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Edition 1.0 2018-05

INTERNATIONAL STANDARD

Compression and mechanical connectors for power cables – Part 1-2: Test methods and requirements for insulation piercing connectors for power cables for rated voltages up to 1 kV (U_m = 1,2 kV) tested on insulated conductors

IEC 61238-1-2:2018-05(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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International Standard IEC 61238-1-2 has been prepared by IEC technical committee 20: Electric cables.

This first edition, together with IEC 61238-1-1 and IEC 61238-1-3, cancels and replaces IEC 61238-1:2003.

This edition includes the following significant technical changes with respect to IEC 61238-1:2003:

a) The scope has been widened to cover connectors for conductors from 10 mm^2 down to 2,5 mm^2 and has been limited to 300 mm^2 for copper conductors and 500 mm^2 for aluminium conductors because test experience and applications for IPC are rare for conductors of larger cross-sectional areas.

b) A new mechanical class has been introduced to satisfy the demand for connectors subjected to no mechanical force.

c) The electrical test method has been updated in order to take into consideration the temperature of the insulated reference conductors.

d) For the short-circuit test, the method of calculation and requirements have been updated.

e) For the mechanical test, the methods and requirements have been updated.

f) Different test proposals for multicore connector testing have been introduced.

g) A test proposal for pre-conditioning using live load pickup for insulation piercing connectors has been introduced.

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

FDIS	Report on voting
20/1789/FDIS	20/1804/RVD

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

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

A list of all parts in the IEC 61238 series, published under the general title *Compression and mechanical connectors for power cables*, can be found on the IEC website.

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

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

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

INTRODUCTION

The IEC 61238 series has been divided into the following parts:

Part 1-1: Test methods and requirements for compression and mechanical connectors for power cables for rated voltages up to 1 kV (U_m = 1,2 kV) tested on non-insulated conductors

Part 1-2: Test methods and requirements for insulation piercing connectors for power cables for rated voltages up to 1 kV (U_m = 1,2 kV) tested on insulated conductors

Part 1-3: Test methods and requirements for compression and mechanical connectors for power cables for rated voltages above 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) tested on non-insulated conductors

This Part 1-2 of IEC 61238-1 deals with type tests for insulation piercing connectors for use on copper or aluminium conductors of power cables for rated voltages up to 1 kV (U_m = 1,2 kV).

When a design of connector meets the requirements of this document, then it is expected that in service:

a) the resistance of the connection will remain stable within specified limits;

b) the temperature of the connector will be of the same order or less than that of the insulated conductor during current heating;

c) if the intended use demands it, application of short-circuit currents will not affect a) and b);

d) independently from the electrical performance, conforming axial tensile strength will ensure an acceptable mechanical performance for the connections to the cable conductors, when applicable.

It should be stressed that, although the object of the electrical and mechanical tests specified in this document is to prove the suitability of connectors for most operating conditions, they do not necessarily apply to situations where a connector may be raised to a high temperature by virtue of connection to a highly rated plant, to corrosive conditions, where the connector is subjected to external mechanical stresses such as excessive vibration, shock and large displacement after installation, where the connector is exposed to low temperature during assembly or where the connector is installed in live conditions. In these instances, the tests in this document may need to be supplemented by special tests agreed between supplier and purchaser.

This document does not invalidate existing approvals of products achieved on the basis of national standards and specifications and/or the demonstration of satisfactory service performance. However, products approved according to such national standards or specifications cannot directly claim approval to this document.

Once successfully completed, these tests are not repeated unless changes are made in material, manufacturing process and design which might adversely change the connector performance characteristics.

COMPRESSION AND MECHANICAL CONNECTORS FOR POWER CABLES –

Part 1-2: Test methods and requirements for insulation piercing connectors for power cables for rated voltages up to 1 kV (U_m = 1,2 kV) tested on insulated conductors

1 Scope

This part of IEC 61238 applies to insulation piercing connectors for power cables for rated voltages up to 1 kV (U_m = 1,2 kV), for example according to IEC 60502-1 or other buried cables and cables installed in buildings, having

a) conductors complying with IEC 60228 having nominal cross-sectional areas between 2,5 mm^2 and 300 mm^2 for copper and between 16 mm^2 and 500 mm^2 for aluminium,

b) a maximum continuous cable temperature not exceeding the insulation material properties.

