भारतीय मानक

Indian Standard

IS 18833 : 2024
IEC 62895 : 2017

उच्च वोल्टेज दिष्ट धारा (एचवीडीसी) पावर संचारण भूमि अनुप्रयोगों के लिए 320 kV तक रेटेड वोल्टेज के लिए एक्सट्रूडेड इन्सुलेशन वाले केबल और उनके सहायक उपकरण — परीक्षण पद्धतियाँ और अपेक्षाएँ

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

ICS 29.060.20

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

August 2024 **Price Group 15**

This Page has been Intentionally left blank

Power cables Sectional Committee, ETD 09

NATIONAL FOREWORD

This Indian Standard which is identical to 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' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Power Cables Sectional Committee and approval of the Electrotechnical Division Council.

The text of the IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to International Standards for which Indian Standards also exists. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60060-2 High-voltage test techniques – Part 2: Measuring systems	IS/IEC 60060-2 : 2010 High-voltage test techniques: Part 2 Measuring systems	Identical
IEC 60228 Conductors of insulated cables	IS 8130 : 2013 Conductors for insulated electric cables and flexible cords — specification (*second revision*)	Technically Equivalent
IEC 60502-2 : 2014 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) — Part 2: Cables for rated voltages from 6 kV (U_m = 7,2 kV) up to 30 kV (U_m = 36 kV)	IS 7098 (Part 2) : 2011 Crosslinked polyethylene insulated thermoplastic sheathed cables — Specification: Part 2 For working voltages from 3.3 kV up to and including 33 kV (*second revision*)	Technically Equivalent
IEC 60502-4 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) — Part 4: Test requirements on accessories for cables with rated voltages from 6 kV (U_m = 7,2 kV) up to 30 kV (U_m = 36 kV)	IS 13573 (Part 2) : 2011 Cable accessories for extruded power cables — Specification: Part 2 For working voltages from 3.3 kV(Ue) up to and including 33 kV(E) — Test requirements (*first revision*)	Technically Equivalent

The Committee has reviewed the provision of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60229	Electric cables – Tests on extruded over sheaths with a special Protective function
IEC 60230	Impulse tests on cables and their accessories
IEC 60287-1-1 : 2006	Electric cables — Calculation of the current rating — Part 1-1: Current rating equations (100 % load factor) and calculation of losses — General
	IEC 60287-1-1 : 2006/AMD 1 : 2014
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 premixed flame
IEC 60811-201	Electric and optical fibre cables — Test methods for non-metallic materials — Part 201: General tests — Measurement of insulation thickness
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 60811-403	Electric and optical fibre cables — Test methods for non-metallic materials — Part 403: Miscellaneous tests — Ozone resistance test on cross-linked compounds
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
IEC 60811-412	Electric and optical fibre cables — Test methods for non-metallic materials — Part 412: Miscellaneous tests — Thermal ageing methods — Ageing in an air bomb
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 insulating 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 insulations and sheaths
IEC 60811-507	Electric and optical fibre cables — Test methods for non-metallic materials — Part 507: Mechanical tests — Hot set test for cross-linked materials
IEC 60811-508	Electric and optical fibre cables — Test methods for non-metallic materials — Part 508: Mechanical tests — Pressure test at high temperature for insulation and sheaths

International Standard	*Title*
IEC 60811-509	Electric and optical fibre cables — Test methods for non-metallic materials — Part 509: Mechanical tests — Test 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 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 60811-606	Electric and optical fibre cables — Test methods for non-metallic materials — Part 606: Physical tests — Methods for determining the density
IEC 62067	Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) — Test methods and requirements

Only English language text has been retained while adopting it in this Indian Standard, and as such the page numbers given here are not the same as in the International Standard.

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'.

CONTENTS

INTRODUCTION

As a result of major developments in cable systems with extruded insulation for high voltage DC (HVDC) applications, CIGRE study committee B1 set up working group (WG) B1.32 in 2008 with the aim to prepare recommendations for testing DC extruded cable systems for power transmission at a rated voltage of up to 500 kV.

The recommendations of WG B1.32 were published in TB 496 in April 2012. At the time of preparing the CIGRE recommendation there was laboratory experience at voltages up to and including 500 kV, but operating experience was limited to 200 kV. At the time of preparation of this standard several projects up to 320 kV are in progress and many others are planned for the near future.

A list of relevant references is given in the Bibliography.

Indian Standard

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

1 Scope

This International Standard specifies test methods and requirements for HVDC transmission power cable systems, employing cables with extruded insulation and their accessories, for fixed land installations, for rated voltages up to and including 320 kV.

Within the scope of this standard “extruded insulation” means insulation manufactured by extrusion of either thermoplastic (e.g. polyethylene) or crosslinked (e.g. crosslinked polyethylene, ethylene propylene rubber, etc.) material. The insulation material may be either unfilled or filled (e.g. with mineral or carbon).

The requirements apply to single-core cables in combination with their accessories, outdoor and terminations for gas insulated systems, joints, and asymmetric joints for usual conditions of installation and operation, but not to special cables and their accessories, such as submarine cables, for which modifications to the standard tests may be necessary or special test conditions may need to be devised.

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 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60228, *Conductors of insulated cables*

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

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

IEC 60287-1-1:2006, *Electric cables – Calculation of the current rating – Part 1-1: Current rating equations (100 % load factor) and calculation of losses – General*
IEC 60287-1-1:2006/AMD1:2014

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 60502-2:2014, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) – Part 2: Cables for rated voltages from 6 kV (U_m = 7,2 kV) up to 30 kV (U_m = 36 kV)*

IEC 60502-4, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) – Part 4: Test requirements on accessories for cables with rated voltages from 6 kV (U_m = 7,2 kV) up to 30 kV (U_m = 36 kV)*

IEC 60811-201, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 201: General tests – Measurement of insulation thickness*

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 60811-403, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 403: Miscellaneous tests – Ozone resistance test on cross-linked compounds*

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*

IEC 60811-412, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 412: Miscellaneous tests – Thermal ageing methods – Ageing in an air bomb*

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 insulating 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 insulations and sheaths*

IEC 60811-507, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 507: Mechanical tests – Hot set test for cross-linked materials*

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

IEC 60811-509, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 509: Mechanical tests – Test 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 60811-606, *Electric and optical fibre cables – Test methods for non-metallic materials – Part 606: Physical tests – Methods for determining the density*

IEC 62067, *Power cables with extruded insulation and their accessories for rated voltages above 150 kV (U_m = 170 kV) up to 500 kV (U_m = 550 kV) – Test methods and requirements*

3 Terms and definitions

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

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 standard, nominal values usually give rise to values to be checked by measurements taking into account specified tolerances.

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

3.2 Definitions concerning tests

3.2.1
routine test
test carried out by the manufacturer on each manufactured component (length of cable or accessory) to check that the component meets the specified requirements

3.2.2
sample test
test carried out 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 carried out before supplying, on a general commercial basis, a type of cable system, 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
PQ test
test carried out before supplying, on a general commercial basis, a type of cable system, in order to demonstrate satisfactory long term performance of the complete cable system

Note 1 to entry: The PQ test need only be carried out once unless there is a substantial change in the cable system with respect to material, manufacturing process, design or design electrical stress levels.

Note 2 to entry: A substantial change is defined as that which might adversely affect the performance of the cable system. The supplier should provide a detailed case, including test evidence, if modifications are introduced, which are claimed not to constitute a substantial change.

3.2.5
electrical test after installation
test carried out to demonstrate the integrity of the cable system as installed

3.2.6
development test
test carried out on test objects to characterize the properties and performance of elements of the cable system or of selected materials and material combinations

3.3 Other definitions

3.3.1
cable system
cable with installed accessories including components used for thermo-mechanical restraint of systems limited to those used for terminations and joints only

3.3.2
nominal electrical stress
electrical stress calculated at U_0 using nominal dimensions and constant material characteristics

Note 1 to entry: See 4.1.

3.3.3
test object
object which is a cable length or an accessory to be subjected to testing

return cable
cable, which is typically a low/medium voltage DC cable used for the return current in monopolar operation of HVDC schemes.

Note 1 to entry: A return cable can either be connected over the full length between the converters or can only be connected for part of the length connecting a converter to an electrode station

3.3.5
transmission cable
cable which is a high voltage cable of a monopolar or bipolar scheme, and which is connected to the HV terminal at the DC side of the converter

3.3.6
test loop
cable loop which is a combination of series connected test objects simultaneously under test

SEE: Figure 1.

3.3.7
line commutated converter
LCC
converter system that has the feature of changing voltage polarity on the cable system when the direction of power flow is reversed

Note 1 to entry: See IEC 60633.

Note 2 to entry: This note 2 only applies to the French language.

3.3.8
voltage source converter
VSC
converter system that does not change the voltage polarity of the cable system when the direction of power flow is reversed

Note 1 to entry: This note only applies to the French language.

3.3.9
extrusion length
length of cable conductor with the insulation and semiconducting layers continuously extruded in the same non-interrupted extrusion operation

3.3.10
manufacturing length
whole extrusion length (or parts thereof if cut), where construction elements (outside the outer semiconducting layer) have been applied

3.3.11
delivery length
typically the completed cable length on a drum for a cable

3.3.12
field joint
joint between two cables that is completed with all construction elements and in a state as installed in the field in the actual cable system

3.3.13
asymmetric joint
joint, which connects two cables with the same insulation system, but of different design

Note 1 to entry: An asymmetric joint is for instance a joint between cables of different conductor, insulation or screen dimension

4 Voltage designations and materials

4.1 Rated voltage

U_0 is the rated DC voltage between conductor and metal screen/sheath for which the cable system is designed. It is used to determine the DC test voltages U_{T}, U_{TP1} and U_{TP2}.

4.2 (spare)

4.3 Cable insulating materials

This standard applies to cables insulated with the materials listed in Table 1. It also specifies, for cables with each type of insulating compound, the maximum operating conductor temperatures on which the specified test conditions are based.

For insulation materials, which deviate from this list of materials, the test program for all non electrical tests on the insulation material shall be agreed between manufacturer and customer.

4.4 Cable metal screens/sheaths

4.4.1 General

This standard applies to the various designs in use. It covers designs providing a radial water tightness, as follows:

- metal sheaths,
- metal screens, as described in IEC TR 61901:2016, 3.3:
  - longitudinally applied metal tapes or foils bonded to the oversheath,
  - composite screens, involving a bundle of screen wires and, in addition, a metal tape or foil bonded to the oversheath, acting as a radial water impermeable barrier.

In all cases the metal screen/sheath should be able to carry the total fault current.

4.4.2 Metal sheath

A metal sheath made of lead or aluminium or their alloys, which is seamless or welded and smooth or corrugated.

4.4.3 Combined design (CD)

A metal screen in combined design combines radial watertightness and electrical properties, by different components:

- insulation system;
- semi-conductive bedding (water swellable if required);
- thick metal foil either welded or glued, that carries the full short circuit current
  - coated, and
  - bonded to the outer sheath, usually ST_7.

Additional wires can be added to match the short circuit requirement. The metal foil is usually aluminium; copper can be used as well.

4.4.4 Separate design (SD)

A metal screen in separate design manages radial watertightness and electrical properties, by different metal components:

- insulation system;
- copper or aluminium wires;
- water swellable tapes to block the screen area;
- coated laminated metal foil i.e. for example Al 0,2 mm + 0,05 mm coating on one side;
- oversheath, usually ST_7.

The foil is usually aluminium; copper or other metal laminated foils can be used.

4.5 Cable oversheathing materials

Tests are specified for four types of oversheath, as follows:

- 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 the mechanical, thermal and fire constraints during operation.

The maximum conductor temperatures in normal operation for different types of oversheathing materials covered by this standard are given in Table 2.

For some applications, the oversheath may be covered by a functional layer (e.g. semi-conductive).

5 Precautions against longitudinal water penetration in cables

The cable can include a system preventing the longitudinal penetration of water between the insulation screen and the metal screen/sheath, or in the conductor.

Longitudinal water barriers may be applied in order to avoid the need to replace long sections of cable in case of damage in the presence of water.

A test for longitudinal water penetration is given in Annex E.

If water blocking materials are used, special care for detrimental effect of such materials to the insulation properties is required.

NOTE A test for radial water penetration is under consideration.

6 Cable characteristics

For the purpose of carrying out the cable system tests described in this standard 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 U_0 (see 4.1).

c) Type of conductor, its material and nominal cross-section, in square millimetres; conductor construction; presence, if any, and nature of measures taken to achieve longitudinal watertightness. If the nominal cross-sectional area is not in accordance with IEC 60228, the DC conductor resistance corrected to 1 km length and to 20 °C shall be declared.

d) Material and nominal thickness of insulation (t_n) (see 3.1 and 4.3).

e) Type of manufacturing process for insulation system.

f) Presence, if any, and nature of watertightness measures in the screen area.

g) Material and construction of metal screen, for example number and diameter of wires, whether the metal screen is in combined or separate design – where applicable (the DC resistance of the metal screen shall be declared.); material, construction and nominal thickness of metal sheath, or longitudinally applied metal tape or foil bonded to the oversheath, if any.

h) Material and nominal thickness of oversheath.

i) Nominal diameter of the conductor (d).

j) Nominal overall diameter of the cable (D).

k) Nominal inner diameter (d_{ii}) and calculated nominal outer diameter (D_{io}) of the insulation.

l) Nominal capacitance for a frequency between 49 Hz and 61 Hz, corrected to 1 km length, between conductor and metal screen/sheath.

m) Calculated Laplace nominal electrical stress at the conductor screen (E_i) and at the insulation screen (E_o): for constant material properties and without field distortion from space charges

$$E_i = \frac{2U_0}{d_{ii} \times \ln(D_{io} / d_{ii})}$$

$$E_o = \frac{2U_0}{D_{io} \times \ln(D_{io} / d_{ii})}$$

where

$D_{io} = d_{ii} + 2t_n$;

d_{ii} is the declared nominal inner diameter of the insulation;

D_{io} is the calculated nominal outer diameter of the insulation;

t_n is the declared nominal insulation thickness.

NOTE Due to different effects the real stress in the cable can be different from this calculated Laplace nominal stress.

n) Calculated average nominal stress, which is the rated voltage U_0 divided by the nominal insulation thickness t_n.

o) Maximum temperature difference ΔT_{max} over the cable insulation in steady state (not including semiconducting screens) at which the cable is designed to operate.

p) Maximum declared conductor temperature $T_{cond,max}$, which is defined by the cable manufacturer and shall not be exceeded during operation. This maximum declared conductor temperature shall be lower than or equal to the material specific maximum conductor temperature of 4.3.

7 Accessory characteristics

For the purpose of carrying out the cable system or accessory tests described in this standard and recording the results, the accessory shall be identified.

