnated paper |                    |
| Type of external insulation                            |       | Porcelain or composite                   |                    |
| Nominal specific creepage distance                     | mm/kV |                                          |                    |
| Shed profile                                           |       | Normal or alternating                    |                    |
| Rated direct withstand voltage ( $U_{dd}$ )            | kV    | As DC GIS or special                     |                    |
| Rated switching impulse withstand voltage ( $U_s$ )    | kV    | As DC GIS or special                     |                    |
| Rated lightning impulse withstand voltage ( $U_p$ )    | kV    | As DC GIS or special                     |                    |
| Cantilever test load                                   | N     |                                          |                    |
| Cantilever operation load                              | N     |                                          |                    |
| Type of line termination                               |       | According to drawing                     |                    |

NOTE There is presently no IEC document for direct voltage bushings containing subclause corresponding to Clause 6 of IEC 60137:2017.

## D.8 Cable connection

Clause 10 of IEC 62271-209:2019 is applicable with the following additions and refer to IEC 62895 in terms of cables for DC application. Table D.6 shows the technical information to be given for cable connections.

**Table D.6 – Cable connection**

|                             | User requirements        | Supplier proposals |
|-----------------------------|--------------------------|--------------------|
| Type of cable termination   | Fluid-filled or dry type |                    |
| Supplier of cable insulator | DC GIS or cable supplier |                    |

NOTE 1 There is presently no IEC document for direct voltage power cables containing subclause corresponding to Clause 10 of IEC 62271-209:2019.

NOTE 2 A CIGRE Joint working group is developing recommendations for dielectric testing of cable connection enclosures [23]. Resulting technical brochure will give more information.

## D.9 Transformer connection

Clause 9 of IEC 62271-211:2014 is applicable with the following additions and refers to IEC/IEEE 60076-57-129 in terms of transformers for DC application. Table D.7 shows the technical information to be given for transformer connections.

**Table D.7 – Transformer connection**

|                                                                  | User requirements | Supplier proposals |
|------------------------------------------------------------------|-------------------|--------------------|
| Insulated junction between transformer tank and DC GIS enclosure | Yes or no         |                    |

NOTE There is presently no IEC document for direct voltage power transformers containing subclause corresponding to Clause 9 of IEC 62271-211:2014.

## D.10 Current transducer

Markings described in 6.13 of IEC 61869-14:2018 are applicable with the following additions. Table D.8 shows the technical information to be given for current transducers.

**Table D.8 – Current transducer**

|                                | User requirements                | Supplier proposals |
|--------------------------------|----------------------------------|--------------------|
| Position of current transducer | According to single-line diagram |                    |
| Number of secondary outputs    | According to single-line diagram |                    |
| burdens and accuracy classes   | According to single-line diagram |                    |

## D.11 Voltage transducer

Markings described in 6.13 of IEC 61869-15:2018 are applicable with the following additions. Table D.9 shows the technical information to be given for voltage transducers.

**Table D.9 – Voltage transducer**

|                                |    | User requirements                | Supplier proposals |
|--------------------------------|----|----------------------------------|--------------------|
| Position of voltage transducer |    | According to single-line diagram |                    |
| Number of secondary outputs    |    | According to single-line diagram |                    |
| Burdens and accuracy classes   |    | According to single-line diagram |                    |
| On-site test voltage           | kV | Supplier information             |                    |

## D.12 Metal-oxide surge arrester

Annex D of IEC 60099-4:2014 is applicable for DC GIS arresters and refers to IEC 60099-9 in terms of arresters for HVDC converter stations.

NOTE There is presently no annex in IEC 60099-9 corresponding to Annex D of IEC 60099-4:2014.

**D.13 Documentation for enquiries and tenders**

Table D.10 shows the technical information to be given regarding documentation of enquiries and tenders.

**Table D.10 – Documentation for enquiries and tenders**

|                                                                                               | User requirements    | Supplier proposals |
|-----------------------------------------------------------------------------------------------|----------------------|--------------------|
| Single-line diagram                                                                           |                      |                    |
| Requirements for service continuity during maintenance, repair, extension and on-site testing |                      |                    |
| General arrangement drawings of substation layout                                             |                      |                    |
| Foundation loading                                                                            | Supplier information |                    |
| Gas schematic diagrams                                                                        | Supplier information |                    |
| List of type test reports                                                                     | Supplier information |                    |
| List of recommended spare parts                                                               | Supplier information |                    |
| DC GIS interface drawings (in case of later extension)                                        |                      |                    |

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**Annex E**  
(informative)

**List of notes concerning certain countries**

| Subclause       | Text                                                                                               |
|-----------------|----------------------------------------------------------------------------------------------------|
| 5.8 and 6.104.2 | National exceptions are required for Italy where rules for the design pressure is required by law. |

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## Annex F (informative)

### Long-term energized test

#### F.1 Test objects

The DC GIS and accessories should be assembled in the manner specified by the manufacturer's instructions with the appropriate grade and quantity of materials supplied.

#### F.2 Test sequence

The test sequence should contain zero-load (ZL) and high-load (HL) conditions. After each HL and ZL long-term stress, superimposed voltage tests should be performed. General recommendations for the test:

- Conductor heating with rated current of the system (alternating current or representative alternating or direct current).
- Enclosure/ambient temperature and PD should be monitored and recorded.
- Indoor or outdoor testing is possible at ambient temperature.

Testing at ambient temperature means that the dielectric time constant could be higher compared to the insulation system test if this test was carried out at maximum permissible ambient temperature.

The following proposed test sequences are examples and should be considered for testing of a DC GIS (Table F.1 or Table F.2).

**Table F.1 – Test sequence for long-term energized test**

|         |             |          |        |       |        |          |        |       |        |
|---------|-------------|----------|--------|-------|--------|----------|--------|-------|--------|
|         | Pre-test    | HL 1     |        |       |        |          |        |       |        |
| DC pol. |             | Positive |        |       |        | Negative |        |       |        |
| voltage |             | $U_T$    | + L/-L | $U_T$ | + S/-S | $U_T$    | + L/-L | $U_T$ | + S/-S |
| Days    |             | 30       |        | 30    |        | 30       |        |       |        |
| Load    |             | HL       |        | HL    |        | HL       |        |       |        |
|         |             | ZL       |        |       |        |          |        |       |        |
| DC pol. |             | Positive |        |       |        | Negative |        |       |        |
| voltage |             | $U_T$    | + L/-L | $U_T$ | + S/-S | $U_T$    | + L/-L | $U_T$ | + S/-S |
| Days    |             | 30       |        | 30    |        | 30       |        |       |        |
| Load    |             | ZL       |        | ZL    |        | ZL       |        |       |        |
|         |             | HL 2     |        |       |        |          |        |       |        |
| DC pol. |             | Positive |        |       |        | Negative |        |       |        |
| voltage |             | $U_T$    | + L/-L | $U_T$ | + S/-S | $U_T$    | + L/-L | $U_T$ | + S/-S |
| Days    |             | 30       |        | 30    |        | 30       |        |       |        |
| Load    |             | HL       |        | HL    |        | HL       |        |       |        |
|         | Cond. check |          |        |       |        |          |        |       |        |

It is allowed to combine the superimposed lightning and the superimposed switching voltage testing. This results in 60 days direct voltage testing and superimposed lightning and switching impulse testing. A resulting test sequence is given in Table F.2.