This document is not applicable to connectors for overhead line conductors nor to connectors with a sliding contact.

The object of this document is to define the type test methods and requirements, which apply to insulation piercing connectors for power cables with copper or aluminium conductors. The reference method is to perform the tests on unused insulated conductors.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-461, *International Electrotechnical Vocabulary – Part 461: Electric cables* (available at http://www.electropedia.org)

IEC 60228, *Conductors of insulated cables*

IEC 60493-1, *Guide for the statistical analysis of ageing test data – Part 1: Methods based on mean values of normally distributed test results*

IEC 60949:1988, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*
IEC 60949:1988/AMD1:2008

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-461 and the following apply.

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

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

3.1
connector
<of cables> device for connecting a conductor to an equipment terminal or for connecting two or more conductors to each other

[SOURCE: IEC 60050-461:2008, 461-17-03, modified – the definition has been revised.]

3.2
through connector
device for connecting two consecutive lengths of conductor together

[SOURCE: IEC 60050-461:2008, 461-17-04, modified – the term "joint ferrule" has been deleted and the definition revised.]

3.3
branch connector
device for connecting a branch conductor to a main conductor at an intermediate point on the latter

[SOURCE: IEC 60050-461:2008, 461-17-05, modified – the term "branch ferrule" has been deleted and in the definition "metallic" has been deleted.]

3.4
reference conductor
length of unjointed insulated conductor or conductor with the insulation rebuilt, which is included in the test loop and which enables the reference temperature and reference resistance to be determined

3.5
equalizer
arrangement used in the test loop to ensure a point of equipotential and uniform current distribution in a stranded conductor

3.6
compression jointing
method of securing a connector to a conductor by using a special tool to produce permanent deformation of the connector and the conductor

3.7
mechanical jointing
method of securing a connector to a conductor, for example by means of a bolt or screw acting on the latter or by alternative methods

3.8
median connector
connector which during the first heat cycle records the third highest temperature of the six connectors in the test loop

3.9
insulation piercing connector
IPC
connector in which electrical contact with the conductor is made by metallic protrusions which pierce the insulation of the cable core

[SOURCE: IEC 60050-461:2008, 461-11-08]

3.10
insulation piercing jointing
method of securing an IPC to an insulated conductor by piercing, boring through, cutting through, or making ineffective in some other manner the insulation of at least one cable conductor without previous stripping during installation

Note 1 to entry: The temperatures are no longer limited by the conductor but by the cable insulation.

Note 2 to entry: This method may allow live line working if the connector provides sufficient insulation properties. Safety requirements for live working are not covered by this document.

3.11
conductor
<of a cable> part of a cable which has the specific function of carrying current

[SOURCE: IEC 60050-461:2008, 461-01-01]

3.12
family of connectors
group of connectors of a manufacturer to be considered of the same design criteria, the same material characteristic and the same installation procedure

4 Symbols

A	nominal cross-sectional area of the conductor
D	change in the resistance factor of the connector
I	direct current flowing through a connection during resistance measurement
I_{RMS}	equivalent RMS short-circuit current
I_N	alternating current necessary to maintain the insulated reference conductor at its equilibrium temperature
I_r	direct current flowing through the insulated reference conductor/conductors during resistance measurement
k	connector resistance factor: ratio of the resistance of a connector to that of the resistance of the equivalent length of the reference conductor
k_0	initial connector resistance factor: ratio of the resistance of a connector to that of the resistance of the equivalent length of the reference conductor at cycle no. 0
l_a, l_b, l_j	lengths of each connector assembly associated with the measurement positions in the test setup after installation
l_r	length of the insulated reference conductor between measurement positions
R	measured resistance value of connector/insulated conductor installation under an electrical test corrected to 20 °C
R_r	measured resistance value of the insulated reference conductor corrected to 20 °C
R_j	length related calculated resistance value of a connector under an electrical test corrected to 20 °C
t_1	heating time
t_2	time necessary for the connectors and the insulated reference conductor to cool to a value equal to or less than 35 °C
U	potential difference between measurement positions while current I is applied
U_r	potential difference between measurement positions on an insulated reference conductor while current I_r is applied
α	temperature coefficient of resistance at 20 °C