The following characteristics shall be known or declared:

a) cables used for testing accessories shall be correctly identified according to Clause 6;

b) conductor connections used within the accessories shall be correctly identified, where applicable, with respect to
   - assembly technique,
   - tooling, dies and necessary setting,
   - preparation of contact surfaces,
   - type, reference number and any other identification of the connector,
   - details of the type test approval of the connector if applicable;

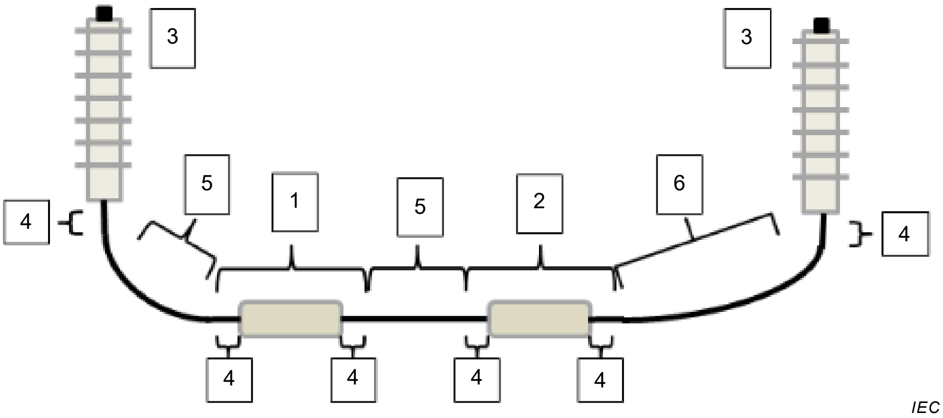
c) accessories to be tested shall be correctly identified with respect to
   - name of manufacturer,
   - type, designation and manufacturing date or date code,
   - rated voltage (see Clause 6, item b) above),
   - installation instructions (reference and date).

8 Test objects & conditions

8.1 Definitions concerning test objects

Test objects are transmission cables and their accessories. 0,5 m of cable on either side of an accessory is considered to be part of the accessory for both determination of tested cable length and allocation of failure between cable and accessory, should this occur. The return cable is referred to in Annex I.

A possible configuration of test objects in a test loop is shown in Figure 1. Special definitions are described hereafter.



Key

1 Test object joint
2 Optional, one or more additional test objects
3 Test object termination (may be of different design)
4 0,5 m cable next to the accessory is deemed to be part of the accessory
5 Minimum 5 m cable between the accessories
6 Test object cable: min. 10 m

Figure 1 – Example of configuration of test objects within a test loop

8.2 Test voltages

U_T is the DC voltage during the type test and routine test. For the scope of this standard U_T = 1,85 U_0.

U_{TP1} is the DC voltage during the PQ test (heating cycle test), type test (polarity reversal test) and test after installation. For the scope of this standard U_{TP1} = 1,45 U_0.

U_{TP2} is the DC voltage during the PQ polarity reversal test. For the scope of this standard U_{TP2} = 1,25 U_0.

U_{P1} is, for the type test, 1,15 × the maximum absolute peak value (Figure 2) of the lightning impulse voltage, which the cable system can experience when the impulse has the opposite polarity to the actual DC voltage. For the PQ test, U_{P1} = 2,1 U_0, if required.

$U_{P2,S}$ is 1,15 × the maximum absolute peak value (Figure 2) of the switching impulse voltage, which the cable system can experience when the impulse has the same polarity as the actual DC voltage.

$U_{P2,O}$ is, for the type test, 1,15 × the maximum absolute peak value (Figure 2) of the switching impulse voltage which the cable system can experience when the impulse has the opposite polarity to the actual DC voltage.

For the PQ test, $U_{P2,O}$ = 1,2 U_0.

$U_{RC,AC}$ is the maximum peak voltage a return cable can be subjected to due to temporary damped alternating overvoltage. This voltage is typically induced by a commutation failure, and the value should be supported by the customer.

$U_{RC,DC}$ is the maximum DC voltage in normal operation of the return cable.

The ripple content of the DC test voltages shall not be greater than 3 %.

Measuring shall be done with an approved measuring system according to IEC 60060-2.

NOTE 1 The basis for the selection of test factors is described in CIGRE Technical Brochure 496.

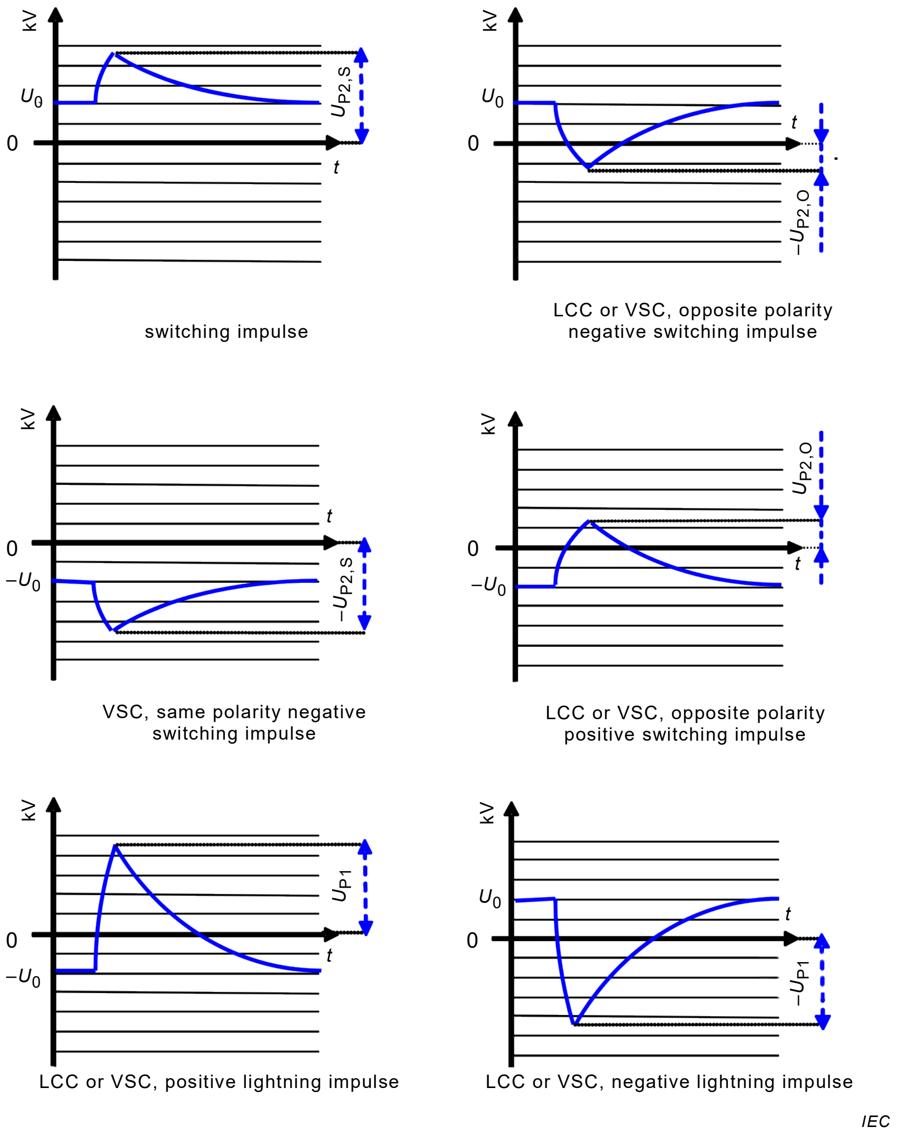


Figure 2 – Schematic representations of the switching impulse and lightning impulse test voltages

NOTE 2 Due to the constraints within the DC system design, $U_{P2,S}$ does not necessarily equal $U_{P2,O}$, i.e. the same polarity impulse is limited by surge arresters, but the opposite polarity impulse can be limited by the converter.

8.3 Thermal conditions

The heating method used shall be conductor heating only. The heating may be achieved by either DC or AC current, possibly in combination with external thermal insulation. Conductor temperature, external cable temperature on the oversheath and ambient temperature shall be measured and reported during the whole duration of the tests. The actual ΔT_{max} and T_{cond} during testing need to be demonstrated (see Annex A).

NOTE 1 Typical tolerance of T_{cond} is -0 K +5 K but heating cycles with higher values are valid.

NOTE 2 The temperature difference ΔT_{max} can be calculated from the measured conductor temperature and the measured temperature on the outer surface of the insulation screen

Heating cycles (HC)	heating cycles consist of both a heating period and a cooling period. • "24 hours" heating cycles (for PQ and type tests) consist of at least 8 h of heating followed by at least 16 h of natural cooling. During at least the last 2 h of the heating period, the conductor temperature ≥ $T_{cond,max}$ and a temperature drop across the insulation ≥ ΔT_{max} shall be maintained. For the type test the temperature of the conductor before beginning the next heating cycle shall not be higher than the ambient temperature + 15 K; this value shall be lower than 45 °C. • "48 hours" heating cycles (for type test only) consist of at least 24 h of heating followed by at least 24 h of natural cooling. During at least the last 18 h of the heating period, the conductor temperature ≥ $T_{cond,max}$ and a temperature drop across the insulation ≥ ΔT_{max} shall be maintained. The temperature of the conductor before beginning the next heating cycle shall not be higher than the ambient temperature + 15 K; this value shall be lower than 45 °C. 48 h heating cycles are only required as part of the type test procedure to ensure that electrical stress inversion is well advanced within the cycle.
Continuous heating (CH)	Within the first 8 h of the continuous heating period a conductor temperature ≥ $T_{cond,max}$ and a temperature drop across the insulation ≥ ΔT_{max} shall be achieved and maintained for the rest of this period . If, for practical reasons, the specified temperatures cannot be reached within the first 8 h, a longer time may be used. This additional time shall not be constituted as being part of the test period.
Zero heating (ZH)	No heating is applied.
Impulse test	Conductor temperature ≥ $T_{cond,max}$ and temperature drop across the insulation ≥ ΔT_{max} shall be reached for a minimum 10 h before voltage impulses (superimposed impulse, switching, lightning) are applied and shall be maintained throughout the duration of the test .
Ambient temperature	Unless otherwise specified in the details for the particular test, tests shall be carried out at an ambient temperature of (20 ± 15) °C.

8.4 Polarity reversal test

The voltage and temperature conditions are defined in 8.2 and 8.3 respectively. Starting with positive voltage, the voltage polarity shall be reversed three times every "24 hours" heating cycle (evenly distributed) and one reversal shall coincide with the cessation of heating current in every "24 hours" heating cycle. The recommended time duration for a polarity reversal is within two minutes.

If, for practical reasons, polarity reversals cannot be achieved within two minutes, the duration for polarity reversals shall be agreed between customer and supplier.

8.5 Superimposed impulse voltage test

8.5.1 General

Prior to the first impulse of each test the test object shall be heated so that the steady state temperature conditions as defined in 8.3 (CH) are achieved for at least 10 h and the test object shall have been subjected to U_0 (of the relevant polarity) for at least 10 h. In the case of interruptions of DC voltage of less than 5 minutes the total time of application of DC voltage need not be increased. However in the case of interruption of the DC voltage of more than 5 minutes up to a maximum of 90 minutes the DC voltage can be reapplied and the total time of application of the DC voltage must be increased by 120 minutes. These conditions have been selected to reflect the electrical dynamics present within extruded insulations used for HVDC. Superimposed impulse voltage shall be applied according to the procedure given in IEC 60230.

8.5.2 Superimposed lightning impulse voltage

The test waveform shall be according to IEC 60230.

8.5.3 Superimposed switching impulse voltage

The test waveform shall be according to IEC 60230.

8.6 Relationship between test voltages and rated voltages

The test voltages are specified in this standard as multiples of the rated voltage U_0.

8.7 Determination of the cable conductor temperature

The test method described in Annex A shall be used to determine the actual conductor temperature.

8.8 Rest period

Between test periods with opposite DC voltage the cable should be exposed to a rest period. In this period the cable is discharged first followed by no voltage under continuous heating at a conductor temperature ≥ $T_{cond,max}$ and at a temperature drop across the insulation ≥ ΔT_{max} for a period of at least 24 h. For not less than 8 h out of this 24 h rest period the conductor should be grounded.

This shall not be applicable to the polarity reversal test of LCC.

During the rest period the outer surface of the cable terminations may be cleaned.

The discharge of the cable should be performed with the help of a discharging resistor dimensioned to avoid rapid voltage change.

9 Routine tests on cables and on the main insulation of prefabricated accessories

9.1 General

The following tests shall be carried out on each manufactured length of cable and for each delivered accessory.

a) voltage test (see 9.2);

b) electrical test on oversheath of the cable, if required (see 9.3).

The order in which these tests are carried out is at the discretion of the manufacturer.

The main insulation of prefabricated accessories shall undergo voltage (see 9.2) routine tests according to either 1), 2) or 3) below:

1) on the main insulation of prefabricated accessories installed on cable;

2) by using a host accessory into which a component of an accessory is substituted for test;

3) by using a simulated accessory rig in which the electrical stress environment of a main insulation component is reproduced.

In cases 2) and 3), the test voltage shall be selected so as to obtain stresses at least the same as those on the component in a complete accessory when subjected to the test voltages specified in 9.2 and 9.3.

NOTE The main insulation of prefabricated accessories consists of the components that come in direct contact with the cable insulation and are necessary and essential to control the electrical field distribution in the accessory. Examples are premoulded or precast elastomer or filled epoxy resin insulating components that can be used singly or jointly to provide the necessary insulation or screening of accessories.

9.2 Voltage test

Every delivery length of cable and each individual prefabricated accessory shall be submitted to a negative DC voltage equal to the test voltage defined for the heating cycle test U_T and applied between conductor and metal screen/sheath for 1 h at ambient temperature.

An AC test combined with PD measurement is recommended – where suitable. Test parameters shall be agreed between manufacturer and customer.

No breakdown of the insulation shall occur.

9.3 Electrical test on oversheath of the cable

When the test is required by the particular contract, the cable oversheath shall be subjected to the electrical test specified in IEC 60229:2007, 3.1.

10 Sample tests on cables

10.1 General

The following tests shall be carried out on samples which, for the tests in items b) and g), may be complete drum lengths of cable, taken to represent batches:

a) conductor examination (see 10.4);
b) measurement of electrical resistance of conductor and of metal screen/sheath (see 10.5);
c) measurement of thickness of insulation and oversheath (see 10.6);
d) measurement of thickness of metal sheath (see 10.7);
e) measurement of diameters, if required (see 10.8);
f) hot set test for XLPE and EPR insulations (see 10.9);
g) measurement of capacitance (see 10.10);
h) measurement of density of HDPE insulation (see 10.11);
i) impulse voltage test (see 10.12);
j) water penetration test, if applicable (see 10.13);
k) adhesion and peel strength of the laminated metal foil of cables with longitudinally applied metal foil, bonded to the oversheath (see 10.14).