It is allowed to change the sequence in Table F.1. This means the sequence of HL cycle 1, HL cycle 2 and ZL cycle can be changed. Table F.1 starts the cycle with positive polarity and ends with negative polarity. It is allowed to change this as well, even between the cycles. Table F.1 specifies superimposed impulse voltage tests with lightning impulse first and switching impulse at the next sequence, but it is allowed to interchange

|                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| lightning impulse and switching impulse. During superimposed impulse testing, the laboratory can decide in which sequence unipolar or bipolar superimposed impulse voltage tests will be performed. Changes are possible as long as all states in Table F.1 are reached and each long-term stress is finished with a superimposed voltage test. A resulting test sequence is given in F.2. |                                                                                                                                                                                                                                                                                                                                    |
| $U_T$                                                                                                                                                                                                                                                                                                                                                                                      | is equal to $1.2 \times U_{rd}$                                                                                                                                                                                                                                                                                                    |
| +LI/-LI                                                                                                                                                                                                                                                                                                                                                                                    | 3 superimposed impulse tests with $+1,0 \times U_{rd}$ and $-0,8 \times U_P$<br>3 superimposed impulse tests with $+1,0 \times U_{rd}$ and $+0,8 \times U_P$<br>or<br>3 superimposed impulse tests with $-1,0 \times U_{rd}$ and $+0,8 \times U_P$<br>3 superimposed impulse tests with $-1,0 \times U_{rd}$ and $-0,8 \times U_P$ |
| +SI/-SI                                                                                                                                                                                                                                                                                                                                                                                    | 3 superimposed impulse tests with $+1,0 \times U_{rd}$ and $-0,8 \times U_S$<br>3 superimposed impulse tests with $+1,0 \times U_{rd}$ and $+0,8 \times U_S$<br>or<br>3 superimposed impulse tests with $-1,0 \times U_{rd}$ and $-0,8 \times U_S$<br>3 superimposed impulse tests with $-1,0 \times U_{rd}$ and $+0,8 \times U_S$ |
| Pre-test:                                                                                                                                                                                                                                                                                                                                                                                  | refer to F.3                                                                                                                                                                                                                                                                                                                       |
| Cond. check                                                                                                                                                                                                                                                                                                                                                                                | refer to F.4                                                                                                                                                                                                                                                                                                                       |

Table F.2 shows an example of a modified test sequence for long-term energized test, in the case a total testing time of 60 days or a combined testing of lightning impulse voltage and switching impulse voltage tests is preferred. Compared to Table F.1, the number of days was increased to 60 days. This is especially of interest if the insulation material has a very low conductivity. In order to achieve suitable impulse voltage testing, the superimposed lightning and switching impulse tests shall be performed directly after the 60 days.

Furthermore, the sequence for HL 1 and ZL was changed in order to place the more critical tests at the beginning of the long-term energized test.

**Table F.2 – Test sequence for long-term energized test with combined switching and lightning impulse voltage tests and changed sequence**

|         | Pre-test | ZL             |                  | HL 1           |                  | ZL             |                  | HL 1           |                  | HL 2           |                  |                |                  | Cond. check |
|---------|----------|----------------|------------------|----------------|------------------|----------------|------------------|----------------|------------------|----------------|------------------|----------------|------------------|-------------|
| DC pol. |          | negative       |                  | negative       |                  | positive       |                  | positive       |                  | negative       |                  | positive       |                  |             |
| voltage |          | U <sub>T</sub> | -S/-SI<br>+L/-LI | U <sub>T</sub> | -S/-SI<br>+L/-LI | U <sub>T</sub> | -S/-SI<br>+L/-LI | U <sub>T</sub> | -S/-SI<br>+L/-LI | U <sub>T</sub> | -S/-SI<br>+L/-LI | U <sub>T</sub> | -S/-SI<br>+L/-LI |             |
| Days    |          | 60             |                  | 60             |                  | 60             |                  | 60             |                  | 60             |                  | 60             |                  |             |
| Voltage |          | ZL             |                  | HL             |                  | ZL             |                  | HL             |                  | ZL             |                  | HL             |                  |             |
|         |          |                |                  |                |                  |                |                  |                |                  |                |                  |                |                  |             |

**Table F.3 – Test procedure for the long-term energized test**

|   | Test                                              | Test criteria                                                                        | Current              | Voltage                                                                            |
|---|---------------------------------------------------|--------------------------------------------------------------------------------------|----------------------|------------------------------------------------------------------------------------|
| 1 | Thermal-mechanical pre-stress                     | Stationary, if maximum temperature change of the test object is $\pm 5$ K within 1 h | $I_{AC}$ or $I_{DC}$ | 0                                                                                  |
| 2 | Cooling down                                      | 24 h cooling                                                                         | 0                    | 0                                                                                  |
| 3 | PD test                                           | At alternating or direct voltage                                                     | 0                    | $U_{pre-stressAC}$ , $U_{pd-testAC}$<br>or<br>$U_{pre-stressDC}$ , $U_{pd-testDC}$ |
| 4 | Superimposed lightning and switching impulse test | No flashovers are allowed.                                                           | 0                    | +LI/-LI<br>+SI/-SI                                                                 |

#### F.4 Condition check

Following the conclusion of the long-term test, a condition check of the overall system should be carried out to prove its integrity. A summary is given in Table F.4.

**Table F.4 – Condition check for the long-term energized test**

|   | Test              | Test criteria                                             | Current | Voltage                                                                            |
|---|-------------------|-----------------------------------------------------------|---------|------------------------------------------------------------------------------------|
| 1 | PD test           | At alternating or direct voltage                          | 0       | $U_{pre-stressAC}$ , $U_{pd-testAC}$<br>or<br>$U_{pre-stressDC}$ , $U_{pd-testDC}$ |
| 2 | Visual inspection | Opening of the test object and visual inspection of parts | 0       | 0                                                                                  |

#### F.5 Success criteria, re-testing and interruptions

The criteria for a successful outcome of the long-term energized test is that all tests should have been performed without breakdown. If there is a breakdown in any part of the test object, the complete long-term energized test should be repeated for that particular part of the test object.

If a breakdown of a test object occurs causing an interruption to the ongoing testing of other connected test objects, the test can be resumed after the failed test object is removed. The cycle (long-term stress and superimposed voltage test) should be repeated for the remaining test objects.

After any interruption, for example an interruption caused by external factors, the test can be resumed. Following rules have to be applied:

During the load cycles, the following test interruptions can be assumed:

- Interruption of the current source
- Interruption of the direct voltage

If the direct voltage is interrupted, the following procedure should be followed:

- If the interruption time  $t_{off} < 40$  min

– If the interruption happens at the end of the cycle

Recharge the test object with minimum 2 h direct voltage  $U_T$  (especially before superimposed voltage testing)

– If the interruption happens during the long-term cycle

The total test time of the long-term cycle shall not be extended

- If the interruption time  $40 \text{ min} < t_{\text{off}} < 3 \text{ days}$ 
  - If the interruption happens at the end of the cycle  
Recharge the test object with direct voltage, so that the remaining test time is minimum  $3 \times t_{\text{off}}$
  - If the interruption happens during the long-term cycle  
Extend the total test time of the long-term cycle by  $t_{\text{off}}$
- If the interruption time  $t_{\text{off}}$  is longer than  $t_{\text{off}} > 3 \text{ days}$ 
  - Repeat the long-term cycle
- If the cumulated interruption time during the long-term cycle  $\Sigma t_{\text{off}}$  is longer than 6 days
  - Repeat the long-term cycle

Interruptions at the end of the cycle can occur in order to initiate the superimposed voltage testing. The following are examples of scenarios which can occur:

- Change of impulse voltage generator parameters during the testing, especially changing from switching impulse voltage to lightning impulse voltage or vice versa
- Installation of coupling or blocking elements for the superimposed impulse voltage testing
- Installation of external impulse voltage generator or e.g. bringing the impulse voltage generator from a neighbouring laboratory

Further scenarios are possible, especially when using a spark gap as coupling element:

- short voltage dip due to ignition of spark gap, when spark gap distance is adjusted
- intentional reduction of direct voltage for pre-shots during set-up of the impulse generator, mainly for unipolar superimposed impulse voltage

Interruptions due to the above-mentioned procedure during the superimposed impulse voltage testing are not considered critical, as long as the direct voltage is switched on again directly after an interruption; no need for recharging shall be considered in such cases.

Before superimposed voltage testing, the current source can be switched off to protect the current source from damage. In this case the superimposed voltage test should be performed within 2 h at maximum. No earthing of the test object or switching off the direct voltage source is allowed. If the current source is interrupted longer than 2 h, follow the same procedure as for interruptions of the direct voltage source as mentioned above. Instead of recharging with  $U_T$ , reheat the assembly with the testing current  $I_{AC}$ , respectively  $I_{DC}$ .

After the load cycle and the superimposed voltage test, the direct voltage source is switched off and the next load cycle is built up. There is no time restriction during this period.

## Annex G (informative)

### Application of DC GIS under composite voltage of alternating and direct voltage components

#### G.1 General

DC technology with voltage-sourced converters (VSC) is known for efficient and reliable power transmission. When it comes to high power, DC VSC bipolar systems have the advantage of utilising a high voltage, i.e.  $\pm 525$  kV, and can therefore transmit more than 2 GW.

For developing converter stations in the most space-saving way possible, DC GIS can be utilized. Hence, DC GIS are applied in the DC switchgear. Within bipolar DC schemes, DC GIS can also be applied between the main transformers and the converters. At this point in bipolar DC systems, the equipment is subjected to a composite voltage stress consisting of alternating and direct voltage components.

