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Superconducting AC power cables and their accessories for rated voltages from 6 kV to 500 kV - Test methods and requirements

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National foreword

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Superconducting ac power cables and their accessories for rated voltages from 6 kV to 500 kV – Test methods and requirements

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ELECTROTECHNICAL
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CONTENTS

FOREWORD 6
INTRODUCTION 8
1 Scope 9
2 Normative references 9
3 Terms and definitions 10
3.1 Definitions of dimensional values (thicknesses, cross-sections, etc.) 10
3.2 Definitions concerning tests 10
3.3 Other definitions (general design and cryogenic system) 11
4 Voltage and current designations 13
4.1 Rated voltages 13
4.2 Rated operating current 13
5 Cable materials 14
5.1 Cable conductor materials 14
5.2 Cable insulating materials (dielectric insulation) 14
5.3 Cable screen materials 14
5.4 Cable cryostat materials (thermal insulation) 14
5.5 Cable oversheathing materials (outside cryostat) 14
6 Cable characteristics 14
7 Accessory characteristics 15
8 Test conditions 16
8.1 Ambient temperature 16
8.2 Frequency and waveform of power frequency test voltages 16
8.3 Wave form of impulse test voltages 16
8.3.1 Lightning impulse voltage 16
8.3.2 Switching impulse voltage 16
8.4 Relationship of test voltages to rated voltages 16
8.5 Cryogen temperature and pressure 17
9 Routine tests on cables and on prefabricated accessories 17
9.1 General 17
9.1.1 Tests on cable core samples 17
9.1.2 Tests on cable cryostat 17
9.1.3 Tests on prefabricated accessories 17
9.2 AC voltage test for cable followed by partial discharge test 18
9.2.1 General 18
9.2.2 Procedure 18
9.2.3 Requirement 18
9.3 Critical current measurement 18
9.3.1 General 18
9.3.2 Procedure 18
9.3.3 Requirement 19
9.4 Pressure test 19
9.4.1 General 19
9.4.2 Procedure 19
9.4.3 Requirement 19
9.5 Vacuum leak test 19
9.5.1 General 19

AVA Documents
Document Sharing Hub

9.5.2 Procedure ... 19
9.5.3 Requirement ... 19
9.6 Electrical test on oversheath of the cable ... 19
9.7 Tests on prefabricated accessories ... 19
9.7.1 Voltage test followed by partial discharge test ... 19
9.7.2 Pressure test and vacuum leak test ... 20
10 Sample tests on cables ... 20
10.1 General ... 20
10.2 Frequency of tests ... 20
10.3 Repetition of tests ... 20
10.4 Conductor examination ... 20
10.5 Measurement of thickness of cable insulation ... 21
10.5.1 General ... 21
10.5.2 Procedure ... 21
10.5.3 Requirement ... 21
10.6 Measurement of thickness of oversheath ... 21
10.6.1 General ... 21
10.6.2 Requirement ... 21
10.7 Measurement of diameters ... 21
10.8 Measurement of capacitance ... 21
10.9 Lightning impulse voltage test ... 22
11 Sample tests on accessories ... 22
11.1 Tests on components ... 22
11.2 Tests on complete accessory ... 22
12 Type tests on cable systems ... 23
12.1 General ... 23
12.2 Range of type approval ... 23
12.3 Summary of type tests ... 24
12.4 Electrical type tests on complete cable systems ... 24
12.4.1 Test voltage values ... 24
12.4.2 Tests and sequence of tests ... 24
12.4.3 Bending test ... 25
12.4.4 Critical current measurement ... 25
12.4.5 Pressure test ... 25
12.4.6 Thermal cycle test ... 26
12.4.7 Partial discharge test ... 26
12.4.8 Tan δ measurement ... 26
12.4.9 Load cycle voltage test ... 26
12.4.10 Impulse voltage tests ... 26
12.4.11 Examination of cable and accessories ... 27
12.5 Non-electrical type tests on cable components and on complete cable ... 27
12.5.1 Overview on non-electrical type tests ... 27
12.5.2 Check of cable construction ... 28
12.5.3 Tests for determining the mechanical properties of oversheaths before and after ageing ... 28
12.5.4 Loss of mass test on PVC oversheaths of type ST_2 ... 28
12.5.5 Test on PVC oversheaths (ST_1 and ST_2) at low temperature ... 28
12.5.6 Heat shock test for PVC oversheaths (ST_1 and ST_2) ... 29