β	mean scatter of the connector resistance factors
δ	initial scatter of the connector resistance factors
λ	resistance factor ratio: the actual resistance factor of the connector at each measurement stage divided by its initial resistance factor
θ	temperature of a connector
θ_{max}	maximum temperature recorded on a connector over the total period of test during heat cycling
θ_R	temperature of the main insulated reference conductor determined in the first heat cycle
θ_{Rb}	temperature of the branch insulated reference conductor determined in the first heat cycle
θ_{ref}	temperature of the related insulated reference conductor at the moment of measuring θ_{max}

5 General

5.1 Definition of classes

Although it is not possible to define precisely the service conditions for all applications, the following requirements have been identified.

a) Electrical requirements:

Class A

These are connectors intended for electricity distribution or industrial networks in which they can be subjected to short-circuits of relatively high intensity and duration. As a consequence, Class A connectors are suitable for the majority of applications.

Class B

These are connectors for networks in which overloads or short-circuits are rapidly cleared by the installed protective devices, for example, fast-acting fuses.

b) Mechanical requirements:

Class 0

Connectors subjected to practically no mechanical pull-out force. These are, for example, connectors inside switchgear where the cable or conductors are secured or anchored.

Class 1

Connectors subjected to a mechanical pull-out force related to the conductor nominal cross-sectional area and material (according to Table 4). These are, for example, connectors for underground cable joints.

Hence, the four classes correspond to the following tests:

Class A: heat cycling and short-circuit tests;

Class B: heat cycling test only;

Class 0: no mechanical test;

Class 1: mechanical test.

5.2 Cable

The following information shall be recorded in the test report:

– conductor material;

– nominal cross-sectional area, dimensions and shape;

– detail of conductor construction shall be given when known, or can be determined by inspection, for example:
  - class according to IEC 60228 (solid, stranded and flexible);
  - compacted or non-compacted for stranded conductor;
  - number and arrangement of strands;
  - type of plating, if applicable;
  - type of impregnation, water blocking, etc., if applicable;

– cable specification, including insulation type and thickness, etc.;

– conditioning of the cable if applied prior to testing.

5.3 Connectors and installation procedure

The following information shall be recorded in the test report:

– the assembly method or the installation instruction that is to be used;

– tooling and any necessary setting;

– identification of the connector, for example name of the supplier, drawing, reference number, type;

– installation temperature and, if applicable, other treatment during installation, for example live load pickup (see Annex I).

5.4 Range of approval

In general, tests made on one type of insulation piercing connector, conductor and insulation combination apply to that arrangement only. However, to limit the number of tests the following is permitted:

– a connector which can be used on stranded round conductors is approved for this type if satisfactory results are obtained on a compacted round conductor;

– a connector which covers a range of consecutive cross-sectional areas shall be approved, if satisfactory results are obtained on the smallest and the largest cross-sectional area;

– if a manufacturer can clearly demonstrate that common and relevant connector design criteria were used for a family of connectors, conformity to this document is achieved by successfully testing the largest, the smallest and two intermediate connector sizes;

  exception no.1: for a family of connectors consisting of five sizes, only the largest connector, the smallest connector, and one connector of a representative intermediate size need to be tested;

  exception no.2: for a family of connectors consisting of four sizes or less, only the largest connector and the smallest connector need to be tested;

– for connectors where one or both sides are designed for a range of cross-sectional areas, and a common clamping or crimping arrangement serves for the connection of the different cross-sectional areas, then mechanical tests on conductors with the largest and smallest cross-sectional areas shall be carried out according to Clause 7 for connectors according to Class 1;

– if conformity to this document is achieved by successfully testing a mechanical connector on round stranded aluminium conductors, this type test approval can be applied to solid aluminium conductors of the same cross-sectional area(s);

– if conformity to this document is achieved by successfully testing a connector on a conductor with water blocking, approval is achieved for the same conductor without any water blocking but not for the same conductor with different types of water blocking.

6 Electrical tests

6.1 Installation

6.1.1 General

All insulated conductors of the same nominal cross-sectional area in the test loop shall be taken from the same insulated conductor length.

For each series of tests, six connectors shall be installed on insulated conductors in accordance with the manufacturer's instructions.

At a distance not less than 100 mm to the entrance of the connector, the insulation can be removed to prepare equalizers according to Annex A.

Reference conductor(s) with the insulation retained shall also be included in the test loop.