NOTE Subclause 9.2.2 of IEC 60060-1:2010 is applicable for definition of 'voltage components'.

#### G.2 Composite voltage consisting of alternating and direct voltage components

Within bipolar DC systems, in the converter pole midpoint, a direct voltage of  $U_{rd}/2$  is present. Due to the design specifics for VSC half-bridge converters, there is a superimposed alternating voltage component at network fundamental frequency, which is in its peak value maintained as close as possible to the crest value of the continuous operating voltage (CCOV). The magnitude of the alternating voltage component is basically driven by the converter transformer transformation ratio, the aim to utilize a modulation index close to 1 for half-bridge converters and the overlay of a third harmonic content.

NOTE Subclause 3.1.1 of IEC 60071-12:2022 [28] is applicable for definition of CCOV.

Figure G.1 shows exemplarily the composite phase-to-earth voltage at the converter side of the main transformers for  $U_{rd} = 525$  kV. A direct voltage component of  $525/2$  kV is superimposed to an alternating voltage component with a frequency of 50 Hz and a corresponding third harmonic. For further consideration of the effect on the insulating system, the 3<sup>rd</sup> harmonic is neglected, and a simplified voltage form is utilized, reaching  $\hat{U} = 525$  kV.

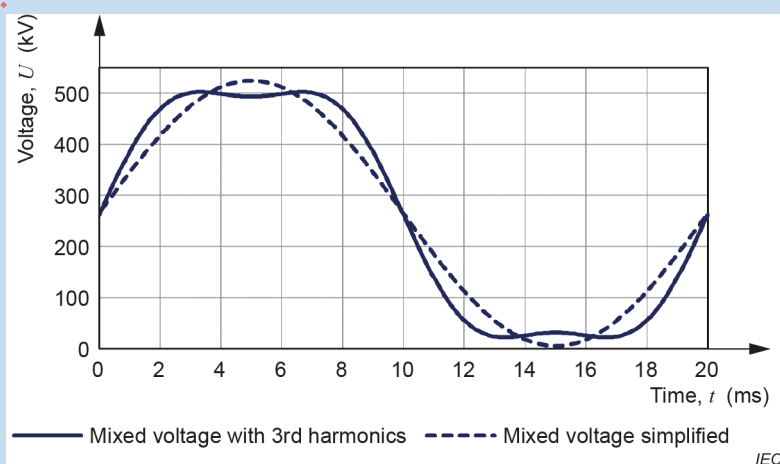


**Figure G.1 – Composite phase-to-earth voltage at midpoint of converter pole including third harmonic content and simplified voltage curve**

### **G.3 Recommendation for application of DC GIS in bipolar DC schemes under composite voltage stress**

After direct voltage application, the electric field is evolving from a capacitive field distribution to a resistive field distribution. The maximum electric field stress under composite voltage is covered by the maximum electric field stress due to pure direct voltage with the same maximum value. 'Pure direct voltage' includes the field transition after direct voltage application.

Hence, no additional testing is necessary for the application of an DC GIS in bipolar DC schemes between main transformer and DC converter, as long as the peak value of the composite voltage of alternating and direct voltage components is equal or lower than  $U_{rd}$  of the tested DC GIS. Under this condition, this document is fully applicable.

For other applications with a different ratio of alternating and direct voltage components, the same recommendation applies as long as the direct voltage component is roughly higher than the alternating voltage peak voltage. For other ratios of alternating and direct voltage components, more investigations are needed.

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## **Annex H** (informative)

### **DC switchgear located on neutral buses**

The switchgear located on neutral buses operates at lower direct voltage levels than the DC system voltage. For this reason, in a 100 kV DC system with 105 kV of maximum direct voltage, the rated direct voltage of a switchgear located in the neutral bus can be lower than 105 kV or even lower than 100 kV. For definition of rated direct voltage and rated withstand voltages IEC TS 62271-315:20—<sup>4</sup>, Table 1 can be used as reference.

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<sup>4</sup> Under preparation. Stage at the time of publication: IEC CDTS 62271-315:2024.

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# TECHNICAL SPECIFICATION



**High-voltage switchgear and controlgear –  
Part 318: DC gas-insulated metal-enclosed switchgear for rated voltages  
including and above 100 kV**

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# INTERNATIONAL ELECTROTECHNICAL COMMISSION

## HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

### Part 318: DC gas-insulated metal-enclosed switchgear for rated voltages including and above 100 kV

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IEC TS 62271-318 has been prepared by subcommittee 17C: Assemblies, of IEC technical committee 17: High-voltage switchgear and controlgear. It is a Technical Specification.

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

|             |                  |
|-------------|------------------|
| Draft       | Report on voting |
| 17C/930/DTS | 17C/937/RVDTS    |

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

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

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/standardsdev/publications](http://www.iec.ch/standardsdev/publications).

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

This document should be read in conjunction with IEC TS 62271-5:2024, to which it refers and which is applicable unless otherwise specified. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in IEC TS 62271-5:2024. Amendments to these clauses and subclauses are given under the same numbering, whilst additional subclauses, are numbered from 101.

The reader's attention is drawn to the fact that Annex E lists all of the "in-some-country" clauses on differing practices of a less permanent nature relating to the subject of this document.

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

- reconfirmed,
- withdrawn, or
- revised.

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## HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

### Part 318: DC gas-insulated metal-enclosed switchgear for rated voltages including and above 100 kV

#### 1 Scope

This part of IEC 62271 specifies requirements for gas-insulated metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas or gas mixture other than air at atmospheric pressure, for direct current of rated voltages including and above 100 kV, for indoor and outdoor installation. This document includes rules for service conditions, ratings, design, and construction requirements. Test requirements and criteria for proof for passing type and routine tests are defined in this document for development and manufacturing of DC switchgear.

For the purpose of this document, the terms "DC GIS" and "DC switchgear" are used for "DC gas-insulated metal-enclosed switchgear".

This specification is applicable for both Line Commutated Converter (LCC) and Voltage Sourced Converter (VSC) for HVDC systems.

The DC gas-insulated metal-enclosed switchgear covered by this document consists of individual components intended to be directly connected together and able to operate only in this manner.

This document completes and amends, if applicable, the various relevant documents applying to the individual components constituting DC gas-insulated metal-enclosed switchgear.

#### 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 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60085:2007, *Electrical insulation – Thermal evaluation and designation*

IEC 60068-2-11:2021, *Environmental testing – Part 2-11: Tests – Test Ka: Salt mist*

IEC 60068-2-17:2023, *Environmental testing – Part 2-17: Tests – Test Q: Sealing*

IEC/IEEE 60076-57-129:2017, *Power transformers – Part 57-129: Transformers for HVDC applications*

IEC 60099-4:2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60099-9:2014, *Surge arresters – Part 9: Metal-oxide surge arresters without gaps for HVDC converter stations*

IEC 60137:2017, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60270:2000, *High-voltage test techniques – Partial discharge measurements*  
IEC 60270:2000/AMD1:2015

IEC 60376:2018, *Specification of technical grade sulphur hexafluoride (SF<sub>6</sub>) and complementary gases to be used in its mixtures for use in electrical equipment*

IEC 60480:2019, *Specifications for the re-use of sulphur hexafluoride (SF<sub>6</sub>) and its mixtures in electrical equipment*

IEC TS 60815-1:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC TS 60815-4:2016, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 4: Insulators for d.c. systems*

IEC 61869-14:2018, *Instrument transformers – Part 14: Additional requirements for current transformers for DC applications*

IEC 61869-15:2018, *Instrument transformers – Part 15: Additional requirements for voltage transformers for DC applications*

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

IEC 62271-4, *High-voltage switchgear and controlgear – Part 4: Handling procedures for gases for insulation and/or switching*

IEC TS 62271-5:2024, *High-voltage switchgear and controlgear – Part 5: Common specifications for direct current switchgear*

IEC 62271-209:2019, *High-voltage switchgear and controlgear – Part 209: Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV – Fluid-filled and extruded insulation cables – Fluid-filled and dry-type cable terminations*  
IEC 62271-209:2019/AMD1:2022

IEC 62271-211:2014, *High-voltage switchgear and controlgear – Part 211: Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

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

IEC TS 62271-313, *High-voltage switchgear and controlgear – Part 314: Direct current disconnectors and earthing switches*

IEC TS 62271-314:2024, *High-voltage switchgear and controlgear – Part 314: Direct current disconnectors and earthing switches*

IEC TS 62271-315:20—<sup>1</sup>, *High voltage switchgear and controlgear — Part 315: Direct current (DC) transfer switches*

IEC 62895:2017, *High voltage direct current (HVDC) power transmission — Cables with extruded insulation and their accessories for rated voltages up to 320 kV for land applications — Test methods and requirements*

ISO 22479:2019, *Corrosion of metals and alloys — Sulfur dioxide test in a humid atmosphere (fixed gas method)*

IEC/IEEE 65700-19-03:2014, *Bushings for DC application*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 62271-5:2024 and the following, apply.