If an insulation material that is not given in Table 1 is used, requirements for the non-electrical tests in items f) and h) shall be agreed between manufacturer and customer

10.2 Frequency of tests

The sample tests in items a) to h) and k) in 10.1 shall be carried out on one delivery length from each batch of the same type and cross-section of cable, but shall be limited to not more than 10 % of the number of delivery lengths in any contract, rounded to the nearest whole number.

The frequency of the tests in items i) and j) in 10.1 shall be in accordance with agreed quality control procedures. In the absence of such an agreement, one test shall be made for contracts with a cable length up to 20 km and one additional test every additional 50 km delivered cable length.

10.3 Repetition of tests

If the sample from any length selected for the tests fails in any of the tests in Clause 10, further samples shall be taken from two further lengths of the same batch and subjected to the same tests as those in which the original sample failed. If both additional samples pass the tests, the other cables in the batch from which they were taken shall be regarded as having complied with the requirements of this standard. If either fails, this batch of cables shall be regarded as having failed to comply.

10.4 Conductor examination

Compliance with the requirements of IEC 60228 for conductor construction shall be checked by inspection and measurement when practicable.

10.5 Measurement of electrical resistance of conductor and of metal screen/sheath

The cable length, or a sample thereof, shall be placed in the test room, which shall be maintained at a reasonably constant temperature for at least 12 h before the test. If there is a doubt that the conductor or metal screen temperature is not the same as the room temperature, the resistance shall be measured after the cable has been in the test room for 24 h. Alternatively, the resistance may be measured on a sample of conductor or metal screen, conditioned for at least 1 h in a temperature-controlled liquid bath.

The DC resistance of the conductor or metal screen shall be corrected to temperature of 20 °C and 1 km length in accordance with the formulae and factors given in IEC 60228. For screens other than copper or aluminium, temperature coefficients and correction formulae shall be taken respectively from Table 1 and IEC 60287-1-1:2006, 2.1.1.

The corrected DC resistance of the conductor at 20 °C shall not exceed either the appropriate maximum value specified in IEC 60228 or the declared value.

The corrected DC resistance of the metal screen at 20 °C shall not exceed the declared value.

10.6 Measurement of thickness of insulation and cable oversheath

10.6.1 General

The test method shall be in accordance with IEC 60811-201 for insulation and IEC 60811-202 for sheath.

Each cable length selected for the test shall be represented by a piece taken from one end after having discarded, if necessary, any portion that may have suffered damage.

10.6.2 Requirements for the insulation

The lowest measured thickness shall not fall below 90 % of the nominal thickness:

$$t_{min} \geq 0{,}90\ t_n$$

and additionally:

$$\frac{t_{max} - t_{min}}{t_{max}} \leq 0{,}10$$

where

t_{max} is the maximum thickness, in millimetres;

t_{min} is the minimum thickness, in millimetres;

t_n is the nominal thickness, in millimetres.

NOTE t_{max} and t_{min} are measured at the same cross-section of the insulation.

The thickness of the semi-conducting screens on the conductor and over the insulation shall not be included in the thickness of the insulation.

10.6.3 Requirements for the cable oversheath

The lowest measured thickness shall not fall below 85 % of the nominal thickness by more than 0,1 mm:

$$t_{min} \geq 0{,}85\ t_n - 0{,}1$$

where

t_{min} is the minimum thickness, in millimetres;

t_n is the nominal thickness, in millimetres.

In addition, for oversheaths applied onto a substantially smooth surface, the average of the measured values rounded to 0,1 mm in accordance with Annex B shall be not less than the nominal thickness.

The latter requirement does not apply to oversheaths applied onto an irregular surface, such as one formed by metal screens of wires and/or tapes or corrugated metal sheaths.

10.7 Measurement of thickness of metal sheath

10.7.1 Lead or lead alloy sheath

10.7.1.1 General

If the cable has a lead or lead alloy sheath, the minimum thickness of the metal sheath shall not fall below 95 % of the nominal thickness by more than 0,1 mm:

$$t_{min} \geq 0{,}95\ t_n - 0{,}1$$

The thickness of the lead sheath shall be measured by one of the following methods, at the discretion of the manufacturer.

10.7.1.2 Strip method

The measurement shall be made with a micrometer with plane faces of 4 mm to 8 mm diameter and an accuracy of ±0,01 mm.

The measurement shall be made on a test piece of lead sheath about 50 mm in length removed from the complete cable. The piece shall be slit longitudinally and carefully flattened. After cleaning the test piece, a sufficient number of measurements shall be made along the circumference of the lead sheath and not less than 10 mm away from the edge of the flattened piece to ensure that the minimum thickness is measured.

10.7.1.3 Ring method

The measurements shall be made with a micrometer having either one flat nose and one ball nose, or one flat nose and a flat rectangular nose 0,8 mm wide and 2,4 mm long. The ball nose or the flat rectangular nose shall be applied to the inside of the ring. The accuracy of the micrometer shall be ±0,01 mm.

The measurements shall be made on a ring of the lead sheath carefully cut from the sample. The thickness shall be determined at a sufficient number of points around the circumference of the ring to ensure that the minimum thickness is measured.

10.7.2 Plain or corrugated aluminium sheath

The minimum thickness of the sheath shall not fall below 90 % of the nominal thickness by more than 0,1 mm for plain aluminium sheath:

$$t_{min} \geq 0{,}9\ t_n - 0{,}1$$

and 85 % of the nominal thickness by more than 0,1 mm for corrugated aluminium sheath:

$$t_{min} \geq 0{,}85\ t_n - 0{,}1$$

The measurements shall be made with a micrometer having ball noses of radii about 3 mm. The accuracy shall be ±0,01 mm.

The measurements shall be made on a ring of the aluminium sheath, about 50 mm wide, carefully removed from the complete cable. The thickness shall be determined at a sufficient number of points around the circumference of the ring to ensure that the minimum thickness is measured.

10.8 Measurement of diameter

If the purchaser requires that the diameter of the core and/or the overall diameter of the cable shall be measured, the measurements shall be carried out in accordance with IEC 60811-203.

10.9 Hot set test for XLPE and EPR insulations

10.9.1 Procedure

The sampling and test procedure shall be carried out in accordance with IEC 60811-507, employing the test conditions given in Table 3.

The test pieces shall be taken from that part of the insulation where the degree of cross-linking is considered to be the lowest for the curing process employed.

10.9.2 Requirements

The test results shall comply with the requirements given in Table 3.

10.10 Measurement of capacitance

The capacitance shall be measured with a frequency between 49 Hz and 61 Hz between conductor and metal screen/sheath at ambient temperature, and the temperature shall be recorded with the test data.

The measured value of the capacitance shall be corrected to a 1 km length and shall not exceed the declared nominal value by more than 8 %.

10.11 Measurement of density of HDPE insulation

10.11.1 Procedure

The density of HDPE shall be measured using the sampling and test procedure given in IEC 60811-606.

10.11.2 Requirements

The results of the test shall comply with the requirements given in Table 3.

10.12 Impulse voltage test

The assembly shall be heated by conductor current only, until the cable reaches the required temperature.

If, for practical reasons, the test temperature cannot be reached, additional thermal insulation may be applied.

The impulse voltage shall be applied as

- either lightning impulse with the voltage calculated as the sum of the moduli of U_0 and the specified superimposed lightning impulse voltage U_{P1}, or
- if the lightning impulse is not specified in the individual project, switching impulse at the voltage that is the sum of the moduli of U_0 and the requested opposite switching impulse voltage $U_{P2,O}$.

Alternatively it can be applied as superimposed impulse voltage according to12.4.5

The cable shall withstand without failure 10 positive and 10 negative voltage impulses of the appropriate value.

No breakdown of the insulation shall occur.

10.13 Water penetration test

If applicable, samples shall be taken from the complete cable, the test shall be applied and the requirements shall be met as described in Annex E.

10.14 Adhesion and peel strength of the laminated metal foil

For cables with a longitudinally applied metal foil, bonded to the oversheath, a 1 m sample shall be taken from the complete cable and subjected to the tests and requirements in 12.4.3.

11 Sample tests on accessories

11.1 Tests on components

The characteristics of each component shall be verified in accordance with the specifications of the accessories manufacturer, either through test reports from the supplier of a given component or through internal tests.

The manufacturer of a given accessory shall provide a list of the tests to be performed on each component, indicating the frequency of each test.

The components shall be inspected against their drawings. There shall be no deviation outside the declared tolerances.

NOTE As components differ from one supplier to another, it is not possible to define common sample tests on components in this standard.

11.2 Tests on complete accessory

For accessories where the main insulation cannot be routine tested (see 9.1), the voltage test (see 9.2) shall be carried out by the manufacturer on a fully assembled accessory.

NOTE Examples of main insulations that are not routine tested are insulations taped and/or moulded on site.

These tests shall be performed on one accessory of each type per contract if the number of that type in the contract is above 50.

If the sample fails either of the above two tests, two further samples of the same accessory type shall be taken from the contract and subjected to the same tests. If both additional samples pass the tests, the other accessories of the same type from the contract shall be regarded as having complied with the requirements of this standard. If either fails, this type of accessory of the contract shall be regarded as having failed to comply.

12 Type tests on cable systems

12.1 General

The tests specified in Clause 12 are intended to demonstrate the satisfactory performance of cable systems.

The subclause references to be considered during a type test on a cable system is given in Table C.1.

NOTE Tests on terminations referring to environmental conditions are not specified in this standard.

12.2 Range of type approval

When type tests have been successfully performed on one or more cable system(s) of specific cross-section(s) and of the same rated voltage and construction, the type approval shall be considered as valid for cable systems within the scope of this standard with other cross-sections, rated voltages and constructions, provided that all the conditions of a) to h) are met.

a) The actual designs, materials, manufacturing processes and service conditions for the cable system are in all essential aspects equal.

b) All service voltages, U_0, U_{P1}, $U_{P2,S}$ and $U_{P2,O}$, are less than or equal to those of the tested cable system.

c) The service maximum conductor temperature $T_{cond,max}$ is less than or equal to that of the tested cable system.

d) The maximum temperature drop across the insulation layer ΔT_{max} (excluding the semiconducting screens) is less than or equal to that of the tested cable system.
e) The actual conductor cross-section is not larger than that of the tested cable system.
f) The calculated average electrical stress in the insulation (given by U_0 divided by the nominal insulation thickness) is less than or equal to that of the tested system.
g) The calculated Laplace electrical stress (using nominal dimensions) at the cable conductor and insulation screen is less than or equal to that of the tested system.
h) A cable system qualified according to this standard for LCC is also qualified for VSC provided that the superimposed impulse withstand tests at $\pm U_{P2,S}$ voltage levels as specified in 12.4.5.3 are carried out. A cable system qualified according to this standard for VSC is not qualified for LCC.

NOTE 1 Type tests which have been successfully performed according to CIGRE test recommendation TB219 and TB496 are valid.

NOTE 2 For the sake of clarity the conditions for range of approval do not involve considerations of DC electrical fields. In the design of DC cable systems, the DC electrical fields are critical design criteria. The supplier has detailed knowledge of the DC electrical fields in the cable system (cable and accessories) under all operating conditions and is able to present a detailed case upon request of the customer.

The non-electrical type tests need not be carried out on samples from cables of different voltage ratings and/or conductor cross-sectional areas unless different materials and/or different manufacturing processes are used to produce them. However, repetition of the ageing tests on pieces of complete cable to check compatibility of materials (see IEC 62067) may be required if the combination of materials applied over the screened core is different from that of the cable on which type tests have been carried out previously.

A type test certificate signed by the representative of a competent witnessing body, or a report by the manufacturer giving the test results and signed by the appropriate qualified officer, or a type test certificate issued by an independent test laboratory shall be acceptable as evidence of type testing.

12.3 Summary of type tests

The type tests shall comprise the electrical tests on the complete cable system as specified in 12.4 and the appropriate non-electrical tests on cable components and complete cable as specified in 12.5.

The non-electrical tests on cable components and complete cable are listed in Table 4, indicating which tests are applicable to each insulation and oversheath material.

The tests listed in 12.4.2 shall be performed on one or more samples of complete cable, depending on the number of accessories involved, at least 10 m in length excluding the accessories.

The minimum length of free cable between accessories shall be 5 m as reported in Figure 1.

Each cable length used for the type test loop shall undergo a bending test in accordance with 12.4.3 before type tests commence. The accessories shall be installed after the bending test.

Cable and accessories shall be assembled in the manner specified by the manufacturer's instructions, with the grade and quantity of materials supplied, including lubricants if any.

The external surface of accessories shall be dry and clean, but neither the cables nor the accessories shall be subjected to any form of conditioning not specified in the manufacturer's instructions which might modify the electrical, thermal or mechanical performance.

Measurement of resistivity of semi-conducting screens described in 12.4.7 shall be made on a separate sample.

12.4 Electrical type tests on complete cable systems

12.4.1 Test voltage values

Prior to the electrical type tests, the insulation thickness shall be measured by the method specified in IEC 60811-201 on a representative piece of the length to be used for the tests, to check that the thickness is not excessive compared with the nominal value.

If the average thickness of the insulation does not exceed the nominal value by more than 5 %, the test voltages shall be the values specified in 8.2 for the rated voltage of the cable.

If the average thickness of the insulation exceeds the nominal value by more than 5 % but by not more than 10 %, the test voltage shall be adjusted to give an electrical average stress in the insulation (given by U_0 divided by the actual insulation thickness) equal to that applying when the average thickness of the insulation is equal to the nominal value, and the test voltages are the normal values specified for the rated voltage of the cable.

The cable length used for the electrical type tests shall not have an average insulation thickness exceeding the nominal value by more than 10 %.

12.4.2 Tests and sequence of tests

The tests in items a) to h) shall be carried out in the following sequence.

a) Bending test on the cable (see 12.4.3) followed by visual inspection and installation of accessories.

b) A DC voltage of 8 kV per millimetre of the specified nominal thickness of the extruded oversheath shall be applied for 1 min between the underlying metal layer at negative polarity and the outer conducting layer, subject to a maximum voltage of 25 kV. No breakdown of the oversheath shall occur during the test.

   NOTE 1 The outer conducting layer can consist of a conductive layer applied to the extruded oversheath or any auxiliary ground electrode applied for the duration of this test.

c) Heating cycle voltage test (see 12.4.4).

d) Superimposed switching impulse voltage test (see 12.4.5.2 and 12.4.5.3).

e) Superimposed lightning impulse voltage test (see 12.4.5.4).

f) Subsequent DC test (see 12.4.5.5).

g) Tests of outer protection for joints (see Annex H).