For stranded conductors, potential differences between the strands at potential measuring positions can cause errors in measuring electrical resistance. Equalizers according to Annex A shall be used to overcome this problem and to ensure uniform current distribution in the reference conductor and between connectors at the equalizer positions. The recommended method is to prepare equalizers on the test loop before installing connectors.

The test loop shall be installed in a location where the air is calm.

The ambient temperature of the test location shall be between 15 °C and 30 °C.

For assembly of the test objects, the temperature shall be (23 ± 3) °C. The test objects should be stored for a sufficient time to reach the required installation temperature.

In the case of solid conductors, the potential measuring positions shall be as close as possible to the connector in order to reduce l_a and l_b. A minimum distance of 10 mm shall be kept to the cable entrance of the IPC to avoid any influence on the IPC by cutting through the cable insulation when setting the measuring position.

The test loop may be of any shape according to Figure 3 or Figure 4 provided that it is arranged in such a way that there is no adverse effect from the floor, walls and ceiling, other test loops and adjacent test branches.

To facilitate the short-circuit test for connectors according to Class A, the loop may be disassembled as shown in Figure 3 b). In this case, the sectioning connections shall not influence the temperatures of the test objects during heating.

Retightening of bolts or screws of the connectors under test is not permitted.

NOTE 1 Informative Annex H proposes electrical tests for multicore connectors. These tests are not internationally recognized and subject to customer/manufacturer agreement.

NOTE 2 Informative Annex I gives recommendations to simulate loads (related to the cross sectional area) acting during installation of an IPC while the cables are still in service. This test is done during the initial insertion of the IPC in the test loop, before starting electric tests.

6.1.2 Through connectors

The test loop shown in Figure 3 indicates the dimensions that shall be used.

6.1.3 Branch connectors

When the branch connector is intended for a branch nominal cross-sectional area equal to the main, or a nominal cross-sectional area immediately above or below the main, it is treated as a through connector between the main and the branch, and the test method for through connectors and the test loop shown in Figure 3 c) are applicable. In other cases, the test loop shall be as shown in Figure 4. Where a type of connector makes it necessary for the insulated main conductor to be cut, that part of the connector which acts as a through connector, shall also be tested as for through connectors.

6.2 Measurements

6.2.1 General

Measurements shall be made at stages throughout the test according to Table 2.

NOTE Recommendations to decrease uncertainties of measurements are given in Annex C.

6.2.2 Electrical resistance measurements

The resistance measurements shall be made under steady temperature conditions of both the test loop and test location. The ambient temperature shall be between 15 °C and 30 °C.

The recommended method is to pass a direct current of up to 10 % of the estimated heat cycling current, through the connectors and the insulated reference conductor, without significantly increasing the temperature and to measure the potential difference between two specific potential measuring positions. The ratio of potential difference and direct current is the resistance between those two positions.

To decrease the uncertainty of the resistance measurement, it is recommended that the direct current is adjusted to the same value throughout the electrical test.

For insulated branch conductors assembled in accordance with Figure 4, the whole of the measuring current shall flow through that part of the connector whose potential difference is being measured. Switches or disconnecting terminals may be provided for this purpose.

Thermoelectric voltages may affect the uncertainty of low resistance measurements (of the order of 10 μΩ). If this is suspected, the recommended method is to take two resistance measurements with the direct measuring current reversed between readings. The mean of the two readings is then the actual resistance of the sample.

The potential measuring positions shall be as indicated in Figure 5 and Annex B. The various lengths shall also be measured individually to enable the actual connector resistances to be determined. The temperature of connector and insulated reference conductor shall be recorded when resistance measurements are made. For direct comparison, the resistance values shall be corrected to 20 °C. Information on the recommended method is also given in Annex B. Temperature measurements at these positions shall be made during the heat cycling test.

Indirect resistance readings:

– voltage measurements shall have a device uncertainty within ± 0,5 % or ± 10 μV, by taking the greater value;
– current measurements shall have a device uncertainty within ± 0,5 % or ± 0,1 A, by taking the greater value.