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

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

#### 3.101

##### **metal-enclosed switchgear and controlgear**

switchgear and controlgear assemblies with an external metal enclosure intended to be earthed, and complete except for external connections

[SOURCE: IEC 60050-441:1984, 441-12-04, modified – The note was deleted.]

#### 3.102

##### **DC gas-insulated metal-enclosed switchgear**

metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas or gas mixture other than air at atmospheric pressure and used for DC applications

Note 1 to entry: This term generally applies to high-voltage switchgear and controlgear.

[SOURCE: IEC 60050-441:1984, 441-12-05, modified – "or gas mixture" and "and used for DC applications" has been added in the definition.]

#### 3.103

##### **DC gas-insulated switchgear enclosure**

part of DC gas-insulated metal-enclosed switchgear retaining the insulating gas under the prescribed conditions necessary to maintain safely the highest insulation level, protecting the equipment against external influences and providing a high degree of protection to personnel

[SOURCE: IEC 62271-203:2022, 3.103, modified – Addition of "DC" in the main term and in the definition.]

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<sup>1</sup> Under preparation. Stage at the time of publication: IEC CDTS 62271-315:2024.

**3.104****isolating link**

part of the conductor which can easily be opened or removed in order to isolate two parts of the GIS from each other

Note 1 to entry: The open gap is designed to withstand the test voltages across isolating distance according to IEC TS 62271-5:2024, Table 1.

Note 2 to entry: The purpose of an isolating link is to ensure electrical isolation between sections of a GIS e.g., during maintenance and repair work.

[SOURCE: IEC 62271-203:2022, 3.104, modified – New reference to Table 1 of IEC TS 62271-5:2024 in Note 1 to entry.]

**3.105****removable link**

part of the conductor which can easily be opened or removed in order to isolate two parts of the GIS from each other

Note 1 to entry: The open gap is designed to withstand the phase-to-earth test voltages according to IEC TS 62271-5:2024, Table 1.

[SOURCE: IEC 62271-203:2022, 3.105, modified – In the definition, "separate" was replaced with "isolate"; addition of a new reference to Table in Note 1 to entry; deletion of Note 2 to entry.]

**3.106****compartment**

part of DC gas-insulated metal-enclosed switchgear, which is gastight and enclosed

Note 1 to entry: A compartment can be designated by the main component contained therein, e.g., busbar compartment.

[SOURCE: IEC 62271-203:2022, 3.106, modified – Addition of "DC" in the definition; deletion of "circuit-breaker compartment" as an example in Note 1 to entry.]

**3.107****component**

essential part of the main or earthing circuits of DC gas-insulated metal-enclosed switchgear which serves a specific function

Note 1 to entry: Examples for components are disconnecter, switch, DCVT, DCCT, bushing, busbar.

[SOURCE: IEC 62271-203:2022, 3.107, modified – Addition of "DC" in the definition; deletion of "circuit-breaker compartment", "switch", "fuse", "instrument transformer" as examples and addition of "DCVT" and "DCCT" as examples.]

**3.108****support insulator**

internal insulator supporting one or more conductors

[SOURCE: IEC 62271-203:2022-05, 3.108]

**3.109****partition**

gas tight support insulator of DC gas-insulated metal-enclosed switchgear separating two adjacent compartments

[SOURCE: IEC 62271-203:2022-05, 3.109, modified – Addition of "DC" in the definition.]

### 3.110

#### **bushing**

device that enables one or several conductors to pass through an enclosure and insulate the conductors from it

[SOURCE: IEC 60050-471:2007, 471-02-01, modified – In the definition, "an enclosure" inserted after "pass through" and "a partition such as a wall or a tank" deleted. Deletion of Note 1 to entry and Note 2 to entry.]

### 3.111

#### **main circuit**

all the conductive parts of DC gas-insulated metal-enclosed switchgear included in a circuit which is intended to transmit electrical energy

[SOURCE: IEC 60050-441:1984, 441-13-02, modified – "DC gas-insulated metal-enclosed switchgear" inserted after "parts of" and "an assembly" deleted.]

### 3.112

#### **auxiliary circuit**

all the conductive parts of DC gas-insulated metal-enclosed switchgear included in a circuit intended to control, measure, signal and regulate

Note 1 to entry: The auxiliary circuits of DC gas-insulated metal-enclosed switchgear include the control and auxiliary circuits of the switching devices.

[SOURCE: IEC 62271-203:2022, 3.112, modified – Addition of "DC" in the definition and in Note 1 to entry.]

### 3.113

#### **enclosure design temperature**

maximum temperature that the enclosures can reach under specified maximum service conditions

[SOURCE: IEC 62271-203:2022, 3.113]

### 3.114

#### **enclosure design pressure**

relative pressure used to determine the design of the enclosure

Note 1 to entry: It is at least equal to the maximum pressure in the enclosure at the highest temperature that the gas used for insulation can reach under specified maximum service conditions.

[SOURCE: IEC 62271-203:2022, 3.114, modified – Note 2 to entry deleted.]

### 3.115

#### **partition design pressure**

relative pressure across the partition

Note 1 to entry: It is at least equal to the maximum differential pressure across the partition during maintenance activities.

[SOURCE: IEC 62271-203:2022, 3.115, modified – In the definition, deletion of "used to determine the design of the partition"; Note 2 to entry deleted.]

**3.116****operating pressure**

<pressure relief device> relative pressure chosen for the opening operation of pressure relief devices

[SOURCE: IEC 62271-203:2022, 3.116]

**3.117****routine test pressure**

<enclosures and partitions> relative pressure to which all enclosures and partitions are subjected after manufacturing

[SOURCE: IEC 62271-203:2022, 3.117]

**3.118****type test pressure**

<enclosures and partitions> relative pressure to which all enclosures and partitions are subjected for type test

[SOURCE: IEC 62271-203:2022, 3.118]

**3.119****fragmentation**

damage to enclosure due to pressure rise with projection of solid material

[SOURCE: IEC 62271-203:2022, 3.119]

**3.120****disruptive discharge**

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

[SOURCE: IEC 62271-203:2022, 3.120]

**3.121****transport unit**

part of DC gas-insulated metal-enclosed switchgear suitable for shipment without being dismantled

[SOURCE: IEC 62271-203:2022, 3.121, modified – Addition of "DC" in the definition.]

**3.122****functional unit**

part of metal-enclosed switchgear and controlgear comprising all the components of the main circuits and auxiliary circuits that contribute to the fulfilment of a single function

Note 1 to entry: Functional units may be distinguished according to the function for which they are intended, for example complete bay or functional parts of a bay like complete, disconnector, earthing switch, current transducer, operating mechanism, enclosure, etc.

[SOURCE: IEC 60050-441:1984, 441-13-04, modified – "metal-enclosed" inserted after "part of" and "an assembly of" deleted. In the note the examples have been exchanged with examples relevant for GIS.]

### 3.123

#### zero-load

ZL

no current flowing through conductor

### 3.124

#### high-load

HL

continuous heating period at rated continuous current, which duration is not less than the thermal stabilization time (time  $d_g$ )

### 3.125

#### thermal stabilisation time

duration  $d_g$

period of time from load current applied to reach thermal steady state

### 3.126

#### thermal steady state

thermal steady state is defined as when the increase of temperature rise does not exceed 1 K in 1 h

### 3.127

#### DC steady state

DC steady state is defined as when minimum 90 % of the resistive field distribution is reached

Note 1 to entry: DC steady state is reached at the end of the transition from a capacitive to a resistive field distribution in the DC GIS. Depending on insulating material properties that are affected by temperature, electric field strength, etc., the transition to a resistive field distribution takes from hours to months.