   NOTE 2 These tests can be applied to a joint which has passed the test in item c), heating cycle voltage test, or to a separate joint which has passed at least three thermal cycles.

   NOTE 3 If the cable and joint are not to be subjected to wet conditions in service (i.e. not directly buried in earth or not intermittently or continuously immersed in water), the tests in H.3 and H.4.2 can be omitted.

h) Examination of the cable system with cable and accessories on completion of the above tests (see 12.4.6);

i) The resistivity of the cable semi-conducting screens (see 12.4.7) shall be measured on a separate sample.

Test voltages shall be in accordance with the values given in 8.2.

12.4.3 Bending test

12.4.3.1 Test Conditions

The cable sample shall be bent around a test cylinder (for example, the hub of a drum) at ambient temperature for at least one complete turn and unwound, without axial rotation. The sample shall then be rotated through 180° and the process repeated.

This cycle of operations shall be carried out three times in total.

The diameter of the test cylinder shall not be greater than

- for cables with a longitudinally applied metal foil, bonded to the oversheath:
  - $20\ (D + d) + 5\ \%$ for CD design;

  - 25 ($D + d$) + 5 % for SD and CD + wires designs;
- for cables with plain aluminium sheaths:
  - 36 ($d + D$) + 5 % for single-core cables;
- for cables with lead, lead-alloy, corrugated metal sheaths:
  - 25 ($d + D$) + 5 % for single-core cables;
- for other cables:
  - 20 ($d + D$) + 5 % for single-core cables;

where

d is the nominal diameter of the conductor, in millimetres (see Clause 6, item i));

D is the nominal overall diameter of the cable, in millimetres (see Clause 6, item j)).

12.4.3.2 Examination

After the bending test one sample of 3 m length shall be examined. There shall be no deterioration and in the case of CD and SD designs no delaminating, folding of the metal foil bonded to the oversheath, buckling or crossing of the screen wires.

In the case of CD and SD designs, adhesion and peel tests (see Annex F) shall comply with the requirements of Table 5.

A negative tolerance is not specified, but testing at diameters below the specified values should only be done by agreement between manufacturer and customer.

12.4.4 Heating cycle voltage test

12.4.4.1 General

The cable shall have a U-bend with a diameter as specified in 12.4.3.

If the test loop consists of cables with different designs connected with an asymmetric joint, then each cable design is qualified to the relevant thermal conditions ($T_{cond,max}$ and ΔT_{max}) and the asymmetric joint is qualified to the higher temperature.

NOTE This means that the cable on one side of the transition joint under test may not have been qualified in this test to its maximum temperature in the scheme.

The temperature conditions are defined in 8.3.

After any interruption caused by external factors, the test may be resumed. If the interruption is less than 30 min, the specific heating cycles shall be resumed at the point of the cycle when the interruption occurred and the cycle is still valid provided the temperature requirements are met. If the interruption is longer than 30 min, the specific lost heating cycle shall be repeated. If the interruption is longer than 24 h, the actual test block (all “24 hours” heating cycles at negative or positive polarity, all “24 hours” heating cycles with polarity reversals, all “48 hours” heating cycles under positive polarity) shall be repeated.

In case of a breakdown of insulation, when testing several objects simultaneously, the faulty object may be removed and the incident treated as an interruption. The faulty object is considered to have failed the test requirements. Any fault within 0,5 m of cable, which is according to 8.1 part of the accessory, is considered to be associated with that accessory only.

In case of deviations in test parameters during a heating cycle, the heating cycle in question shall be repeated.

12.4.4.2 Heating cycle test for cable system to be qualified for LCC

The test objects shall be subjected to the conditions (definitions of “24 hours” heating cycles and “48 hours” heating cycles are described in 8.3) as specified in Table 6.

Positive polarity was selected for the “48 hours” heating cycles as this is believed to be the most stringent condition for accessories.

12.4.4.3 Heating cycle test for cable system to be qualified for VSC

The test objects shall be subjected to heating cycles according to Table 7.

Positive polarity was selected for the "48 hours" heating cycles as this is believed to be the most stringent condition for accessories.

12.4.5 Superimposed impulse voltage test

12.4.5.1 General

The superimposed impulse voltage test is to be performed on test objects that have successfully passed the heating cycle test.

Deviation of the sequence to perform SI and LI tests with same DC polarity in one block is allowed.

The tests shall be performed with respect to the following requirements:

- The conductor temperature shall be $\geq T_{condmax}$ with temperature drop across the insulation $\geq \Delta T_{max}$.

These thermal conditions shall be maintained for at least a minimal duration of 10 h before the tests; moreover, these conditions shall be held during the whole impulse test.

During the 10 h before the application of the first impulse, a direct voltage U_0 with the polarity of the DC voltage of the following superimposed impulse test shall be applied between conductor and metal screen with the screen grounded. The sign of polarity is referred to the voltage of the conductor in respect to ground. The DC voltage shall be maintained during the application of the voltage impulses.

In case of a breakdown of insulation, when testing several objects simultaneously, the faulty object may be removed and the incident treated as an interruption. The faulty object is considered to have failed the test requirements. Any fault within 0,5 m of a test object, for example an accessory, is considered to be associated with that test object only.

In case of deviations in test parameters during superimposed impulse voltage test, the superimposed impulse in question shall be repeated.

The test procedure is described in 8.5.

12.4.5.2 Superimposed switching impulse withstand test for cable system to be qualified for LCC

The definitions of the different levels of voltage are given in 8.2.

The test shall be performed as given in Table 8.

The time between each impulse shall not be shorter than two minutes.

The test waveform shall be according to IEC 60230.

No breakdown of the insulation or flashover along cable terminations shall occur.

12.4.5.3 Superimposed switching impulse withstand test for cable system to be qualified for VSC

The definitions of the different levels of voltage are given in 8.2.

The test shall be performed as given in Table 9.

The time between each impulse shall not be shorter than two minutes.

The test waveform shall be according to IEC 60230.

No breakdown of the insulation or flashover along cable terminations shall occur.

12.4.5.4 Superimposed lightning impulse withstand test

If the intended installation of the cable system is such that it is not exposed to lightning strikes (direct or indirect), this test need not be done.

20 voltage impulses shall be applied as specified in Table 8 and Table 9.

The time between each impulse shall not be shorter than two minutes.

The test waveform shall be according to IEC 60230.

No breakdown of the insulation or flashover along the cable terminations shall occur.

12.4.5.5 Subsequent DC test

After the successful completion of the superimposed impulse testing the test object shall be subjected for 2 h at a negative DC voltage of U_T. At the discretion of the manufacturer this test may be carried out either during the cooling period or at ambient temperature.

A rest period prior to this test is acceptable.

No breakdown of the insulation shall occur.

12.4.6 Examination

12.4.6.1 Cable samples

Three samples of cable – approximately 1 m each – taken from the whole loop that has undergone tests shall be subjected to examination: two samples shall be taken from the curved part of the loop, and one from a straight part.

12.4.6.2 Examination of cable and accessories

Examination of the cable by dissection of a sample and, whenever possible, of the accessories by dismantling, with normal or corrected vision without magnification, shall reveal no signs of deterioration (e.g. electrical degradation, leakage, corrosion or harmful shrinkage) which could affect the system in service operation.

12.4.6.3 Cables with a longitudinally applied metal tape or foil, bonded to the oversheath

One of the 1 m samples taken from the curved part of the type test loop and used for the examination of 12.4.6.2 shall also be subjected to the examination as described in 12.4.3.2.

12.4.7 Resistivity of semi-conducting screens

12.4.7.1 General

Measurement of resistivity of the cable semi-conducting screens shall be made on a separate sample.

The resistivity of extruded semi-conducting screens applied over the conductor and over the insulation shall be determined by measurements on test pieces taken from the core of a sample of cable as manufactured, and a sample of cable which has been subjected to the ageing treatment to test the compatibility of component materials as specified in 12.5.5.

12.4.7.2 Procedure

The test procedure shall be in accordance with Annex D.

The measurements shall be made at a temperature within ±2 K of the maximum conductor temperature in normal operation.

12.4.7.3 Requirements

The resistivity, both before and after ageing, shall not exceed the following values:

- conductor screen: 1 000 Ω · m;
- insulation screen: 500 Ω · m.

12.5 Non-electrical type tests on cable components and on complete cable

12.5.1 General

The tests are as follows:

a) check of cable construction (see 12.5.2);
b) tests for determining the mechanical properties of insulation before and after ageing (see 12.5.3);
c) tests for determining the mechanical properties of oversheaths before and after ageing (see 12.5.4);
d) ageing tests on pieces of complete cable to check compatibility of materials (see 12.5.5);
e) loss of mass test on PVC oversheaths of type ST_2 (see 12.5.6);
f) pressure test at high temperature on oversheaths (see 12.5.7);
g) tests on PVC oversheaths (ST_1 and ST_2) at low temperature (see 12.5.8);
h) heat shock test for PVC oversheaths (ST_1 and ST_2) (see 12.5.9);
i) ozone resistance test for EPR insulations (see 12.5.10);
j) hot set test for EPR and XLPE insulations (see 12.5.11);
k) measurement of density of HDPE insulation (see 12.5.12);
l) measurement of carbon black content of black PE oversheaths (ST_3 and ST_7, see 12.5.13);
m) test under fire conditions (see 12.5.14);
n) water penetration test (see 12.5.15).

If an insulation material that is not given in Table 1 is used, requirements for the non-electrical tests in items b), d) and j) shall be agreed between manufacturer and customer.

12.5.2 Check of cable construction

The examination of the conductor and measurements of insulation, oversheath and metal sheath thicknesses shall be carried out in accordance with and shall comply with the requirements given in 10.4, 10.6 and 10.7.

12.5.3 Tests for determining the mechanical properties of insulation before and after ageing

12.5.3.1 Sampling

Sampling and preparation of test pieces shall be carried out in accordance with IEC 60811-501.

12.5.3.2 Ageing treatment

The ageing treatment shall be carried out in accordance with IEC 60811-401 under the conditions specified in Table 10.

12.5.3.3 Conditioning and mechanical tests

Conditioning and the measurement of mechanical properties shall be carried out in accordance with IEC 60811-501.

12.5.3.4 Requirements

The test results for unaged and aged test pieces shall comply with the requirements given in Table 10.

12.5.4 Tests for determining the mechanical properties of oversheaths before and after ageing

12.5.4.1 Sampling

Sampling and preparation of test pieces shall be carried out in accordance with IEC 60811-501.

12.5.4.2 Ageing treatment

The ageing treatment shall be carried out in accordance with IEC 60811-401 under the conditions given in Table 11.

12.5.4.3 Conditioning and mechanical tests

Conditioning and the measurement of mechanical properties shall be carried out in accordance with IEC 60811-501.

12.5.4.4 Requirements

The test results for un-aged and aged test pieces shall comply with the requirements given in Table 11.

12.5.5 Ageing tests on pieces of complete cable to check compatibility of materials

12.5.5.1 General

The ageing test on pieces of complete cable shall be carried out to check that the insulation, the extruded semi-conducting layers and the oversheath are not liable to deteriorate excessively in operation due to contact with other components in the cable.

The test is applicable to cables of all types.

12.5.5.2 Sampling

Samples for the test on insulation and oversheath shall be taken from the complete cable as described in IEC 60811-401.

12.5.5.3 Ageing treatment

The ageing treatment of the pieces of cable shall be carried out in an air oven, as described in IEC 60811-401, under the following conditions:

- temperature: (10 ± 2) K above the maximum conductor temperature for the insulation material as given in Table 10
- duration: 7×24 h.

12.5.5.4 Mechanical tests

Test pieces of insulation and oversheath from the aged pieces of cable shall be prepared and subjected to mechanical tests as described in IEC 60811-401.

12.5.5.5 Requirements

The variations between the median values of tensile strength and elongation at break after ageing, and the corresponding values obtained without ageing (see 12.5.3 and 12.5.4), shall not exceed the values applying to the test after ageing in an air oven as given in Table 10 for insulations and in Table 11 for oversheaths.

12.5.6 Loss of mass test on PVC oversheaths of type ST_2

12.5.6.1 Procedure

The loss of mass test for ST_2 oversheaths shall be carried out as described in IEC 60811-409 under the conditions given in Table 12.

12.5.6.2 Requirements

The results shall comply with the requirements given in Table 12.

12.5.7 Pressure test at high temperature on oversheaths

12.5.7.1 Procedure

The pressure test at high temperature for ST_1, ST_2 and ST_7 oversheaths shall be carried out as described in IEC 60811-508, employing the test conditions given in the test method and in Table 11.

12.5.7.2 Requirements

The results shall comply with the requirements given in IEC 60811-508.

12.5.8 Test on PVC oversheaths (ST_1 and ST_2) at low temperature

12.5.8.1 Procedure

The test at low temperature for ST_1 and ST_2 oversheaths shall be carried out as described in IEC 60811-505 and IEC 60811-506 respectively, employing the test temperature given in Table 12.

12.5.8.2 Requirements

The results of the test shall comply with the requirements given in IEC 60811-505 and IEC 60811-506 respectively.

12.5.9 Heat shock test for PVC oversheaths (ST_1 and ST_2)

12.5.9.1 Procedure

The heat shock test on ST_1 and ST_2 oversheaths shall be carried out as described in IEC 60811-509, the test temperature and duration being in accordance with Table 12.

12.5.9.2 Requirements

The results of the test shall comply with the requirements given in IEC 60811-509.

12.5.10 Ozone resistance test for EPR insulation

12.5.10.1 Procedure

EPR insulation shall be tested for resistance to ozone using the sampling and test procedure described in IEC 60811-403. The ozone concentration and test duration shall be in accordance with Table 3.

12.5.10.2 Requirements

The results of the test shall comply with the requirements given in IEC 60811-403.

12.5.11 Hot set test for EPR and XLPE insulations

EPR and XLPE insulations shall be subjected to the hot set test described in 10.9 and shall comply with its requirements.

12.5.12 Measurement of density of HDPE insulation

The density of HDPE insulations shall be measured in accordance with 10.11 and shall comply with its requirements.

12.5.13 Measurement of carbon black content of black PE oversheaths (ST_3 and ST_7)

12.5.13.1 Procedure

The carbon black content of ST_3 and ST_7 oversheaths shall be measured using the sampling and test procedure described in IEC 60811-605.

12.5.13.2 Requirements

The nominal value of the carbon black content shall be (2,5 ± 0,5) %.

Lower values are allowed for special application not exposed to UV.

12.5.14 Test under fire conditions

The test under fire condition in accordance with IEC 60332-1-2 shall be carried out on a sample of completed cable, if the manufacturer wishes to claim that the particular design of cable complies with the requirements.

The results shall comply with the recommendations given in IEC 60332-1-2.