AVA Documents
Document Sharing Hub
Full document details: BS EN 63075:2019

12.5.7 Measurement of carbon black content of black PE oversheaths (ST_3 and ST_7) 29
12.5.8 Test under fire conditions 29
12.5.9 Pressure test of cable cryostat 29
12.5.10 Pressure test of components of accessories 30
13 Prequalification test of the cable system 30
14 Type test on cables 30
15 Type test on accessories 30
16 Tests after installation 30
16.1 General 30
16.2 Tests at ambient temperature 31
16.2.1 Vacuum test 31
16.2.2 Pressure test 31
16.3 Tests at operating temperature 32
16.3.1 General 32
16.3.2 DC current test 32
16.3.3 AC voltage test of the insulation 32
16.3.4 DC voltage test of the oversheath 33
Annex A (informative) Cooling system considerations 37
A.1 Introductory remarks 37
A.2 Cryogenic refrigeration 37
A.2.1 General process 37
A.2.2 General hardware components 38
A.3 Recommendations for tests after installation 39
A.3.1 General 39
A.3.2 Pressure test followed by vacuum leak test 39
A.3.3 Cooling capacity test and efficiency measurement 40
A.3.4 Circulation pump mass flow and pressure test 40
A.3.5 Temperature and pressure control test 40
A.3.6 Noise measurements 40
A.3.7 Other measurements 40
Annex B (normative) Critical current measurement 41
B.1 Critical current measurement test 41
B.1.1 General 41
B.1.2 Procedure 41
B.1.3 Test method 41
Annex C (informative) Tests for engineering information 43
C.1 Overview 43
C.2 AC loss 43
C.2.1 General 43
C.2.2 Electrical method 43
C.2.3 Calorimetric – vaporization method 43
C.2.4 Calorimetric – cryogen mass flow method 43
C.3 Heat invasion of cryostat 44
C.3.1 General 44
C.3.2 Calorimetric – vaporization of liquid cryogen 44
C.3.3 Calorimetric – liquid cryogen mass flow method 44
C.4 Electrical parameters 44

AVA Documents
Document Sharing Hub
Full document details: BS EN 63075:2019

C.5 Short-circuit tests (fault current) ... 44
Annex D (informative) List of type tests on cable systems ... 45
Annex E (normative) Tests on outer protection for joints ... 46
E.1 General ... 46
E.2 Range of approval ... 46
E.3 Voltage tests ... 46
E.3.1 General ... 46
E.3.2 Assemblies embodying accessories without sheath sectionalizing insulation ... 46
E.3.3 Assemblies embodying sheath sectionalizing insulation ... 46
E.4 Examination of test assembly ... 47
Annex F (informative) Prequalification test of the cable system ... 48
Bibliography ... 49

Figure A.1 – General refrigeration process with indication of temperature and energy flows ... 37
Figure A.2 – General system components and process flow ... 39
Figure B.1 – Test setup for electrical four-probe method ... 41
Figure B.2 – Voltage-current characteristic for superconductor ... 42

Table 1 – Test voltages ... 34
Table 2 – Non-electrical type tests for oversheathing compounds for cables ... 35
Table 3 – Test requirements for mechanical characteristics of oversheathing compounds for cables (before and after ageing) ... 36
Table 4 – Test requirements for particular characteristics of PVC oversheathing for cables ... 36
Table D.1 – Type tests on cable systems ... 45
Table E.1 – Impulse voltage tests ... 47