### 3.128

#### electric field transition time

duration  $d_{DC}$

period of time from direct voltage application to the DC steady state

### 3.129

#### superimposed impulse voltage test

S/IMP

simultaneous stress consisting of the direct voltage and the lightning or switching impulse voltage superimposed upon it

## 4 Normal and special service conditions

### 4.1 Normal service conditions

Subclause 4.1 of IEC TS 62271-5:2024 is applicable, taking into account the recommended values presented in Table 1 of this document.

### 4.2 Special service conditions

Subclause 4.2 of IEC TS 62271-5:2024 is applicable, taking into account the recommended values presented in Table 1 of this document.

In the cases where higher than (>) is used in the table, the values shall be specified by the user as described in IEC TS 62271-5:2024.

NOTE Seismic evaluation is part of IEC 62271-207.

#### 4.101 General

**Table 1 – Reference table of service conditions relevant to DC GIS**

| Item                                                                                                                                                                                         | Normal                                               |                                                      | Special                                              |                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|
|                                                                                                                                                                                              | Indoor                                               | Outdoor                                              | Indoor                                               | Outdoor                                              |
| Ambient air temperature:                                                                                                                                                                     |                                                      |                                                      |                                                      |                                                      |
| Minimum (°C)                                                                                                                                                                                 | –5                                                   | –25                                                  | –25                                                  | –50                                                  |
| Maximum (°C)                                                                                                                                                                                 | +40                                                  | +40                                                  | +50                                                  | +50                                                  |
| Solar radiation (W/m <sup>2</sup> )                                                                                                                                                          | Not applicable                                       | 1 000                                                | Not applicable                                       | >1 000                                               |
| Altitude (m)                                                                                                                                                                                 | 1 000                                                | 1 000                                                | >1 000                                               | >1 000                                               |
| RUSCD <sub>dc</sub> <sup>a</sup>                                                                                                                                                             | reference is made to IEC TS 62271-5:2024, Clause B.2 | reference is made to IEC TS 62271-5:2024, Clause B.2 | Reference is made to IEC TS 62271-5:2024, Clause B.3 | Reference is made to IEC TS 62271-5:2024, Clause B.3 |
| Ice coating (mm)                                                                                                                                                                             | Not applicable                                       | 20                                                   | Not applicable                                       | >20                                                  |
| Wind (m/s)                                                                                                                                                                                   | Not applicable                                       | 34                                                   | Not applicable                                       | >34                                                  |
| Average humidity over 24 hours (%)                                                                                                                                                           | 95                                                   | 100                                                  | 98                                                   | 100                                                  |
| Condensation or precipitation                                                                                                                                                                | Occasional                                           | Yes                                                  | Yes                                                  | Yes                                                  |
| Abnormal vibrations, shock or tilting                                                                                                                                                        | Not applicable                                       | Not applicable                                       | Applicable                                           | Applicable                                           |
| NOTE The user's specification can use any combination of normal or special service conditions above.                                                                                         |                                                      |                                                      |                                                      |                                                      |
| <sup>a</sup> Usually DC site severity is covered by a reference d.c. Unified Specific Creepage Distance, and IEC TS 60815-4:2016 gives information on how to determine RUSCD <sub>dc</sub> . |                                                      |                                                      |                                                      |                                                      |

At any altitude the dielectric characteristics of the internal insulation are identical with those measured at sea-level. For this internal insulation no specific requirements concerning the altitude are applicable.

Some items of a DC GIS such as pressure relief devices and pressure and density monitoring devices can be affected by altitude. The manufacturer shall take appropriate measures if necessary.

## 5 Ratings

### 5.1 General

Subclause 5.1 of IEC TS 62271-5:2024 is applicable with the following addition:

- j) rated values of the components forming part of DC gas-insulated metal-enclosed switchgear, including their operating devices and auxiliary equipment.

### 5.2 Rated direct voltage ( $U_{rd}$ )

Subclause 5.2 of IEC TS 62271-5:2024 is applicable with the following addition:

Components forming part of the DC GIS can have individual values of rated voltage for equipment in accordance with the relevant documents.

### 5.3 Rated insulation level ( $U_{dd}$ , $U_p$ , $U_s$ )

Subclause 5.3 of IEC TS 62271-5:2024 is applicable with the following addition:

The DC GIS comprises components having a definite insulation level. Although internal faults can largely be avoided by the choice of a suitable insulation level, measures to limit external overvoltages (e.g. surge arresters,) should be considered.

NOTE 1 Regarding the external parts of bushings (if any), see to IEC/IEEE 65700-19-03:2014.

NOTE 2 The waveforms are standardized lightning impulse and switching impulse shapes, pending the results of studies on the ability of this equipment to withstand other types of impulses.

NOTE 3 The choice between alternative insulation levels for a particular rated voltage for equipment can be based on insulation coordination studies, taking into account also the self-generated transient overvoltages due to switching.

NOTE 4 Annex H provides further information about DC switchgear located on a neutral bus.

### 5.4 Rated continuous current ( $I_{rd}$ )

Subclause 5.4 of IEC TS 62271-5:2024 is applicable with the following addition:

Some main circuits of DC GIS (e.g. busbars, feeder circuits, etc.) can have different values of rated continuous current. However, these values should also be selected from R10 series.

### 5.5 Rated values of short-time withstand current

#### 5.5.1 Typical waveform of short-circuit current

Subclause 5.5.1 of IEC TS 62271-5:2024 is applicable.

#### 5.5.2 Rated short-time withstand direct current ( $I_{kd}$ )

Subclause 5.5.2 of IEC TS 62271-5:2024 is applicable.

#### 5.5.3 Rated peak withstand current ( $I_{pd}$ )

Subclause 5.5.3 of IEC TS 62271-5:2024 is applicable.

#### 5.5.4 Rated duration of short-circuit ( $t_{kd}$ )

Subclause 5.5.4 of IEC TS 62271-5:2024 is applicable.

### 5.6 Rated supply voltage of auxiliary and control circuits ( $U_a$ )

Subclause 5.6 of IEC TS 62271-5:2024 is applicable.

### 5.7 Rated supply frequency of auxiliary and control circuits

Subclause 5.7 of IEC TS 62271-5:2024 is applicable.

### 5.8 Rated pressure of compressed gas supply for controlled pressure systems

Subclause 5.8 of IEC 62271-1:2017 is applicable. Annex E provides further information about notes concerning certain countries.

## **6 Design and construction**

### **6.1 Requirements for liquids in switchgear and controlgear**

Subclause 6.1 of IEC TS 62271-5:2024 is applicable.

### **6.2 Requirements for gases in switchgear and controlgear**

Subclause 6.2 of IEC TS 62271-5:2024 is applicable.

### **6.3 Earthing of switchgear and controlgear**

Subclause 6.3 of IEC TS 62271-5:2024 is applicable.

#### **6.3.101 Earthing of the main circuit**

To ensure safety during maintenance work, all parts of the main circuit to which access is required or provided shall be capable of being earthed.

Earthing can be made by:

- a) earthing switches with a making capacity equal to the rated peak withstand current, if there is still a possibility that the circuit connected is energised;
- b) earthing switches without a making capacity or with a making capacity lower than the rated peak withstand current, if there is certainty that the circuit connected is not energised.

Furthermore, it shall be possible, after opening the enclosure, to connect removable earthing devices for the duration of the work on a circuit element previously earthed via an earthing switch. The removable earthing device shall have the relevant short-circuit withstand capability and/or induced current capability.

The earthing circuit can be degraded after being subjected to the short-circuit current. After such event, it can be applicable to replace the earthing circuit.

#### **6.3.102 Earthing of the enclosure**

The enclosures shall be connected to earth. All metal parts which do not belong to a main or an auxiliary circuit shall be earthed. For the interconnection of enclosures, frames, etc., fastening (e.g. bolting or welding) is acceptable for providing electrical continuity.

The continuity of the earthing circuits can be ensured taking into account the thermal and electrical stresses caused by the current they have to carry.

### **6.4 Auxiliary and control equipment and circuits**

Subclause 6.4 of IEC TS 62271-5:2024 is applicable.

### **6.5 Dependent power operation**

Subclause 6.5 of IEC TS 62271-5:2024 is applicable.

### **6.6 Stored energy operation**

Subclause 6.6 of IEC TS 62271-5:2024 is applicable.

### **6.7 Independent unlatched operation (independent manual or power operation)**

Subclause 6.7 of IEC TS 62271-5:2024 is applicable.

## 6.8 Manually operated actuators

Subclause 6.8 of IEC TS 62271-5:2024 is not applicable.