12.5.15 Water penetration test

The water penetration test shall be applied to those designs of cable where barriers to longitudinal water penetration have been included as declared in Clause 6, item c) and Clause 6, item f).

The apparatus, sampling, test procedure and requirements shall be in accordance with Annex E.

13 Prequalification test of the cable system

13.1 General and range of prequalification test approval

The PQ test is intended to indicate the long-term performance of the complete cable system and should normally be completed after the development tests have been carried out. The PQ test need only be carried out once, unless there is a substantial change in the cable system with respect to materials, manufacturing processes, construction or design parameters.

Substantial change is defined as that which might adversely affect the performance of the cable system. The supplier shall provide a detailed case including test evidence if modifications are introduced, which are claimed not to constitute a substantial change.

The PQ test qualifies the manufacturer as a supplier of cable systems provided that the following conditions are fulfilled.

a) The rated voltage U_0 is not more than 10 % higher than that of the tested cable system.

b) The calculated average electrical stress in the insulation (given by U_0 divided by the nominal insulation thickness) is less than or equal to that of the tested system.

c) The calculated Laplace nominal electrical stress at U_0 (using nominal dimensions) at the cable insulation screen calculated according to Clause 6, item m) is less than or equal to that of the tested system.

d) The maximum conductor temperature $T_{cond,max}$ is less than or equal to that of the tested system.

e) The maximum temperature drop across the insulation layer ΔT_{max} (excluding the semiconducting screens) is less than or equal to that of the tested system.

f) A cable system prequalified according to this standard for LCC is also prequalified for VSC. A cable system prequalified according to this standard for VSC is not prequalified for LCC.

NOTE For the sake of clarity the conditions for range of approval do not involve considerations of DC electrical fields. In the design of DC cable systems, the DC electrical fields are critical design criteria. The supplier has detailed knowledge of the DC electrical fields in the cable system under all operating conditions and can present a detailed case upon request of the customer.

PQ tests that have been successfully performed according to CIGRE TB 496 are valid.

The reason for the superimposed impulse test at the end of the PQ test is to verify that no major thermo-mechanical changes have taken place during the long-term testing. This test is not intended to qualify the system for a specific impulse level. Project-specific impulse levels should be qualified during the type test.

It is recommended to carry out a PQ test using a cable of a large conductor cross-section.

A list of PQ tests is given in Table C.2.

A PQ test certificate signed by the representative of a competent witnessing body, or a report by the manufacturer giving the test results and signed by the appropriate qualified officer, or a PQ test certificate issued by an independent test laboratory shall be acceptable as evidence of PQ testing.

13.2 Prequalification test on complete cable system

13.2.1 Summary of prequalification tests

The PQ test shall comprise the electrical tests on the complete cable system with approximately 100 m of full sized cable, including at least one of each type of accessory. The minimum length of free cable between accessories shall be 10 m. 8.1 applies regarding test objects. The sequence of tests shall be as follows:

a) bending test on the cable (see 12.4.3.1) followed by installation of accessories;

   for practical reasons the bending test can be performed on the whole length in one operation, or in sections;

   for cable systems with conductive layer on the oversheath a DC voltage test of the oversheath according to IEC 60229 after installation shall be performed;

b) heating cycle voltage test (see 13.2.4);

c) superimposed impulse voltage test (see 13.2.5);

d) examination of the cable system after completion of the tests above (see 13.2.6).

It could be the case that one or more of the accessories did not fulfil all the requirements of the PQ tests in 13.2. After repair of the test assembly, the PQ tests may be continued on the remaining cable system (cable with the remaining accessories). In case all the requirements of the tests in 13.2 are met by this remaining cable system, this remaining system is prequalified. The accessory or accessories that did not fulfil the requirements are excluded from this PQ. However the test may be continued for PQ of the cable with the replaced accessory until all requirements of 13.2 are met. If the manufacturer decides to include the repaired accessory in the cable system PQ, then, after the repair, the PQ test of the complete system shall be started from the beginning of the heating cycle voltage test.

If a breakdown of a test object occurs, causing an interruption to the ongoing testing of connected test objects, the test may be resumed after the failed test object is removed. The actual heating cycle or impulse during which the failure occurred shall be repeated for the remaining test objects. If breakdown occurs during a constant heat period, then the time elapsed without applied voltage shall be added behind the originally planned end date of that period. This means, the overall number of days with voltage remains the same as specified in the test requirements. After any interruption, for example an interruption caused by external factors the test may be resumed. If the interruption is less than 30 min, the specific heating cycle shall be resumed, at the point of the cycle, when the interruption occurred and is still valid. If the interruption is longer than 30 min, then the specific heating cycle shall be repeated. If the interruption occurs during a constant heat period and is longer than 30 min, the test on the day the interruption occurred shall be repeated.

13.2.2 Test voltage values

Prior to the PQ test of the cable system, the insulation thickness of the cable shall be measured and the test voltage values adjusted, if necessary, as stated in 12.4.1.

13.2.3 Test arrangement

Cable and accessories shall be assembled in the manner specified by the manufacturer’s instructions, with the grade and quantity of materials supplied, including lubricants, if any.

NOTE The main objective of the PQ test is to satisfactorily demonstrate the insulation integrity during long periods under DC, given the long dielectric time constants, compared to AC. It is however recognized that other aspects of a specific installation can be important, such as the thermo-mechanical effects due to the installation conditions. The representation of specific installation conditions in the test set-loop can be considered.

Ambient conditions may vary between installations and during the test and are not considered to have any major influence. The ambient temperature minimum limit of 8.3 does not apply. In case of change in ambient conditions, the conductor current shall be adjusted to maintain the conductor temperature and temperature drop across the insulation as specified in 8.3.

13.2.4 Heating cycle voltage test

General conditions are as follows.

a) Minimum duration is 360 days.
b) Conductor temperature and temperature difference across the insulation shall both be controlled to the design level. Design levels in accessories and adjacent cables may differ.

The sequence of tests for LCC and VSC are shown in Table 13 and Table 14.

Guidance on test conditions are defined in 8.2 and 8.3.

No breakdown of the insulation shall occur.

13.2.5 Superimposed impulse voltage test

After the heating cycle voltage test, and an optional rest period, the superimposed switching impulse voltage test shall be performed as specified in 12.4.5.2 and 12.4.5.3.

The aim of the superimposed impulse test after the long duration test is only to check the integrity of the cable system. Evaluation of available specifications for different projects show that the values of $U_{\mathrm{P2,O}}$ and U_{P1} vary between the different projects. In this respect, and based on the recorded experience, the impulse voltage values to be considered for the PQ test have been specified in 8.2.

Project specific requirements regarding impulse levels should be covered by the electrical type test 12.4.5.

The test shall be performed according to 8.5 on one or more cable samples and one or more accessories of each type of the tested system, the test objects being taken from the PQ test loop. All test objects together shall have a minimum cumulative active cable length of 30 m. If required for safety reasons, oil or gas filled accessories can be emptied and refilled for the preparation of the test objects. The temperature conditions are defined in 8.3.

As an alternative, the test may be carried out on the whole test assembly.

The test objects shall withstand without failure 10 positive and 10 negative superimposed switching impulses at the voltage levels $U_{\mathrm{P2,O}}$.

If by agreement between supplier and customer a superimposed lightning impulse test is also to be performed, the test objects shall withstand 10 positive and 10 negative superimposed lightning impulses.

No breakdown of the insulation or flashover along the cable terminations shall occur.

In case of a failure in an accessory during impulse testing and the root cause of the failure is proven to be originated from moving the accessory prior to the impulse test, impulse testing may be repeated on another accessory of the same kind taken from the PQ test loop. That accessory shall still be considered as prequalified, if the repeated test is passed.

13.2.6 Examination

Samples of cable – at least 1 m each – taken from each section of the whole loop representing a laying condition, for example one sample from the curved part of the loop, one sample from the loop that has been exposed to the highest mechanical or thermal constraints and one sample from a straight part.

The cable samples and all accessories of the test loop shall be examined as specified in 12.4.6.2.

13.3 Tests for the extension of the PQ of a cable system

For future consideration.

14 Type test on cables

Cables shall be type tested as part of a cable system.

15 Type test on accessories

Accessories shall be type tested as part of a cable system.

16 Electrical tests after installation

16.1 General

Tests on new installations are carried out when the installation of the cable system has been completed.

A DC oversheath test according to 16.2 and a DC insulation test according to 16.3 are recommended.

For installations where only the oversheath test according to 16.2 is carried out, quality assurance procedures during installation of accessories may, by agreement between the purchaser and contractor, replace the insulation test according to 16.3.

16.2 DC voltage test of the oversheath

The voltage level and duration specified in IEC 60229:2007, Clause 5 shall be applied between the metal sheath or metal screen and the ground.

For the test to be effective, it is necessary that the ground makes good contact with all of the outer surface of the oversheath. A conductive layer on the oversheath can assist in this respect.

16.3 High voltage test of the insulation

The installed HV cable system shall be subjected to a negative polarity DC voltage of U_{TP1}. The test duration shall be one hour.

Negative polarity shall be used regardless of the polarity of the pole.

16.4 TDR measurement

An optional TDR measurement according to Annex J may be performed for information.

Table 1 – Insulation compounds for cables

Insulating compound		Maximum conductor temperature °C	
		Normal operation[a]	Short-circuit (maximum duration 5 s)[a]
Low density thermoplastic polyethylene (filled or nonfilled)	(PE)	70	130[b]
High density thermoplastic polyethylene(filled or nonfilled)	(HDPE)	80	160[b]
Cross-linked polyethylene(filled or nonfilled)	(XLPE)	90	250
Ethylene-propylene rubber(filled or nonfilled)	(EPR)	90	250

[a] The temperatures given here are the maximum temperature for the mechanical characteristics of the material. The maximum operating temperature for the electrical performance of the system shall be equal or lower than the given values here and shall be specified by the cable manufacturer.

[b] For PE and HDPE, short-circuit temperatures up to 20 °C in excess of those shown may be acceptable with suitable semi-conducting layers over the conductor and the insulation and by agreement between manufacturer and purchaser.

Table 2 – Oversheathing compounds for cables

Oversheathing compound	Abbreviated designation	Maximum conductor temperature in normal operation °C
Polyvinyl chloride (PVC)	ST_1	80
	ST_2	90
Polyethylene (PE)	ST_3	80
	ST_7	90

Table 3 – Test requirements for particular characteristics of insulating compounds for cables

Designation of compound (see 4.3)	Unit	PE	HDPE	XLPE	EPR
Ozone resistance test (IEC 60811-403)					
Ozone concentration (by volume)	%	–	–	–	0,025 to 0,030
Test duration without cracks	h	–	–	–	24
Hot set test (IEC 60811-507)					
Treatment: air temperature	°C	–	–	200	250
– tolerance	K	–	–	±3	±3
– time under load	min	–	–	15	15
– mechanical stress	N/cm^2	–	–	20	20
Maximum elongation under load	%	–	–	175	175
Maximum permanent elongation after cooling	%	–	–	15	15
Density (IEC 60811-606)					
Minimum density	g/cm^3	–	0,94	–	–

Table 4 – Non-electrical type tests for insulating and oversheath compounds for cables

Designation of compound (see 4.3 and 4.5)	**Insulation**				**Oversheath**			
	PE	**HDPE**	**EPR**	**XLPE**	**ST_1**	**ST_2**	**ST_3**	**ST_7**
Checks on construction Water penetration test[a]	Applicable irrespective of insulation and oversheathing materials							
Mechanical properties (Tensile strength and elongation at break)								
a) without ageing	x	x	x	x	x	x	x	x
b) after ageing in air oven	x	x	x	x	x	x	x	x
c) after ageing of the complete cable (compatibility test)	x	x	x	x	x	x	x	x
Pressure test at high temperature	–	–	–	–	x	x	–	x
Behaviour at low temperature								
a) cold elongation test	–	–	–	–	x	x	–	–
b) cold impact test	–	–	–	–	x	x	–	–
Loss of mass in air oven	–	–	–	–	–	x	–	–
Heat shock test	–	–	–	–	x	x	–	–
Ozone resistance test	–	–	x	–	–	–	–	–
Hot set test	–	–	x	x	–	–	–	–
Measurement of density	–	x	–	–	–	–	–	–
Carbon black content[b]	–	–	–	–	–	–	x	x
Test under fire[c]								

NOTE x indicates that the type test is to be applied.

[a] To be applied to those designs of cable where the manufacturer claims that barriers to longitudinal water penetration have been included.

[b] For black oversheaths only.

[c] The test under fire conditions is only required if the manufacturer wishes to claim compliance with this test as a special feature of the design of the cable

Table 5 – Test requirements for adhesion or peel strength forces

	Min adhesion or peel strength (N/mm)	
	CD	SD
copper	1,5	1,0
aluminium	1,5	1,0
overlap	1,5	1,0

Table 6 – Sequence of heating cycle voltage test for LCC type test

	HC	**RP**	**HC**	**HC & PR**	**HC**	**RP**
Number of cycles	8	Optional, according to 8.8	8	8	3	Optional, according to 8.8
Duration of cycle	24h	Min. 24 h	24 h	24 h	48 h	Min. 24 h

Test Voltage	−		+	+/-	+	
	U_T		U_T	U_{TP1}	U_T	
HC = heating cycle, PR = polarity reversal, RP = rest period						

Table 7 – Sequence of heating cycle voltage test for VSC type test

	HC	RP	HC	HC	RP
Number of cycles	12	Optional, according to 8.8	12	3	Optional, according to 8.8
Duration of cycle	24 h	Min. 24 h	24 h	48 h	Min. 24 h
Test Voltage	−		+	+	
	U_T		U_T	U_T	
HC = heating cycle, RP = rest period					

Table 8 – Sequence of switching and lightning impulse test for LCC type test

	SI	RP	SI	RP	LI	RP	LI	SDT
Duration/number	10		10		10		10	2 h
Impulse voltage	−	24 h Optional, according to 8.8	+	Optional, according to 8.8	−	24 h Optional, according to 8.8	+	n.a.
	U_{P2O}		U_{P2O}		U_{P1}		U_{P1}	
DC test voltage	+		−		+		−	−
	U_0		U_0		U_0		U_0	U_T
SI = switching impulse, RP = rest period, LI = lightning impulse, SDT = subsequent DC test								

Table 9 – Sequence of switching and lightning impulse test for VSC type test

	SI	SI	RP	SI	SI	RP	LI	RP	LI	SDT
Duration/number	10	10		10	10		10		10	2 h
Impulse voltage	+	−	24 h Optional, according to 8.8	−	+	24 h Optional, according to 8.8	−	24 h Optional, according to 8.8	+	n.a.
	U_{P2S}	U_{P2O}		U_{P2S}	U_{P2O}		U_{P1}		U_{P1}	
DC test voltage	+	+		−	−		+		−	−
	U_0	U_0		U_0	U_0		U_0		U_0	U_T
SI = switching impulse, RP = rest period, LI = lightning impulse, SDT = subsequent DC test										

Table 10 – Test requirements for mechanical characteristics of insulating compounds for cables (before and after ageing)

Designation of compound (see 4.3)	**Unit**	**PE**	**HDPE**	**XLPE**	**EPR**
Maximum conductor temperature in normal operation[a]	°C	70	80	90	90
Without ageing (IEC 60811-501)					
Minimum tensile strength	N/mm^2	10,0	12,5	12,5	4,2
Minimum elongation at break	%	300	350	200	200
After ageing in air oven (EC 60811-401)					
Treatment: temperature	°C	100	110	135	135
tolerance	K	±2	±2	±3	±3
duration	h	240	240	168	168
Tensile strength					
a) minimum value after ageing	N/mm^2	–	–	–	–
b) maximum variation[b]	%	–	–	±25	±30
Elongation at break					
a) minimum value after ageing	%	300	350	–	–
b) maximum variation[b]	%	–	–	±25	±30

[a] The temperatures given here are the maximum temperature for the mechanical characteristics of the material. The maximum operating temperature for the electrical performance of the system shall be equal or lower than the given values here and shall be specified by the cable manufacturer.