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SUPERCONDUCTING AC POWER CABLES AND THEIR ACCESSORIES FOR RATED VOLTAGES FROM 6 KV TO 500 KV – TEST METHODS AND REQUIREMENTS

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

FDIS	Report on voting
20/1858/FDIS	20/1865/RVD

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

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

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INTRODUCTION

As a result of major developments in superconducting cable systems with cold dielectric for medium- and high-voltage AC applications, CIGRE study committee B1 set up working group (WG) B1.31 in 2009 with the aim to prepare recommendations for testing superconducting AC cable systems for power transmission at a rated voltage of up to 150 kV.

The recommendations of CIGRE WG B1.31 were published in TB 538 in June 2013 [1][1]. At the time of preparation of the CIGRE recommendation, laboratory experience at voltages up to and including 275 kV was available, but operating experience was limited to 154 kV. At the time of preparation of this document, several projects up to 220 kV are in progress, and many others are planned for the near future. As the insulation system of high-temperature superconducting (HTS) cable systems considered in this document is comparable to oil-filled cable systems, it was agreed to extend the voltage range to 500 kV in order to be compatible with IEC 60141-1 [2].

In 2014, TC 20 decided to start the standardization work on testing of HTS AC cables based on the published CIGRE TB 538. Manufacturers of HTS cable systems, utilities as the main users, and independent test laboratories will benefit from this document.

A list of relevant references is given in the Bibliography (see [3], [4], [5], [6]).

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

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SUPERCONDUCTING AC POWER CABLES AND THEIR ACCESSORIES FOR RATED VOLTAGES FROM 6 KV TO 500 KV – TEST METHODS AND REQUIREMENTS

1 Scope

This document specifies test methods and requirements for high-temperature superconducting (HTS) AC power cable systems, cables and their accessories, for fixed installations, for rated voltages from 6 kV (U_m = 7,2 kV) up to and including 500 kV (U_m = 550 kV).

The requirements apply to single-core, three-core and three-phase concentric cables with cold dielectric and their accessories that are not intended for fault current limitation purposes.

This document does not cover special cables and their accessories, such as fault current limiting cables or submarine cables, for which modifications to the standard tests may be necessary or special test conditions may need to be devised.

This document does not cover test methods and requirements for the cooling system.

NOTE For considerations regarding cooling systems, refer to Annex A.

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

IEC 60229:2007, *Electric cables – Tests on extruded oversheaths with a special protective function*

IEC 60230, *Impulse tests on cables and their accessories*

IEC 60332-1-2, *Tests on electric and optical fibre cables under fire conditions – Part 1-2: Test for vertical flame propagation for a single insulated wire or cable – Procedure for 1 kW pre-mixed flame*

IEC 60811-202, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 202: General tests – Measurement of thickness of non-metallic sheath*

IEC 60811-203, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 203: General tests – Measurement of overall dimensions*

IEC 60811-401, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 401: Miscellaneous tests – Thermal ageing methods. Ageing in an air oven*

IEC 60811-409, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 409: Miscellaneous tests – Loss of mass test for thermoplastic insulations and sheaths*

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IEC 60811-501, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 501: Mechanical tests – Tests for determining the mechanical properties of insulation and sheathing compounds*

IEC 60811-505, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 505: Mechanical tests – Elongation at low temperature for insulations and sheaths*

IEC 60811-506, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 506: Mechanical tests – Impact test at low temperature for PVC insulations and sheaths*

IEC 60811-508, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 508: Mechanical tests – Pressure test at high temperature for insulations and sheaths*

IEC 60811-509, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 509: Mechanical tests – Tests for resistance of insulations and sheaths to cracking (heat shock test)*

IEC 60811-605, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 605: Physical tests – Measurement of carbon black and/or mineral filler in polyethylene* compounds

IEC 60885-3, *Electrical test methods for electric cables – Part 3: Test methods for partial discharge measurements on lengths of extruded power cables*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

3.1 Definitions of dimensional values (thicknesses, cross-sections, etc.)

3.1.1
nominal value
value by which a quantity is designated and which is often used in tables

Note 1 to entry: In this document, nominal values usually give rise to values to be checked by measurements, taking into account specified tolerances.