## 6.9 Operation of releases

Subclause 6.9 of IEC TS 62271-5:2024 is applicable.

## 6.10 Pressure/level indication

Subclause 6.10 of IEC TS 62271-5:2024 is applicable with the following addition:

The performance of the DC GIS is dependent upon the gas density of the pure gas or the gas mixtures.

For DC GIS it is not sufficient to monitor the gas pressure without temperature compensation.

The gas density or temperature compensated gas pressure in each compartment shall be continuously monitored. The monitoring device shall provide at least two alarm levels for pressure or density (alarm and minimum functional pressure or density). The correct functioning of gas monitoring devices shall be able to be checked with the high-voltage equipment in service.

NOTE 1 When the filling density differs between adjacent compartments, an additional alarm indicating over pressure or density can be used, if the DC GIS design requires it.

NOTE 2 Tolerances of the monitoring device, as well as possible differences in temperature (e.g. inside/outside of a building) between the monitoring device and the volume of gas being monitored, can be considered.

NOTE 3 Checking of gas monitoring can initiate wrong alarms which can initiate or inhibit switching operations.

NOTE 4 It is preferable for gas monitoring devices to be placed as close as possible to the gas compartment which is being monitored to ensure measuring accuracy and minimum leakage, however consideration can be given to safety and accessibility when choosing the location.

NOTE 5 The preferred solution for checking the gas monitoring device is to separate the density monitor from the gas compartment without mechanically removing it from the DC GIS, in order to minimize gas losses.

## 6.11 Nameplates

Subclause 6.11 of IEC TS 62271-5:2024 is applicable with the following addition:

A common nameplate shall be provided to identify the DC GIS. It shall, as a minimum, detail the ratings listed in Clause 5 of this document. The common nameplate shall be clearly readable from the position of local operation side.

For each individual device a nameplate according to its relevant document is required where ratings are not detailed on the common nameplate.

The nameplates shall be durable and clearly legible for the lifetime of the DC GIS.

The manufacturer shall give information of the type, volume and mass of the gas contained in each gas compartment as well as the total mass for the entire DC GIS installation either on the nameplate or on a label placed in a visible location. If required, more information shall be provided in the instruction manual.

## 6.12 Locking devices

Subclause 6.12 of IEC TS 62271-5:2024 is applicable with the following addition:

The following provisions are mandatory for apparatus installed in main circuits which are used as isolating distance and earthing:

- apparatus installed in main circuits, which are used for ensuring isolating distances during maintenance work, shall be provided with visible locking devices to prevent closing (e.g. padlock);
- earthing switches shall be provided with locking devices to avoid opening during maintenance work.

## 6.13 Position indication

Subclause 6.13 of IEC TS 62271-5:2024 is applicable with the following addition:

In case of disconnector switch and earthing switch subclause 6.104.2 of IEC TS 62271-314:2024 is applicable.

## 6.14 Degrees of protection provided by enclosures

Subclause 6.14 of IEC TS 62271-5:2024 is applicable.

## 6.15 Creepage distances for outdoor insulators

Subclause 6.15 of IEC TS 62271-5:2024 is applicable with the following addition:

This applies to bushings only.

## 6.16 Gas and vacuum tightness

### 6.16.1 General

Subclause 6.16.1 of IEC TS 62271-5:2024 is applicable with the following addition:

This applies only to insulating and switching medium, not to operating medium of switchgear and controlgear.

DC GIS shall be a closed pressure system or a sealed pressure system.

Leakage losses and handling releases shall be considered separately. The objective is to minimize the release of gas in the atmosphere due to leakage and handling (see IEC 62271-4).

The cause of any leakage shall be investigated carefully, and corrective actions shall be considered, especially if it is above the specified values.

### 6.16.2 Controlled pressure systems for gas

Subclause 6.16.2 of IEC TS 62271-5:2024 is applicable.

### 6.16.3 Closed pressure systems for gas

Subclause 6.16.3 of IEC TS 62271-5:2024 is applicable with the following addition:

The relative leakage rate from any single compartment of DC GIS to atmosphere and between compartments shall not exceed 0,5 % per year for the expected operation duration of the equipment.

NOTE 1 Expected operation duration is typically 40 years under normal service condition as specified in Annex D.

The permissible relative leakage rate  $F_{rel}$  for type tests is specified as:

- $\leq 0,1$  % per year for SF<sub>6</sub>, SF<sub>6</sub> mixtures and for other gas mixtures with GWP > 1 000.
- $\leq 0,5$  % per year for other gas mixtures with GWP  $\leq 1$  000.

NOTE 2 The global warming potential (GWP) of gases in DC GIS is the major reason for requiring low permissible leakage rates. Solutions with alternative gases with GWP lower than 1 000 exist. GWP (100 years) of SF<sub>6</sub> is 24 300 according to the IPCC – AR6 Climate Change 2021 [1]<sup>2</sup>.

For small gas compartments containing less than 1 kg gas, the permissible relative leakage rate  $F_{rel}$  for type tests is specified as:

- $\leq 0,2$  % per year for SF<sub>6</sub>, SF<sub>6</sub> mixtures and for other gas mixtures with GWP > 1 000.

#### 6.16.4 Sealed pressure systems

Subclause 6.16.4 of IEC TS 62271-5:2024 is applicable.

##### 6.16.101 Leakage

In accordance with standardized procedure defined in Clause 10 of IEC TR 62271-306:2012 and IEC TR 62271-306:2012/AMD1:2018, the manufacturer shall demonstrate that the relative leakage rate from any compartment of DC GIS or between compartments complies with 6.16.3 or 6.16.4.

##### 6.16.102 Gas handling

The DC GIS shall be designed to minimize life cycle gas-handling losses (including end of life activities). The manufacturer shall specify test and maintenance procedures for minimizing gas-handling releases and shall identify the gas releases associated with each procedure.

Procedures for gas handling according to IEC 62271-4 shall be used.

#### 6.17 Tightness for liquid systems

Subclause 6.17 of IEC TS 62271-5:2024 is not applicable.

#### 6.18 Fire hazard (flammability)

Subclause 6.18 of IEC TS 62271-5:2024 is applicable.

#### 6.19 Electromagnetic compatibility (EMC)

Subclause 6.19 of IEC TS 62271-5:2024 is applicable.

#### 6.20 X-Ray emission

Subclause 6.20 of IEC TS 62271-5:2024 is applicable.

<sup>2</sup> Numbers in square brackets refer to the Bibliography.

## 6.21 Corrosion

Subclause 6.21 of IEC TS 62271-5:2024 is applicable with the following addition:

The continuity of the earthing circuits shall be ensured taking into account the corrosion of bolted and screwed assemblies.

## 6.22 Filling levels for insulation, switching and/or operation

Subclause 6.22 of IEC TS 62271-5:2024 is applicable.

### 6.101 General requirements for DC GIS

DC GIS shall be designed so that normal service, inspection and maintenance operations, earthing of connected cables, locating of cable faults, voltage tests on connected cables or other apparatus and the elimination of dangerous electrostatic charges, can be carried out safely, after installation and extension.

The design of the equipment shall be such that the agreed permitted movement of foundations and mechanical or thermal effects do not impair the assigned performance of the equipment.

All components of the same type (rating, design and construction, etc.) which can be replaced shall be interchangeable.

The various components contained within the enclosure are subject to their relevant documents except where modified by this document.

### 6.102 Pressure coordination

The pressure inside a DC GIS can vary from the filling pressure  $p_{re}$  due to different service conditions.

In service conditions, the mechanical stresses are associated with the internal pressure which depends on the gas temperature. Consequently, the maximum pressure in service corresponds to the filling pressure at the maximum temperature the gas can reach due to continuous current and service conditions (e.g. temperature, solar radiation).

Figure 1 shows the various pressure levels and their relationship.