[b] Variation: difference between the median value obtained after ageing and the median value obtained without ageing, expressed as a percentage of the latter.

Table 11 – Test requirements for mechanical characteristics of oversheathing compounds for cables (before and after ageing)

Designation of compound (see 4.5)	**Unit**	**ST_1**	**ST_2**	**ST_3**	**ST_7**
Without ageing (IEC 60811-501)					
Minimum tensile strength	N/mm^2	12,5	12,5	10,0	12,5
Minimum elongation at break	%	150	150	300	300
After ageing in air oven (of IEC 60811-401)					
Treatment: temperature	°C	100	100	100	110
tolerance	K	±2	±2	±2	±2
duration	h	168	168	240	240
Tensile strength:					
a) minimum value after ageing	N/mm^2	12,5	12,5	–	–
b) maximum variation[a]	%	±25	±25	–	–
Elongation at break					
a) minimum value after ageing	%	150	150	300	300
b) maximum variation[a]	%	±25	±25	–	–
Pressure test at high temperature (IEC 60811-508)					
Test temperature	°C	80	90	–	110
Tolerance	K	±2	±2	–	±2

[a] Variation: difference between the median value obtained after ageing and the median value obtained without ageing, expressed as a percentage of the latter.

Table 12 – Test requirements for particular characteristics of PVC oversheathing for cables

Designation of compound (see 4.5)	**Unit**	**ST_1**	**ST_2**
Loss of mass in air oven (IEC 60811-409)			
Treatment: temperature	°C	–	100
tolerance	K	–	±2
duration	h	–	168
Maximum permissible loss of mass	mg/cm^2	–	1,5
Behaviour at low temperature[a]			
Tests to be carried out without previous ageing			
a) Cold elongation test on dumb-bells (IEC 60811-505)			
Test temperature	°C	–15	–15
Tolerance	K	±2	±2
b) Cold impact test (IEC 60811-506)			
Test temperature	°C	–15	–15
Tolerance	K	±2	±2
Heat shock test (IEC 60811-509)			
1) Test temperature	°C	150	150
Tolerance	K	±3	±3
2) Test duration	h	1	1

[a] Due to climatic conditions, national standards may require the use of a lower test temperature.

Table 13 – Sequence of heating cycle voltage test for LCC PQ test

	HC	**RP**	**HC**	**HC+ PR**	**CH**	**RP**	**CH**	**ZH**	**RP**	**HC**	**RP**	**HC**	**HC+ PR**	**RP**
Number of cycles or duration	30 Cycl.	24h	30 Cycl.	20 Cycl.	40 days	24h	40 days	120 days	24 h	30 Cycl.	24 h	30 Cycl.	20 Cycl.	24 h
Test voltage	+	a	–		+	a	–	–	a	+	a	–		a
	U_{TP1}		U_{TP1}	U_{TP2}	U_{TP1}		U_{TP1}	U_{TP1}		U_{TP1}		U_{TP1}	U_{TP2}	

HC = heating cycle, CH = continuous heating, PR = polarity reversal,
ZH = zero heating,RP = rest period.

[a] Rest period is optional and can be performed according to 8.8.

Table 14 – Sequence of heating cycle voltage test for VSC PQ test

	HC	RP	HC	RP	CH	RP	CH	ZH	RP	HC	RP	HC	RP
Number of cycles or days	40 Cycl.	24 h	40 Cycl	24 h	40 days	2 4 h	40 days	120 days	24 h	40 Cycl.	24 h	40 Cycl.	24 h
Test Voltage	+	a	−	a	+	a	−	−	a	+	a	−	a
	U_{TP1}		U_{TP1}		U_{TP1}		U_{TP1}	U_{TP1}		U_{TP1}		U_{TP1}	

HC = heating cycle, CH = continuous heating, ZH = zero heating, RP = rest period.

[a] Rest period is optional and can be performed according to 8.8.

Annex A
(informative)

Determination of the cable conductor temperature

A.1 Purpose

For some tests, it is necessary to raise the cable conductor to a given temperature, while the cable is energized, either at DC or under impulse conditions. It is therefore not possible to have access to the conductor to enable direct measurement of temperature.

In addition, the conductor temperature shall be maintained within a restricted range (5 K) and the temperature drop across the insulation shall be at or above a specified value, whereas the ambient temperature may vary over a wider range.

Although preliminary calibration on the cable under test or calculations may be satisfactory in the first place, the variation of ambient conditions throughout the duration of the test may lead to deviations of the temperature of the conductor outside range. Therefore, methods shall be used in which the conductor temperature can be monitored and controlled throughout the duration of the test.

Guidance is given hereafter on the commonly used method.

A.2 Calibration of the temperature of the main test loop

A.2.1 General

The purpose is to determine the conductor temperature and, calculated from direct measurements, the temperature drop across the insulation of the main loop by direct measurements of the conductor, the insulation screen and the sheath temperature of the reference loop and, for monitoring purpose, the sheath temperature of the main loop for a given current, within the temperature range required for the test. The cable used for calibration (hereafter called reference cable) should be taken from the same manufacturing length as the cable used for the main test loop.

A.2.2 Installation of cable and temperature sensors

The calibration should be performed on a minimum cable length of 5 m, taken from the same cable as the one being tested. The length should be such that the longitudinal heat transfer to the cable ends does not affect the temperature in the centre 2 m of cable by more than 2 K.

The temperature sensors should be attached to the middle of the reference cable: one on the conductor (TC_{1c}), one on the insulation screen (TC_{1os}), and one on the external surface or directly under the external surface (TC_{1s}).

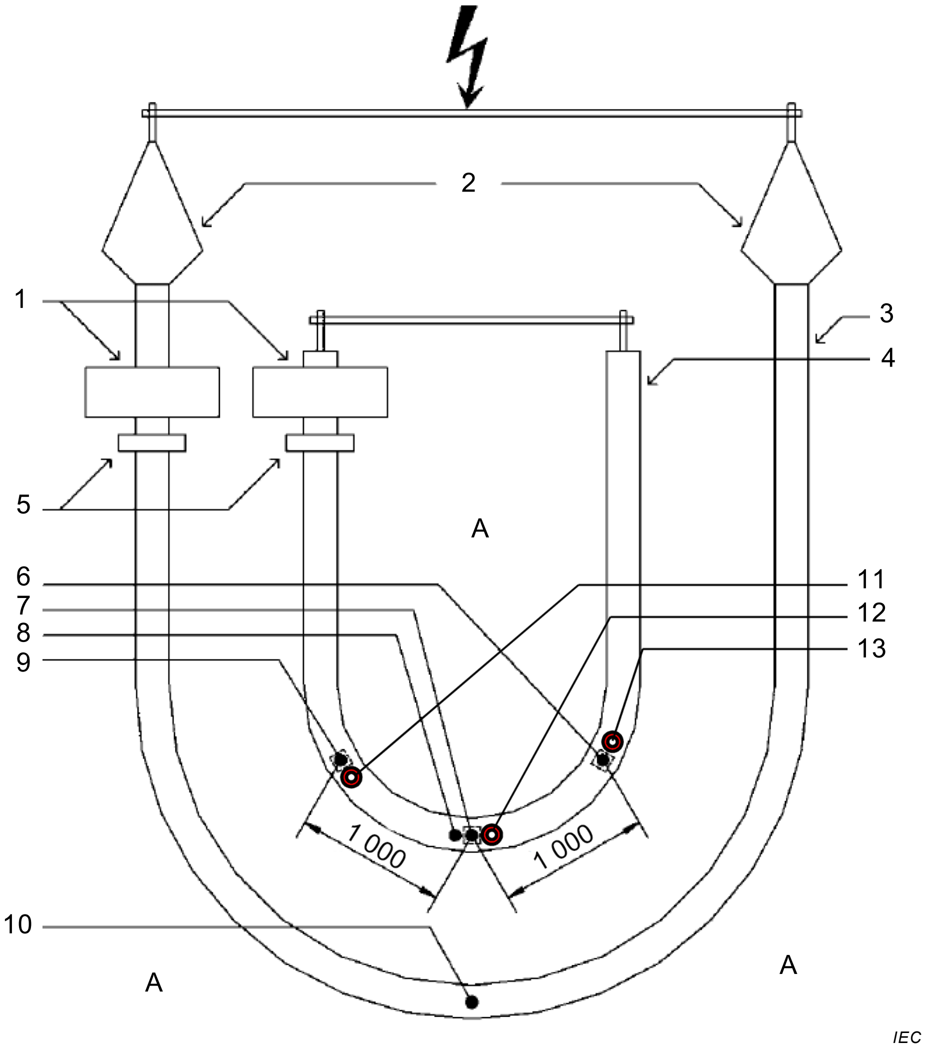
Two other temperature sensors, TC_{2c} and TC_{3c}, should be installed on the conductor of the reference cable, each one about 1 m from the middle, and two temperature sensors, TC_{2os} and TC_{3os}, should be installed on the insulation screen of the reference cable (see Figure A.1).

The temperature sensors should be attached to the conductor and to the insulation screen by mechanical means since they may move due to expansion and vibrations of the cable during heating. Care should be taken to maintain good thermal contact during the tests and to prevent leakage of heat to the ambient. It is recommended to mount the temperature sensor(s) as shown in Figure A.2 between two strands of a stranded conductor or between the (solid) conductor and the conductor screen. To enable access to the conductor in the middle of the reference cable, a small hatch should be made by careful removal of the layers above the conductor. After installing the temperature sensor(s), the layers that have been removed may be put back. This may restore the thermal behaviour of the reference cable.

To prove a negligible heat transfer towards the cable ends, the difference between the readings of TC_{1C}, TC_{2C} and TC_{3C} should be less than 2 K.

If the actual main test loop includes several individual cable lengths installed close to each other, these lengths will be subjected to thermal proximity effect. The calibration should therefore be carried out taking into account the actual test arrangement, measurements being performed on the hottest cable length (usually the middle length).

Dimensions in millimetres

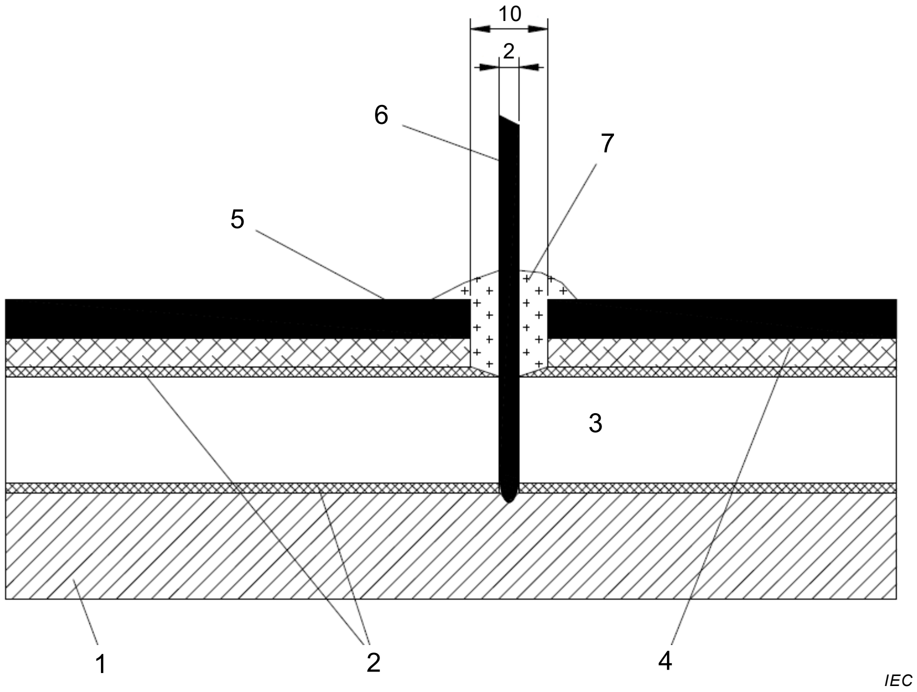


Key

1	current inducing transformers	8	TC_{1s} (sheath)
2	terminations	9	TC_{2C} (conductor)
3	cable under test	10	TC_s (sheath)
4	reference cable (≥ 5 m)	11	TC_{2OS} (insulation screen)
5	current measuring transformers		
6	TC_{3C} (Conductor)	13	TC_{3OS} (insulation screen)
7	TC_{1C} (Conductor)	A	ambient temperature

Figure A.1 – Schematic of sensor position in test set-up for the reference loop and the main test loop

Dimensions in millimetres



Key

1	conductor	5	cable oversheath
2	semi-conducting screens	6	temperature sensor
3	insulation	7	flexible thermal insulating compound
4	metal sheath		

Figure A.2 – Example of an arrangement of the temperature sensors on the conductor of the reference loop

A.2.3 Calibration method

The calibration should be carried out in a draught-free situation at a temperature of (20 ± 15) °C.

Temperature recorders should be used to measure the conductor, insulation screen, oversheath and ambient temperatures simultaneously.

The cable should be heated until the conductor temperature, indicated by temperature sensor TC_{1c} of Figure A.1, has stabilized and reached the following temperatures: between 0 K and 5 K above the maximum conductor temperature of the cable in normal operation.

When stabilization has been reached, the following should be noted:

- conductor temperature: average value at positions 1, 2 and 3;
- insulation screen temperature: average value at positions 1, 2 and 3;
- oversheath temperature at position TC_{1s};
- ambient temperature; average value of 3 positions around the test loop;
- heating current.