3.1.2
median value
middle value if the number of available values is odd, and mean of the two middle values if the number is even, when several test results have been obtained and ordered in an increasing (or decreasing) succession

3.2 Definitions concerning tests

3.2.1
routine test
test made by the manufacturer on each manufactured cable system component to check that the component meets the specified requirements

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3.2.2
sample test
test made by the manufacturer on samples of complete cable, or components taken from a complete cable or accessory, at a specified frequency, so as to verify that the finished product meets the specified requirements

3.2.3
type test
test made before supplying, on a general commercial basis, a type of cable system covered by IEC 63075, in order to demonstrate satisfactory performance characteristics to meet the intended application

Note 1 to entry: Once successfully completed, these tests need not be repeated, unless changes are made in the cable or accessory with respect to materials, manufacturing process, design or design electrical stress levels, which might adversely change the performance characteristics.

3.2.4
prequalification test
test made before supplying, on a general commercial basis, a type of cable system covered by IEC 63075, in order to demonstrate satisfactory long-term performance of the complete cable system

3.2.4
extension of prequalification test
test made before supplying, on a general commercial basis, a type of cable system covered by IEC 63075, in order to demonstrate satisfactory long-term performance of the complete cable system, taking into account an already prequalified cable system

3.2.5
test after installation
test made to demonstrate the integrity of the cable system as installed

3.3 Other definitions (general design and cryogenic system)

3.3.1
cable system
cable with installed terminations and/or joints

3.3.2
nominal electrical stress
electrical stress calculated at U_0 using nominal dimensions

3.3.3
high-temperature superconductor
HTS
class of superconductors with a critical temperature generally higher than about 25 K

[SOURCE: IEC 60050-815:2015, 815-11-11] [7]

3.3.4
HTS cable
cable comprising one or more phase conductors consisting of HTS material and a cryostat

Note 1 to entry: An HTS cable can be a single-core, a three-core and a three-phase concentric cable, all within a common cryostat.

3.3.5
cold dielectric
dielectric material which operates within a cryogenic environment

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3.3.6
HTS cable core
either one or three concentrically arranged phase conductors consisting of HTS material with cold dielectric insulation and a screen

Note 1 to entry: A screen consists of metal or HTS material, or both.

3.3.7
single-core HTS cable
cable with HTS cable core comprising one phase conductor placed in a cryostat

3.3.8
three-core HTS cable
cable with three HTS cable cores, each comprising one phase conductor placed in a common cryostat

3.3.9
three-phase concentric HTS cable
cable with an HTS cable core comprising three concentric phase conductors placed in a cryostat

3.3.10
cryostat
container that provides the cryogenic environmental conditions to operate a superconducting device

[SOURCE: IEC 60050-815:2015, 815-15-51]

3.3.11
termination
device fitted to the end of a cable to ensure electrical connection with other parts of the system and to maintain the insulation up to the point of connection

Note 1 to entry: The termination is also an interface between cryogenic temperature and ambient temperature.

Note 2 to entry: The termination could also comprise an interface to the cooling system.

[SOURCE: IEC 60050-461:2008, 461-10-01, modified – The notes to entry have been added.]

3.3.12
joint
accessory making a connection between two HTS cables to form a continuous electrical circuit and a continuous thermal insulation

Note 1 to entry: The joint could also comprise an interface to the cooling system.

3.3.13
critical current
I_c
maximum direct current that can be regarded as flowing without resistance practically

Note 1 to entry: I_c is a function of magnetic field strength and temperature.

[SOURCE: IEC 60050-815:2015, 815-12-01, modified – "and strain" has been deleted from Note 1 to entry.]