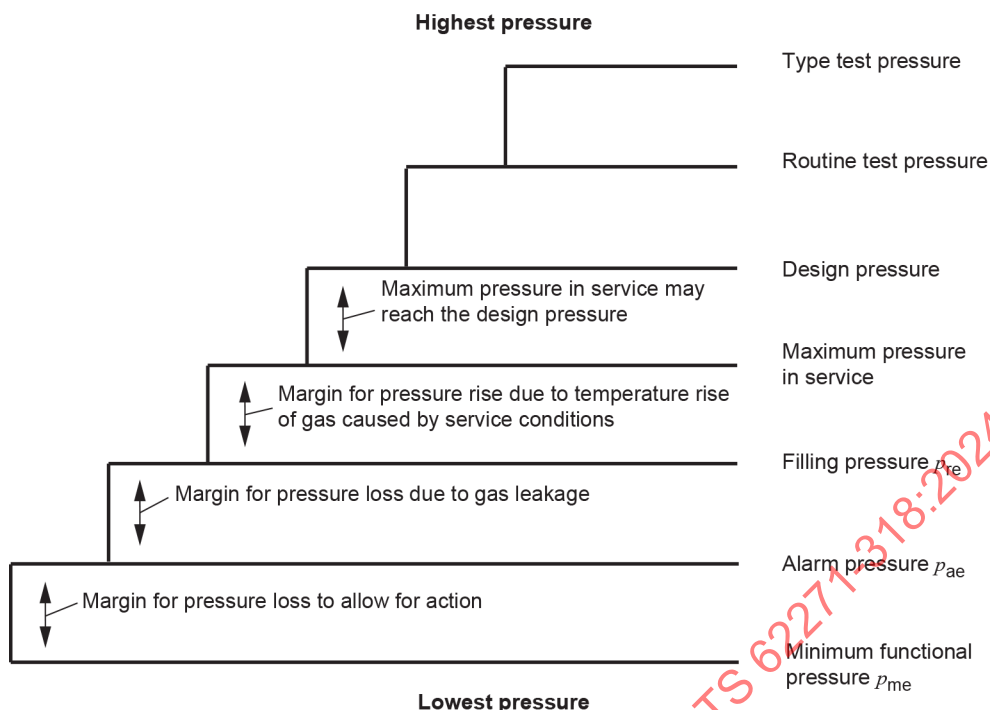


**Figure 1 – Pressure coordination**

The manufacturer is responsible for choosing the minimum functional pressure for insulation  $p_{me}$  and filling pressure  $p_{re}$ .

The manufacturer shall propose the alarm pressure  $p_{ae}$  which is related to both the filling pressure  $p_{re}$  and the minimum functional pressure. The alarm pressure  $p_{ae}$  will inform the user of any gas leak. For DC GIS using gas with a GWP > 1000, the filling pressure  $p_{re}$  and the alarm pressure  $p_{ae}$  shall be as close as possible, considering the tolerances of the density sensors, in order to make the user aware as soon as possible of gas losses.

Installation conditions (indoor, outdoor, direct solar radiations, ...), design and tolerances of the gas monitoring device shall be taken into consideration.

The time between the alarm pressure  $p_{ae}$  and the minimum functional pressure  $p_{me}$  allows corrective actions to be undertaken by the user and is dependent upon the gas leakage rate. During this period of time, the tolerances of the gas monitoring devices shall be taken into consideration.

## **6.103 Internal arc fault**

### **6.103.1 General**

A fault leading to arcing within DC GIS built according to this document has a very low order of probability. This results from the application of an insulating gas other than air at atmospheric pressure which will not be altered by pollution, humidity or vermin.

DC GIS shall be designed, manufactured and operated in order to prevent the occurrence of internal fault within DC GIS. All possible measures to keep a very low probability of occurrence shall be taken such as:

- insulation co-ordination;
- gas leakage limitation and control;
- control of gas quality;
- high quality of work on-site;
- interlocking of switching device.

The very low probability of such an event shall be considered. Arrangements shall be made to minimize the effects of internal faults on service continuity (e.g. high-speed protection, remote control, additional gas compartments). The internal arc shall not propagate into adjacent gas compartments.

After such an event, an intervention will be necessary in order to isolate the faulty compartment. The general partitioning of DC GIS design shall permit the restoration of the part of DC GIS which is not affected in order to satisfy the service continuity requirements when defined (see IEC 62271-203:2022, Annex F).

### 6.103.2 External effects of the arc

The effects of an internal arc are:

- pressure increase of gas (see Annex C),
- possible burn-through of enclosure.

The external effects of the arc shall be limited to the appearance of a hole or a tear in the enclosure without any fragmentation (by a suitable protective system). The duration of the arc is related to the performance of the protective system.

Table 2 gives the performance criteria depending on a dedicated Joule integral value of the short-circuit current derived by applying the Joule integral value  $E_j = \int i^2 dt$  for both alternating and direct short-circuit current (see IEC TS 62271-5:2024, Clause D.6).

**Table 2 – Performance criteria**

| Joule integral value ( $E_j$ )        | Explanation                                 | Performance criteria                                                            |
|---------------------------------------|---------------------------------------------|---------------------------------------------------------------------------------|
| $< 320 \text{ (kA)}^2 \cdot \text{s}$ | This corresponds to the main protection.    | No external effect other than the operation of suitable pressure relief devices |
| $< 800 \text{ (kA)}^2 \cdot \text{s}$ | This corresponds to the back-up protection. | No fragmentation (burn-through is acceptable)                                   |

NOTE 1 Energy limits have been calculated using the Joule integral according to IEC TS 62271-5:2024, Clause D.6 based on performance criteria of IEC 62271-203:2022, 6.103.2. Value of  $320 \text{ (kA)}^2 \cdot \text{s}$  was calculated by  $E_j = \int I^2 dt$  for 40 kA RMS and 0,2 s. Value of  $800 \text{ (kA)}^2 \cdot \text{s}$  was calculated by  $E_j = \int I^2 dt$  for 40 kA RMS and 0,5 s.

NOTE 2 For current and expected near term implementations of HVDC, the short-circuit current is much lower than in AC systems.

The term "no fragmentation of the enclosure" is interpreted as follows:

- no explosion of the compartment;
- no solid parts flying off from the compartment.

Exceptions are:

- parts of the pressure relief device or parts installed in these, if their ejection is directed;
- glowing particles and molten material resulting from burn-through of the enclosure.

Additionally, manufacturer and user can define a time during which an arc due to an internal fault up to a given value of short-circuit current will cause no external effects. The definition of this time shall be based on test results or an acknowledged calculation procedure. See Equation (C.1).

NOTE 3 Using an alternating current for testing, Annex C is applicable. If considering direct current for testing, there is currently insufficient experience to derive a calculation procedure.

The duration of current without burn-through for different values of the short-circuit AC current can be estimated from an acknowledged calculation procedure like CIGRE Technical Brochure 602 [2], CIGRE Session 1998 – WG 21/23/33-03 [3] and RGE: 04/82 [4].

Hence, Annex C is not applicable when using direct current for testing.

### 6.103.3 Internal fault location

The manufacturer of the DC GIS should propose appropriate methods for the determination of the location of a fault, if required by the user.

## 6.104 Enclosures

### 6.104.1 General

The enclosure shall be capable of withstanding the normal and transient pressures to which it is subjected in service.

### 6.104.2 Design of enclosures

The design of the enclosure shall be made in accordance with established documents for pressurized enclosures of gas-filled, high-voltage switchgear and controlgear with inert, non-corrosive, low pressurized gases. For further information, see EN 50052 [5], EN 50064 [6], EN 50068 [7], EN 50069 [8]. Annex E provides further information about notes concerning certain countries.

Methods for the calculation of the thickness and the construction of enclosures either by welding or casting shall be based on the design pressure (see definition in 3.114).

When designing an enclosure, account shall also be taken of the following:

- a) the possible recovery or evacuation gas or air in the enclosure as part of the normal filling process;
- b) the full differential pressure possible across the enclosure walls or partitions;
- c) the resulting pressure in the event of an accidental leak between the compartments in the case of adjacent compartments having different service pressures if overpressure is not monitored;
- d) the possibility of the occurrence of an internal fault (see 6.103);
- e) the corrosive impact on enclosures shall be considered by appropriate measures (e.g. filter material to absorb humidity and decomposition products).

In determining the design pressure, the gas temperature shall be taken as the mean of the upper limits of the enclosure temperature and the main circuit conductor temperature with rated continuous current flowing unless the design pressure can be established from existing continuous current test records.

For enclosures and parts thereof, the strength of which has not been fully determined by calculation, proof tests (see 7.103) shall be performed to demonstrate that they fulfil the requirements.

Materials used in the construction of enclosures shall be of known and certified minimum physical properties on which calculations and/or proof tests are based. The manufacturer shall be responsible for the selection of the materials and the maintenance of these minimum properties, based on certification of the material supplier, or tests conducted by the manufacturer, or both.