A.3 Heating for the test

A reference cable identical to the cable should be used for the test, heated with the same current value as the main test loop.

The installation of cable and temperature sensors for both loops should be as given in Clause A.2.

The test arrangement should be such that

- the reference cable carries the same current as the main test loop at any time,
- it is installed in such a way that mutual heating effects are taken into account throughout the test.

The heating current of both loops should be adjusted such that the conductor temperature is kept within the specified limits.

A temperature sensor (TC_s) should be mounted on or under the external surface of the main test loop at the hottest spot, usually in the middle of it, in the same way as the temperature sensor TC_{1s} is mounted on the hottest spot of the reference cable.

NOTE 1 The temperature measured with the temperature sensors on or under the oversheath of the main test loop (TC_s) and on the reference loop (TC_{1s}) are used to check whether the oversheath of both loops has the same temperature.

The temperature measured with temperature sensors TC_{1c} on the conductor of the reference loop may be considered as to be representative for the conductor temperature of the energized test loop.

NOTE 2 The temperature of the conductor of the main test loop can be slightly higher than that of the reference loop because of dielectric losses.

All temperature sensors should be connected to a recorder to enable temperature monitoring. The heating current of each loop should also be recorded to prove that the two currents are of the same value throughout the duration of the test. The difference between the heating currents should be kept within ±1 %.

The reference cable may be connected in series with the test cable if the temperature is measured via an optical fibre link or equivalent.

Annex B
(normative)

Rounding of numbers

When values are to be rounded to a specified number of decimal places, for example in calculating an average value from several measurements or in deriving a minimum value by applying a percentage tolerance to a given nominal value, the procedure shall be as follows.

If the figure in the last place to be retained is followed, before rounding, by 0, 1, 2, 3 or 4, it shall remain unchanged (rounding down).

If the figure in the last place to be retained is followed, before rounding, by 9, 8, 7, 6 or 5, it shall be increased by one (rounding up).

EXAMPLES

2,449	≈	2,45	rounded to two decimal places
2,449	≈	2,4	rounded to one decimal place
2,453	≈	2,45	rounded to two decimal places
2,453	≈	2,5	rounded to one decimal place
25,047 8	≈	25,048	rounded to three decimal places
25,047 8	≈	25,05	rounded to two decimal places
25,047 8	≈	25,0	rounded to one decimal place

Annex C
(informative)

List of type and prequalification tests of cable systems

Type tests of cable systems are covered by Clause 12.

Table C.1 gives a summary and references for type testing of these cable systems.

PQ tests of cable systems are covered by 13.1 and 13.2.

Table C.2 gives a summary and references for PQ testing of these cable systems.

Table C.1 – Type tests on cable systems

Item	**Test**	**Clauses**
		Cable systems
a	General	12.1
b	Range of type approval	12.2
c	Electrical type tests	12.4
d	Test voltage values	12.4.1
e	Bending test	12.4.3
f	Heating cycle voltage test	12.4.4
g	Superimposed impulse voltage test	12.4.5
h	Subsequent DC test	12.4.5.5
i	Tests of outer protection of joints	Annex H
j	Examination	12.4.6
k	Resistivity of semi-conducting screens	12.4.7
l	Non-electrical type tests on cable components and on completed cable	12.5

Table C.2 – PQ tests on cable systems

Item	**Test**	**Clauses**
		Cable systems
a	General and range of PQ test approval	13.1
b	PQ test on complete cable system	13.2
c	Summary of PQ tests	13.2.1
d	Test voltage values	13.2.2
e	Test arrangement	13.2.3
f	Bending test	13.2.1
g	Heating cycle voltage test	13.2.4
h	Superimposed impulse voltage test	13.2.5
i	Examination	13.2.6

Annex D
(normative)

Method of measuring resistivity of semi-conducting screens

Each test piece shall be prepared from a 150 mm sample of complete cable.

The conductor screen test piece shall be prepared by cutting a sample of core in half longitudinally and removing the conductor and separator, if any (see Figure D.1a)). The insulation screen test piece shall be prepared by removing all the coverings from a sample of core (see Figure D.1b)).

The procedure for determining the volume resistivity of the screens shall be as follows.

Four silver-painted electrodes A, B, C and D (see Figure D.1a) and D.1b)) shall be applied to the semi-conducting surfaces. The two potential electrodes, B and C, shall be 50 mm apart and the two current electrodes, A and D, shall be each placed at least 25 mm beyond the potential electrodes.

Connections shall be made to the electrodes by means of suitable clips. In making connections to the conductor screen electrodes, it shall be ensured that the clips are insulated from the insulation screen on the outer surface of the test sample.

The assembly shall be placed in an oven preheated to the specified temperature and, after an interval of at least 30 min, the resistance between the electrodes shall be measured by means of a circuit, the power of which shall not exceed 100 mW.

After the electrical measurements, the diameters over the conductor screen and insulation screen and the thicknesses of the conductor screen and insulation screen shall be measured at ambient temperature, each being the average of six measurements made on the sample shown in Figure D.1b).

The volume resistivity ρ in ohm metres shall be calculated as follows:

a) conductor screen:

$$\rho_c = \frac{R_c \times \pi \times (D_c - T_c) \times T_c}{2L_c}$$

where

ρ_c is the volume resistivity, in ohm metres (Ω·m);

R_c is the measured resistance, in ohms (Ω);

L_c is the distance between potential electrodes, in metres (m);

D_c is the diameter over the conductor screen, in metres (m);

T_c is the average thickness of conductor screen, in metres (m).

b) insulation screen:

$$\rho_i = \frac{R_i \times \pi \times (D_i - T_i) \times T_i}{L_i}$$

where

ρ_i is the volume resistivity, in ohm metres (Ω·m);

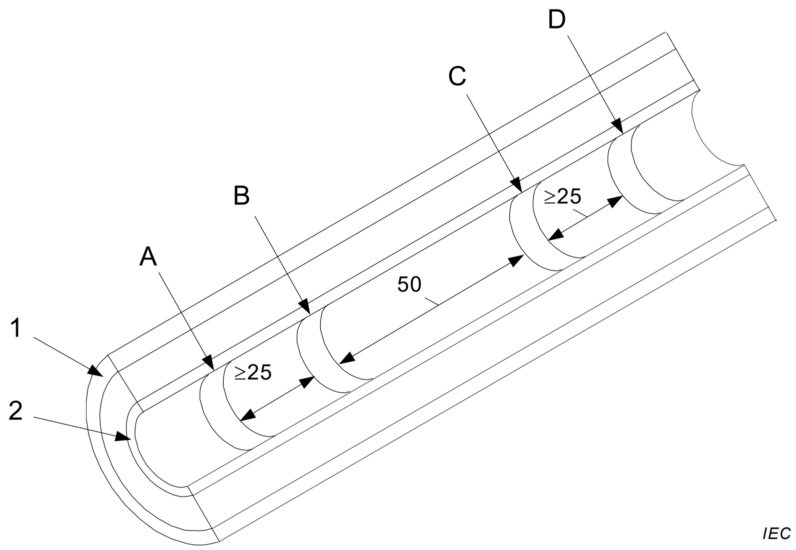
R_i is the measured resistance, in ohms (Ω);

L_i is the distance between potential electrodes, in metres (m);

D_i is the diameter over the insulation screen, in metres (m);

T_i is the average thickness of insulation screen, in metres (m).

Dimensions in millimetres

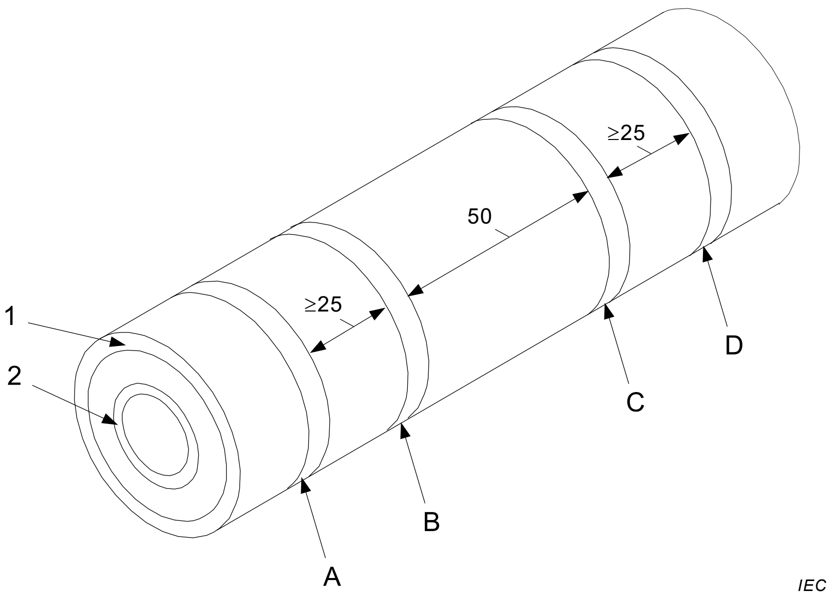


Key

1	insulation screen	B, C	potential electrodes
2	conductor screen	A, D	current electrodes

a) Measurement of the volume resistivity of the conductor screen

Dimensions in millimetres



Key

1	insulation screen	B, C	potential electrodes
2	conductor screen	A, D	current electrodes

b) Measurement of the volume resistivity of the insulation screen

Figure D.1 – Preparation of samples for measurement of resistivity of conductor and insulation screens

Annex E
(normative)

Water penetration test

E.1 Test piece

A sample of complete cable at least 8 m in length which has not been subjected to any of the tests described in 12.4 shall be subjected to the bending test described in 12.4.3.

An 8 m length of cable shall be cut from the length which has been subjected to the bending test and placed horizontally. A ring approximately 50 mm wide shall be removed from the centre of the length. This ring shall comprise all the layers external to the insulation screen. Where the conductor is also claimed to contain a barrier, the ring shall comprise all layers external to the conductor.

If the cable contains intermittent barriers to longitudinal water penetration, then the sample shall contain at least two of these barriers, the ring being removed from between the barriers. In this case, the average distance between the barriers in such cables should be known.

The surfaces shall be cut so that the interfaces intended to be longitudinally watertight shall be readily exposed to water. The interfaces not intended to be longitudinally watertight shall be sealed with a suitable material or the outer coverings removed.

Examples of such interfaces include

– when the cable only has a conductor barrier,
– when the interface is positioned between the oversheath and the metal sheath.

Arrange a suitable device (see Figure E.1) to allow a tube having a diameter of at least 10 mm to be placed vertically over the exposed ring and sealed to the surface of the oversheath. The seals where the cable exits the apparatus shall not exert mechanical stress on the cable.

The response of certain barriers to longitudinal penetration can be dependent on the composition of the water (e.g. pH, ion concentration). Normal tap water should be used for the test unless otherwise specified.

E.2 Test

The tube is filled with water within 5 min at a temperature of (20 ± 10) °C so that the height of the water in the tube is 1 m above the cable centre (see Figure E.1).

The sample shall be required to stand for 24 h.

The sample shall then be subjected to 10 heating cycles. The conductor shall be heated by a suitable method until it has reached a steady temperature 5 K to 10 K above the maximum conductor temperature in normal operation; it shall not, however, reach 100 °C.

The heating shall be applied for at least 8 h. The conductor temperature shall be maintained within the stated temperature limits for at least 2 h of each heating period. This shall be followed by at least 16 h of natural cooling.

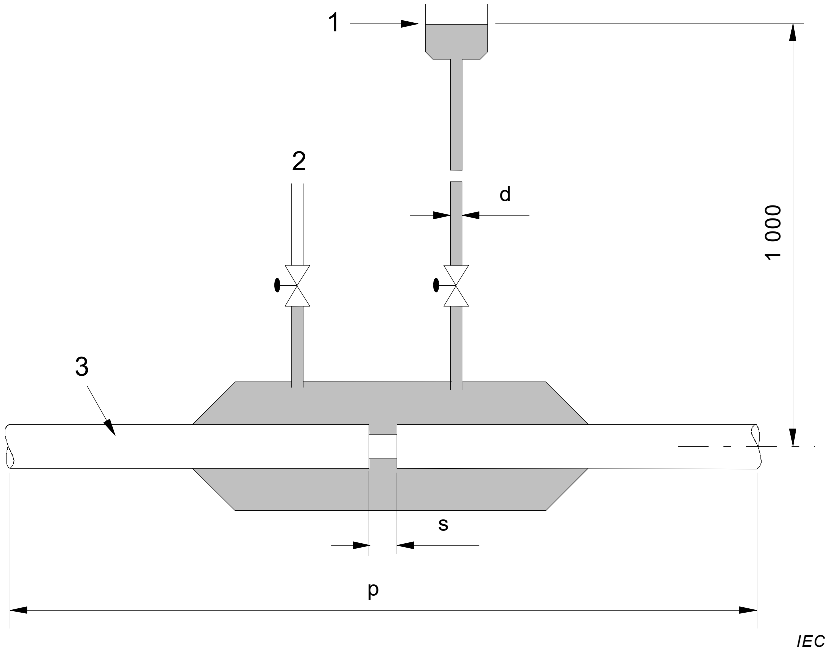
The water head shall be maintained at 1 m.

No voltage being applied throughout the test, it is advisable to connect a dummy cable in series with the cable to be tested, the temperature being measured directly on the conductor of this cable.

E.3 Requirements

During the period of testing, no water shall emerge from the ends of the test piece.

Dimensions in millimetres



Key

1	water header tank	d	Ø10 mm minimum (inner)
2	vent	s	50 mm approximately
3	cable	p	length = 8 000 mm

Figure E.1 – Schematic diagram of apparatus for water penetration test

Annex F
(normative)

Tests on components of cables with a longitudinally applied metal tape or foil, bonded to the oversheath

F.1 Visual inspection

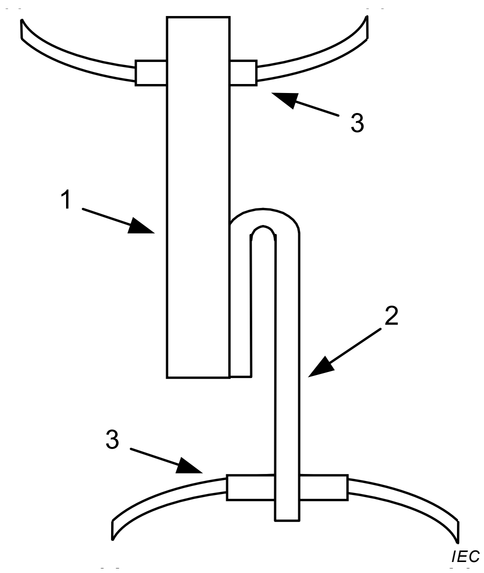
The cable shall be dissected and visually examined. Examination of the samples with normal or corrected vision without magnification shall reveal no cracks or separation of the metal foil of laminated protective coverings or damage to other parts of the cable.