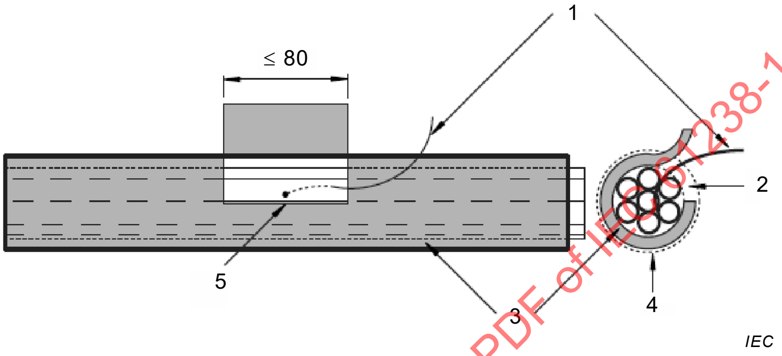
Direct resistance readings:

Resistance measurements shall have a device uncertainty within ± 1 % or ± 0,5 µΩ, whichever is the greater when the instrument is calibrated against a certified standard resistance.

6.2.3 Temperature measurements

Temperatures of both connectors and insulated reference conductors shall be measured at the positions indicated in Figure 5. The recommended method of temperature measurement is to use thermocouples. The temperature measurements shall have a device uncertainty within ± 2 K.

Recommended position and preferred installation methods for thermocouples are described in Figure 1 which provides typical examples.



a) Position of thermocouple on stranded insulated reference cable

Key

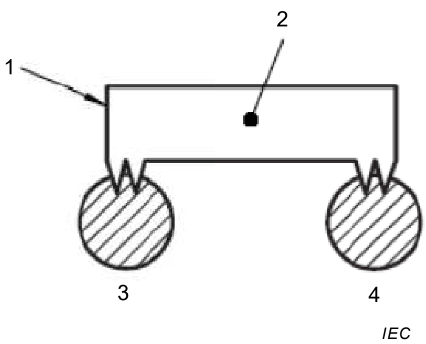
1 thermocouple

2 open position to place the thermocouple

3 conductor insulation

4 adhesive tape; thermocouple and insulation are covered with 2 half-lap layers adhesive tape

5 small windows in the insulation of the reference conductor



b) Position of thermocouple in an IPC

Key

1 metallic current path

2 thermocouple position

4 main conductor

5 branch conductor

Figure 1 – Position of thermocouples

6.3 Heat cycling test

6.3.1 General

The heat cycling test shall be made with alternating current.

In the case of DC applications, direct current might be used.

6.3.2 First heat cycle

The object of the first heat cycle is to identify the median connector (see 3.8) and its temperature at equilibrium.

Equilibrium is reached when the insulated reference conductor and the connectors do not vary in temperature by more than ± 2 K during application of the heating current. Minimum periods to maintain temperature stability are defined in Table 1.

a) Through connectors

The circulated current shall be set so that the temperature of the insulated reference conductor at equilibrium θ_R is adjusted between 10 K and 15 K above the maximum cable operating temperature in normal operation.

Where the connected insulated conductors are of different operating temperatures (insulation types) or unequal cross-sectional areas, the one having the lowest current carrying capacity shall be used as the reference for the duration of the test.

b) Branch connectors

The circulated current shall be set so that the temperature of each branch and main insulated reference conductors at equilibrium θ_R and θ_{Rb} are adjusted between 10 K and 15 K above the maximum cable operating temperature in normal operation.

For this purpose, it may be necessary at intervals throughout the test, to adjust the current in an individual branch.

Table 1 – Minimum period of temperature stability

Nominal conductor cross-sectional area A (mm^2)	for aluminium:	$A \leq 300$	$300 < A \leq 500$
	for copper:	$A \leq 240$	$240 < A \leq 300$
Minimum period (min)		15	20

6.3.3 Second heat cycle

The object of this second heat cycle is to determine the heat cycle duration and temperature profile which will be used on the test loop for all subsequent heat cycles.

For through connectors, the current is circulated in the loop until the insulated reference conductor temperature reaches the value θ_R as defined in 6.3.2 and the median connector temperature is stable within a band of 2 K over a 10 min period and does not differ by more than 3 K compared to the temperature measured during the first heat cycle.

For branch connectors that need to use the circuit shown in Figure 4, current is circulated in the loop until the branch insulated reference conductor temperature θ_{Rb} reaches a value between 10 K and 15 K above the maximum cable temperature in normal operation and the main insulated reference conductor temperature θ_R reaches a value between 5 K and 15 K above the maximum cable temperature in normal operation. The median connector temperature is stable within a band of 2 K over a 10 min period and does not differ by more than 3 K compared to the temperature measured during the first heat cycle.