## **6.105 Partitions**

### **6.105.1 Design of partitions**

Partitions shall be used to separate compartments of the DC GIS and shall be gas tight such that contamination between adjacent compartments cannot occur. Partitions shall be made of material having insulating and mechanical properties so as to ensure proper operation over the lifetime of the DC GIS. Partitions shall maintain their dielectric withstand strength at voltages, which can occur in service (including temporary and transient voltages), when contaminated by by-products of gases and gas mixtures generated from normal load switching.

The design pressure of a partition is defined by the situation where the partition is pressurized on one side and maintenance is being carried out on the other side at atmospheric pressure (e.g. when maintenance is being carried out). In this case the pressure to be considered on the pressurized side of the partition is the pressure at maximum ambient temperature with solar radiation effects (where applicable) and rated continuous current (where applicable and without time limit). The pressure so derived is the design pressure of the partition.

During maintenance activities, the gas pressure can be lowered to a specified and controlled pressure. If this pressure is below the minimum functional pressure the concerned gas compartments shall be switched off. Warning notices and gas handling procedures shall be written in the operating and maintenance manuals.

Beyond the design pressure, account shall be taken of the following, if applicable:

- recovery or evacuation of gas or air in a gas compartment on one side of the partition with service pressure on the other, as part of the filling process; if there is a pressure differential limitation, or a time limitation related to the pressure differential, these shall be clearly stated by the manufacturer in the operating and maintenance manuals;
- for non-symmetrical partitions, as far as the pressure on the partition is concerned, the worst-case pressure direction;
- superimposed loads and vibration;
- the possibility of maintenance being carried out adjacent to a pressurized partition, with special care to avoid rupture of the partition and the risk of injuries for maintenance people.

NOTE Enhanced pressure due to internal fault is not considered to establish the pressure design since in such situation, partition will be closely inspected and replaced if applicable.

### **6.105.2 Partitioning**

The selection of the electrical single-line diagram is the primary consideration to fulfil service continuity requirements. Layout arrangements and introduction of dismantling facilities will influence service continuity during maintenance, repair and extension.

Partitioning of a DC GIS is influenced by the service continuity requirements during maintenance, repair and extension. Local health and safety requirements shall also be considered, see Clause 12.

Annex F of IEC 62271-203:2022 provides guidance for specifying service continuity.

NOTE 1 Annex F of IEC 62271-203:2022 applies to AC GIS. In principle, this guideline can also be applied to DC GIS.

DC GIS shall be divided into compartments in such a manner that:

- during various activities requiring de-energization of parts of the DC GIS, compartments to be taken out of service comply with the user's service continuity requirements. These activities include:
  - maintenance;
  - repair;
  - extension;
  - on-site dielectric test;
- the effects of an arc inside a compartment are limited to that compartment (see 6.103.1);
- duration of unavailability in case of major failure shall be in accordance with the user's service continuity requirements;
- the gas or air of the compartment can be recovered, evacuated and filled in a reasonable time considering the gas handling devices available.

NOTE 2 For on-site dielectric tests (after maintenance, repair or extension), see 11.101.2.

Partitions are generally of insulating material. They are not intended to provide electrical safety of personnel. For this purpose, other means such as separating by an isolating distance and earthing of the equipment can be used.

Partitions provide mechanical safety against the gas pressure still present in the adjacent compartment during maintenance, repair and extension. During such activities, other mechanical stresses than pressure should be considered on partitions, such as shock of any piece, or transient mechanical stresses from conductors in order to define the safety rules and avoid health risk for people.

Where a DC GIS bus-duct pass between indoor and outdoor locations (for example, DC GIS installed within a building with outdoor bushings), the gas compartment can be provided with a partition close to the wall, separating the compartment between the indoor and outdoor environments to prevent problems arising from false alarms of the gas monitoring devices and condensation occurring due to indoor and outdoor temperature differences.

Each compartment shall be equipped with the following accessories:

- filling valve;
- gas monitoring device (see 6.10).

Depending on the DC GIS design or on users request each compartment can be equipped with the following accessories:

- pressure relief device (see 6.106.3);
- desiccant;
- internal arc fault location detector (see 6.103.3).

Figure 2 gives an example of an arrangement of enclosures and partitions for different types of adjacent compartments.

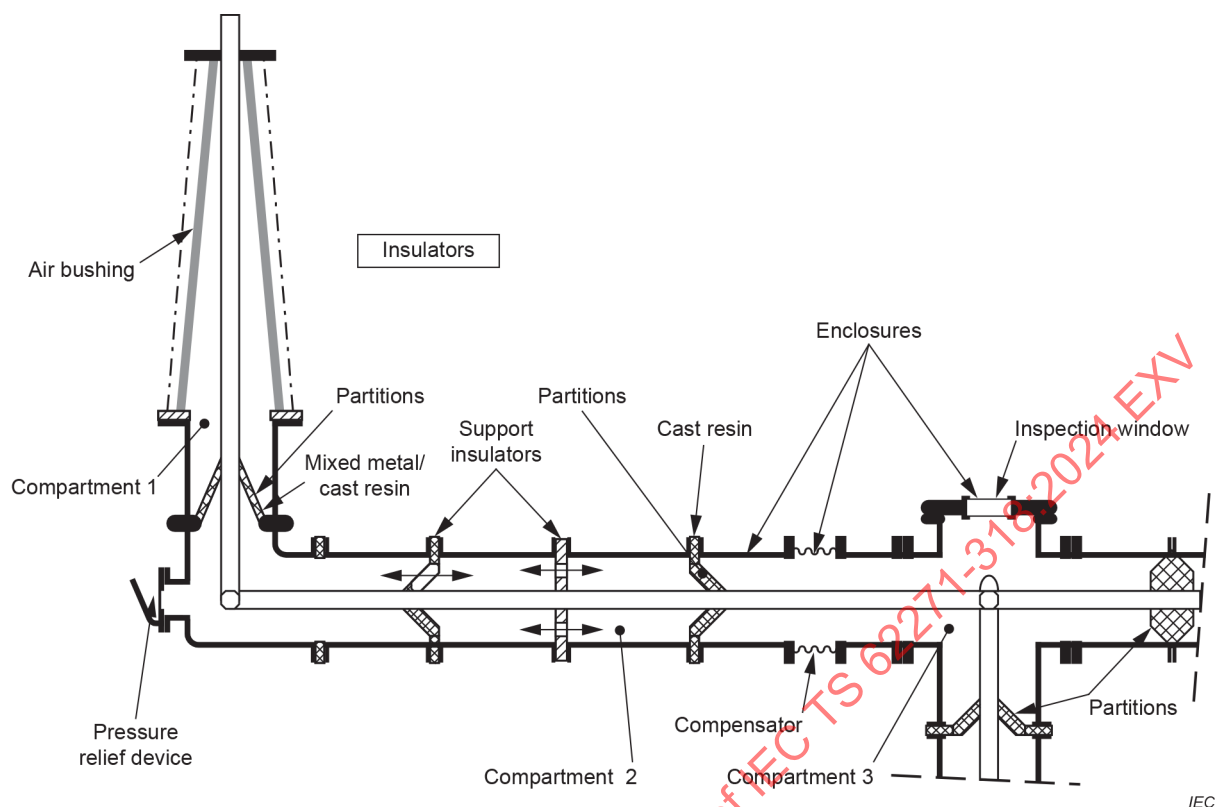


**Figure 2 – Example of arrangement of enclosures and gas compartments**

## 6.106 Pressure relief

### 6.106.1 General

Pressure relief device includes both pressure relief valves, characterized by an opening pressure and a closing pressure; and non-reclosing pressure relief devices, such as diaphragms and bursting disks. Pressure relief devices in accordance with this subclause shall be arranged so as to minimize the danger to an operator performing normal operating duties in the DC gas-insulated substation if gases or vapours are escaping under pressure.

### 6.106.2 Non-reclosing pressure relief device

Since, after an arc due to an internal fault, the damaged enclosures will be replaced, non-reclosing pressure relief devices shall only be proportioned to limit the external effects of the arc (see 6.103.2).

### 6.106.3 Pressure relief valve

For filling a gas compartment, a pressure relief valve shall be fitted to the filling pipe to prevent the gas pressure from rising to more than 10 % above the design pressure during the filling of the enclosure.

After an opening operation, a pressure relief valve shall reclose before the pressure has fallen to 75 % of the design pressure.

The filling pressure  $p_{re}$  should be corrected to take into account the gas and ambient temperature at the time of filling.