F.2 Adhesion strength of metal foil – Procedure

The test specimen shall be taken from the cable covering where the metal foil is adhered to the oversheath.

The length and width of the test specimen shall be 200 mm and 10 mm, respectively.

One end of the test specimen shall be peeled between 50 mm and 120 mm and inserted in a tensile testing machine by clamping the free end of the oversheath or the insulation screen in one grip. The free end of the metal foil shall be turned back and clamped in the other grip as shown in Figure F.1.



Key

1 oversheath 2 metal foil or laminated metal foil 3 grip

Figure F.1 – Test arrangement for adhesion strength of metal foil

The specimen shall be maintained approximately vertical in the plane of the grips during the test by holding the specimen.

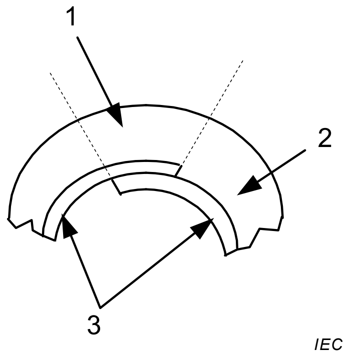
After adjusting the continuous recording device, the metal foil shall be stripped from the specimen at an angle of approximately 180° and the separation continued for a sufficient distance to indicate the adhesion strength value. At least one half of the remaining bonded area shall be peeled with a speed of approximately 50 mm/min.

The adhesion strength shall then be calculated by dividing the peel force, in Newtons, by the width of the specimen, in millimetres. At least five specimens shall be submitted to the test. The test result is the smallest measurement or determined value.

When the adhesion strength is greater than the tensile strength of the metal foil so that the latter breaks before peeling, the test shall be terminated and the break point shall be recorded.

F.3 Peel strength of overlapped metal foil – Procedure

A sample specimen 200 mm in length shall be taken from the cable including the overlapped portion of the metal foil. The test specimen shall be prepared by cutting only the overlapped portion from this sample as shown in Figure F.2.

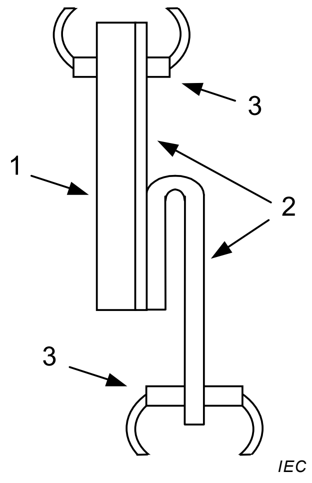


Key

1 specimen 2 oversheath 3 metal foil or laminated metal foil

Figure F.2 – Example of overlapped metal foil

The test shall be conducted in the same manner as described in Clause F.2. The arrangement of the test specimen is shown in Figure F.3.



1 oversheath 2 metal foil or laminated metal foil 3 grip

Figure F.3 – Test arrangement for peel strength of overlapped metal foil

When the peel strength is greater than the tensile strength of the metal foil so that the latter breaks with a higher value than specified, but before peeling, the test is passed and the value of break shall be recorded.

Annex G
(informative)

Development test on cable and cable system with longitudinal applied metal foil, bonded to the oversheath

G.1 General

It is recommended to subject the cable and cable system with a longitudinally applied metal foil, bonded to the oversheath to the development tests as specified in IEC TR 61901.

G.2 List of tests

G.2.1 Tests on cable

G.2.1.1 Impact test

Test should be performed in accordance with IEC TR 61901:2016, 4.1.1.

G.2.1.2 Abrasion test

Test should be performed in accordance with IEC TR 61901:2016, 4.1.2.

G.2.1.3 Sidewall loading test

Test should be performed in accordance with IEC TR 61901:2016, 4.1.3.

G.2.1.4 Long term ageing of the adhesive bonds of the components of the laminate covering

Test should be performed in accordance with IEC TR 61901:2016, 4.1.4.

G.2.1.5 Mechanical properties of the welding, when applicable

Test should be performed in accordance with IEC TR 61901:2016, 4.1.5.

G.2.2 Tests on cable system – Short circuit test including accessories

Test should be performed in accordance with IEC TR 61901:2016, 4.2.2.

Annex H
(normative)

Tests of outer protection for joints

H.1 General

Annex H specifies the procedure to be adopted for type approval testing of joint outer protection of all types, used in buried joints or sheath interrupters employed on insulated sheath power cable systems and, where employed, the associated sheath sectionalizing insulation with screen interruption.

The manufacturer of the joint shall provide a drawing in which all water-protection barriers are clearly identified.

H.2 Range of approval

Where approval is required for joint outer protection embodying entries for items such as bonding leads, the outer protection tested shall include these design features.

A successful test on the joint outer protection for a sheath sectionalizing insulation accessory for the diameters of complete cable for which approval is being sought in accordance with 12.2, will give approval to such protection for a similar accessory without sheath sectionalizing insulation, but not the converse.

The tests in Clauses H.3 and H.4 shall be applied successively to a joint which has passed the heating cycle voltage test (see 12.4.6) or to a separate joint which has undergone at least three thermal cycles without voltage, as specified in 12.4.2, item g), NOTE 2.

H.3 Water immersion and heat cycling

The test assembly shall be immersed in water to a depth of not less than 1 m at the highest point of the outer protection. Where desired, this may be achieved by using a header tank connected to a sealed-off vessel containing the test assembly. Water shall have access to the water barrier(s) declared by the manufacturer.

A total of 20 heating/cooling cycles shall be applied by raising the water temperature to within 15 K to 20 K below the maximum temperature of the cable conductor in normal operation. In each cycle the water shall be raised to the specified temperature, maintained at that level for at least 5 h and then be permitted to cool to within 10 K above ambient temperature. The test temperature may be achieved by mixing the water with water of higher or lower temperature. The minimum duration of each heating cycle shall be 12 h and the duration for raising the water temperature to the specified temperature shall be as much as possible the same as the duration for cooling the water equal to or less than 30 °C or 10 K above ambient temperature.

H.4 Voltage tests

H.4.1 General

On completion of the heating cycles, and with the test assembly still immersed, voltage tests shall be carried out as follows.

H.4.2 Assemblies embodying accessories without sheath sectionalizing insulation

A test voltage of 25 kV DC shall be applied for 1 min between the metal screen/sheath of the power cable and the earthed exterior of the joint outer protection.

H.4.3 Assemblies embodying accessories with sheath sectionalizing insulation

H.4.3.1 DC voltage tests

A test voltage of 25 kV DC shall be applied for 1 min between the metal screens/sheaths of the power cable, at either end of the accessory, and also between the metal screens/sheaths and the earthed exterior of the joint outer protection.

H.4.3.2 Impulse voltage tests

For systems, in which no lightning strike can occur, the lightning impulse test is not required.

To test each part to earth, a test voltage in accordance with Table H.1 shall be applied between the metal screens/sheaths and the exterior of the assembly whilst immersed. If it is not practicable to carry out the impulse test on the assembly whilst immersed, it may be removed from the water and impulse tested with a minimum of delay or it may be maintained wet by wrapping with a wet fabric, or a conductive coating may be applied over the entire exterior surface of the test assembly.

For the test between the metal screens/sheaths, the assembly shall be removed from the water before the impulse test.

The testing procedure shall be performed in accordance with IEC 60230, the joint being at ambient temperature.

Table H.1 – Impulse voltage tests

Equivalent rated lightning impulse voltage for main insulation The equivalent lightning voltage shall be calculated as the sum of the moduli of DC voltage and superimposed lightning impulse voltage	**Impulse level**			
	Between parts		**Each part to earth**	
	Bonding leads ≤ 3 m	**Bonding leads > 3 m and ≤ 10 m**	**Bonding leads ≤ 3 m**	**Bonding leads > 3 m and ≤ 10 m**
kV	kV	kV	kV	kV
250 to 325	60	60	30	30
>325 to 750	60	75	30	37,5
>750	60	95	30	47,5

No breakdown shall occur during any of the above tests.

The performing of the voltage tests of Clause H.4 (in reverse order) may be considered before starting the heat cycling in order to check the proper installation of the assembly.

H.5 Examination of test assembly

On completion of the tests described in Clause H.4, the test assembly shall be examined.

Joint outer protection boxes filled with removable compounds shall be regarded as satisfactory if there is no visible evidence of either internal voids or internal displacement of compound by water ingress, or of compound loss via the various seals or box walls.

For joint outer protections employing alternative designs and materials, there shall be no evidence of water ingress and no sign of corrosion of any metal part of the accessory: connection of the cable to the accessory, accessory screen, accessory bonding leads.

Annex I
(normative)

Return cable

Return cables are grounded at one end and are subjected to a DC voltage determined by the converter configuration and the cable characteristics.

The nature of any overvoltage depends upon the configuration of the HVDC system and needs to be calculated for each case, to determine the relevant temporary over-voltages in the power frequency domain for the return cable for the actual link. In particular, temporary over-voltages caused by commutation failure may be the criteria for dimensioning of the return cable insulation and accessories. To verify that the cable system can withstand over-voltages caused by commutation failure, the return cable and accessories shall be in accordance with IEC 60502-2 and IEC 60502-4 respectively with a rated voltage U of at least $U_{\text{RC,AC}}$.

If different designs (different insulation thicknesses) are used along the return path, each design shall be considered individually.

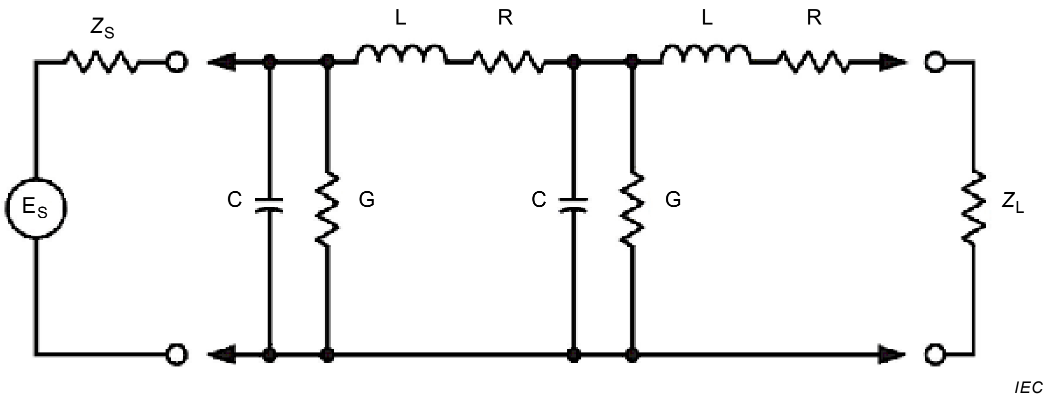
After installation the return cable system shall be subjected to the DC electrical test after installation according to 20.3.2 of IEC 60502-2:2014.

Annex J
(informative)

TDR measurement

A time domain reflectometry (TDR) measurement could be performed for engineering information.

If TDR equipment is to be used during the operation of the cable link it is advisable to perform a TDR measurement after installation to obtain a “fingerprint” of the wave propagation characteristics of the cable. The propagation of the pulses used during TDR measurements is dependent upon resistance, capacitance and inductance of the cable. As all electrical signals travel so as to consume a minimum of energy, the pulse propagates where the inductance/resistance is its lowest. Power cables have a metallic screen and the pulses do not propagate outside the screen since the inductance (and impedance) would increase considerably. Hence the pulse is not affected by the coiling on a drum or after installation. See Figure J.1.



E_S, Z_S: Equivalent circuit of the voltage source

C,G,L,R: Equivalent circuit of the cable;

Z_L: Impedance to terminate the cable link

Figure J.1 – Circuit diagram for TDR testing, traditional transmission line diagram, π-model

Bibliography

IEC 60633, *Terminology for high-voltage direct current (HVDC) transmission*

CIGRE Technical Brochure 496, *Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to 500 kV*; CIGRE Working Group B1.32; 2012

IEC TR 61901:2016, *Development tests recommended on cables with a longitudinally applied metal foil for rated voltages above 30 kV (U_m = 36 kV)*

IEC 60183, *Guidance for the selection of high-voltage A.C. cable systems*

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

IEC 60840, *Power cables with extruded insulation and their accessories for rated voltages above 30 kV (U_m = 36 kV) up to 150 kV (U_m = 170 kV) – Test methods and requirements*

IEC 60853-2, *Calculation of the cyclic and emergency current rating of cables – Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages*

Electra No. 128, *Guide to the protection of specially bonded cable systems against sheath overvoltages, January 1990, pp 46-62*

Electra No. 157, *CIGRE Technical Brochure: Accessories for HV extruded cables*, December 1994, pp 84-89

Electra No. 173, *After laying tests on high-voltage extruded insulation cable systems*, August 1997, pp 32-41

Electra No. 227, *Revision of qualification procedures for extruded high voltage AC underground cable systems,* August 2006, pp 31-37

CIGRE Technical brochure 289, *VSC Transmission*, Cigré WG B4.37, April 2005

Electra No. 72, Recommendations for tests of power transmission DC cables for a rated voltage up to 800 kV (1980 – revision), April 2000

Electra No 189 (2000), Recommendations for test of power transmission DC Cables for a rated voltage up to 800 kV

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 2016 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the website-www.bis.gov.in or www.standardsbis.in.

This Indian Standard has been developed from Doc No.: ETD 09 (24969).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:		*Telephones*
Central	: 601/A, Konnectus Tower -1, 6th Floor, DMRC Building, Bhavbhuti Marg, New Delhi 110002	2323 7617
Eastern	: 8th Floor, Plot No 7/7 & 7/8, CP Block, Sector V, Salt Lake, Kolkata, West Bengal 700091	2367 0012 2320 9474
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg, Chandigarh 160019	265 9930
Southern	: C.I.T. Campus, IV Cross Road, Taramani, Chennai 600113	2254 1442 2254 1216
Western	: Manakalya, 4th Floor, NTH Complex (W Sector), F-10, MIDC, Andheri (East), Mumbai 400093	283 25838

Branches : AHMEDABAD, BENGALURU, BHOPAL, BHUBANESHWAR, CHANDIGARH, CHENNAI, COIMBATORE, DEHRADUN, DELHI, FARIDABAD, GHAZIABAD, GUWAHATI, HARYANA (CHANDIGARH), HUBLI, HYDERABAD, JAIPUR, JAMMU, JAMSHEDPUR, KOCHI, KOLKATA, LUCKNOW, MADURAI, MUMBAI, NAGPUR, NOIDA, PARWANOO, PATNA, PUNE, RAIPUR, RAJKOT, SURAT, VIJAYAWADA.

Published by BIS, New Delhi