At the beginning of the heat cycle, an elevated current up to 150 % of I_N may be used as the preferred method, to reduce the heating period. The current shall thereafter be decreased or regulated to a mean value of the current close to I_N to ensure stable conditions during the median-connector control period. It may be necessary to use more than one cycle to determine the second heat cycle.

The insulated reference conductor temperature shall be the control parameter, in order to keep the temperature profile during the heat cycling test. In this way, the fluctuation of the ambient temperature will not affect the temperature profile of the insulated reference conductor within the tolerances given in this document.

The determined heating profile of the insulated reference conductor containing the characteristics of temperatures during time, as shown in Figure 2, shall be recorded and reproduced for all subsequent heat cycles.

The heating period t_1 is followed by a cooling period t_2 to bring the temperatures of all connectors and the insulated reference conductor to values ≤ 35 °C.

It may be necessary in subsequent heat cycles to adjust t_2 to ensure that the temperature conditions are reached, in particular during the measurement of resistances in order to respect the conditions of 6.2.2.

If accelerated cooling is used, it shall act on the whole of the loop, and use air within ambient temperature limits.

The total period t_1 + t_2 constitutes a heat cycle (see Figure 2).

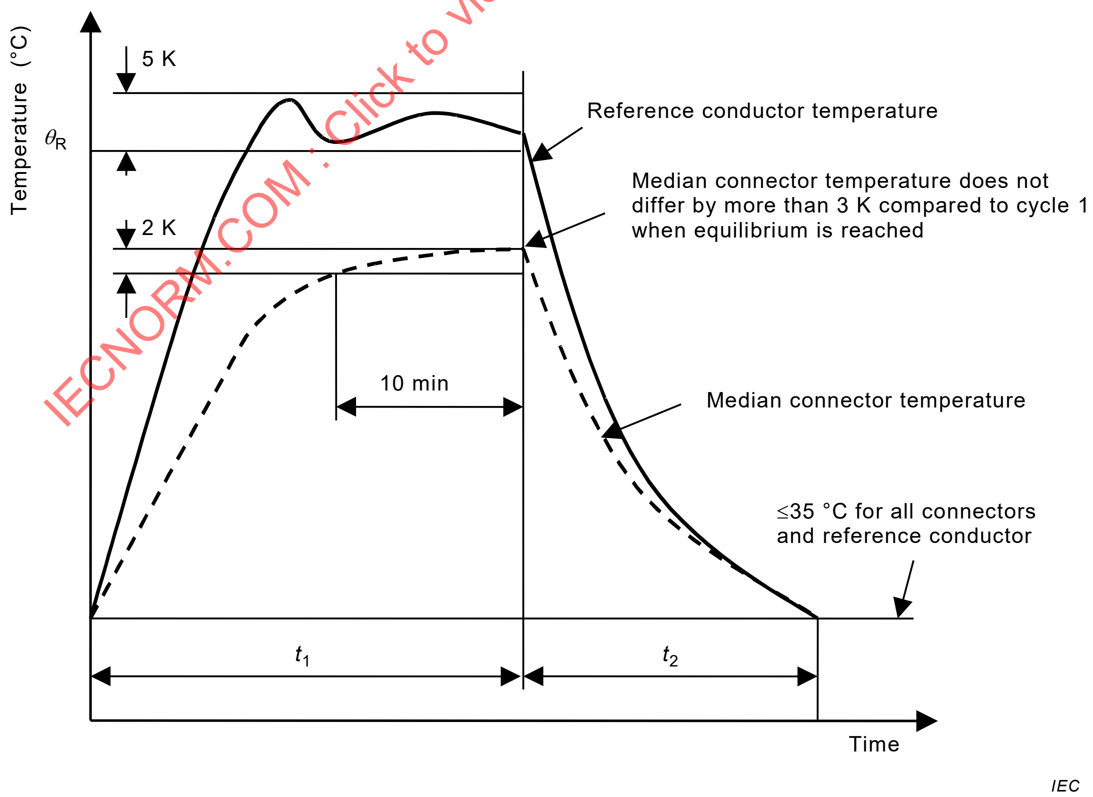


Figure 2 – Example of second heat cycle profile

6.3.4 Subsequent heat cycles

A total of 1 000 heat cycles shall be made according to 6.3.3. After the cooling period of the cycles indicated in Table 2, the resistance and temperature of each connector and each insulated reference conductor shall be recorded as described in 6.2. The maximum temperature of each connector during the cycle just prior to or following the resistance measurements shall also be recorded.