3.3.14
fault current limiting cable
HTS cable that limits fault currents to acceptable values

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3.3.15
AC loss
power dissipated in an HTS cable core owing to application of a time-varying magnetic field, electric current or voltage

Note 1 to entry: AC loss includes time average hysteresis loss of the HTS material, a coupling current loss and an eddy current loss of the conductor, an eddy current loss of the structural material, and a dielectric loss of the electric insulation.

Note 2 to entry: AC loss customarily also includes the power dissipated in the HTS material owing to application of transient changes in magnetic field or current.

3.3.16
cryogenics
study of the production and behaviour of materials at temperatures below 120 K

3.3.17
cryogen
liquid that boils at cryogenic temperatures below 120 K and is used to obtain very low temperatures

Note 1 to entry: The most common cryogen for HTS cables is liquid nitrogen due to its availability, cost and dielectric properties.

3.3.18
cryogenic refrigeration system
cryogenic cooling system
system that is capable of cooling cryogen at cryogenic temperatures

3.3.19
maximum allowable working pressure
maximum pressure (gauge) across the entire operating and testing temperature range to which the superconducting cable system may be exposed and operated

Note 1 to entry: The maximum allowable working pressure is referred to for pressure testing.

Note 2 to entry: The maximum allowable working pressure includes pressure variations within the normal operation.

Note 3 to entry: The maximum operating pressure shall be less or equal to the maximum allowable working pressure.

4 Voltage and current designations

4.1 Rated voltages

In this document, the symbols U_0, U and U_m are used to designate the rated voltages of cables and accessories, where these symbols have the meanings given in IEC 60183 [9].

4.2 Rated operating current

In this document, the symbol I_r is used to designate the rated operating current of the cable and accessories. The rated operating current is the RMS value of the current that the system shall be able to carry continuously under specified conditions of the cryogen. Preferably, current ratings in accordance with IEC 60059 [10] should be applied.

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5 Cable materials

5.1 Cable conductor materials

This document is applicable to cables having a conductor consisting of HTS material. In addition, the cable conductor may comprise metal.

NOTE Commonly used HTS materials for the cable conductor are copper-oxide superconductors (see IEC 60050-815:2015, 815-11-08) in the form of tapes.

5.2 Cable insulating materials (dielectric insulation)

This document is applicable to cables having a cold dielectric consisting of lapped insulating tapes impregnated with the cryogen.

NOTE 1 Commonly used insulating tapes are kraft paper, polypropylene laminated paper, etc.

NOTE 2 Commonly used cryogen is liquid nitrogen.

5.3 Cable screen materials

This document is applicable to cables having a screen consisting of either HTS material or metal or a combination of both.

NOTE Commonly used HTS materials for the cable screen are copper-oxide superconductors (see IEC 60050-815:2015, 815-11-08) in the form of tapes.

5.4 Cable cryostat materials (thermal insulation)

This document is applicable to cables having a cryostat consisting of an inner envelope at cryogenic temperature and an outer envelope at ambient temperature with a thermal insulation in between.

NOTE The cable cryostat generally consists of an inner and outer tube made of stainless steel or aluminium alloys with a vacuum insulation in between.

5.5 Cable oversheathing materials (outside cryostat)

The oversheath is optional.

If an oversheath is required (e.g. using the cryostat as metal screen), it shall be tested.

Tests are specified for the following types of oversheath:

– ST_1 and ST_2 based on polyvinyl chloride (PVC);
– ST_3 and ST_7 based on polyethylene (PE).

The choice of the type of oversheath will depend on the design of the cable and on the mechanical, thermal and fire constraints during installation and operation.

6 Cable characteristics

For the purposes of carrying out the cable system tests described in this document and recording the results, the cable shall be identified. The following characteristics shall be known or declared:

a) name of manufacturer, type, designation and manufacturing date or date code;
b) rated voltage: values shall be given for U_0, U, U_m (see 4.1 and 8.4);
c) rated operating current: value shall be given for I_r;
d) maximum and minimum operating temperature of cryogen shall be given.

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