Table 2 – Electrical resistance measurements during the electrical test

Class A	Class B
cycle no. 0, before the first heat cycle, see 6.3.2	cycle no. 0, before the first heat cycle, see 6.3.2
after cycle no. 200 before the short-circuit test	
after cycle no. 200 and after the short-circuit test	
after cycle no. 250[a]	after cycle no. 250 [a]
then after 75 cycle intervals [a]	then after 75 cycle intervals [a]
(in total 14 measurements)	(in total 12 measurements)
[a] A tolerance of ±10 cycles may be used for collecting measurements.	

6.4 Short-circuit test for connectors according to Class A

The short-circuit test shall be made with alternating current.

After finishing 200 heat cycles, six short-circuit currents shall be applied on each connector.

After each short-circuit current application, the test loop shall be cooled to a temperature ≤ 35 °C.

The measured initial insulated reference conductor temperature, the current and the duration, as well as the Joule integral of each short-circuit current application shall be recorded in the test report.

When connectors are used to connect different cables in the same test, the cable with the lowest calculated short-circuit test current shall be used as reference cable.

When branch connectors are used, the short-circuit test current shall be applied from the main cable to the branch cable for each connector under test.

As stated in 6.1.1, the test loop may be disassembled for this test. Since the short-circuit test is intended to reproduce the thermal effects of high currents only, the recommended method is to use a concentric return conductor in order to reduce the electro-dynamic forces. The test arrangements shall be described in the test report.

The short-circuit test current level shall be such, that it raises the insulated reference cable from a temperature ≤ 35 °C to a temperature between the maximum permissible temperature of the insulation and the maximum permissible temperature of the insulation +20 K.

The duration of the short-circuit test current shall be $(1^{+0,5}_{-0,1})$ s with a maximum current of 25 kA.

If the required short-circuit test current exceeds this value, a longer duration ≤ 5 s with a current between 25 kA and 45 kA shall be used.

The minimal applicable adiabatic Joule integral $I^2{}_{AD}t$, which raises the temperature of the insulated reference cable to the maximum permissible temperature of the insulation, shall be calculated according to the formula in Annex D, as well as the maximum applicable adiabatic Joule integral $I^2{}_{AD}t$ necessary to reach the maximum permissible temperature of the insulation +20 K.

The adiabatic Joule integral $I^2{}_{AD}t$ used for each short-circuit current application during the short-circuit test shall be between both previous calculated values of Joule integrals $I^2{}_{AD}t$.

When determining the short-circuit current RMS value, a device taking into account the DC component should be used. Alternatively, the determination of I^2t can be obtained using the method described in Annex E, noting this method does not take into account the DC component of the current.

NOTE1 The measured final reference conductor temperature can be recorded in the test report for information.

NOTE2 To allow adjustment of the current for the short-circuit test, the first short-circuit test current can be extended to achieve the maximum permissible temperature of the insulation +30 K.

6.5 Assessment of results

An individual connector resistance factor k enables a common method of connector assessment to be made over the range of conductor cross-sectional areas applicable to this document. The parameters listed below shall be calculated according to Annex F:

a) the connector resistance factor k shall be calculated according to Clause F.3, for each of the six connectors at all the measurement intervals listed in Table 2;

b) the initial scatter δ, between the six initial values of k_0, measured before heat cycling, shall be calculated according to Clause F.4;

c) the mean scatter β, between the six values of k, averaged over the last 11 measurement intervals, shall be calculated according to Clause F.5;

d) the change in resistance factor D for each of the six connectors shall be calculated according to Clause F.6. D is the change in the value of k taken over the last 11 measurement intervals, calculated as a fraction of the mean value of k in this interval;

e) the resistance factor ratio λ shall be calculated according to Clause F.7;

f) the maximum temperature θ_{max} on each connector shall be recorded according to Clause F.8.

NOTE An explanation of assessing the results of the electrical test on connectors can be found in Annex G.

6.6 Requirements

The six connectors shall satisfy the requirements shown in Table 3. If one connector out of the six does not satisfy one or more of the requirements, a re-test may be carried out. In this event, all six new connectors shall satisfy the requirements.

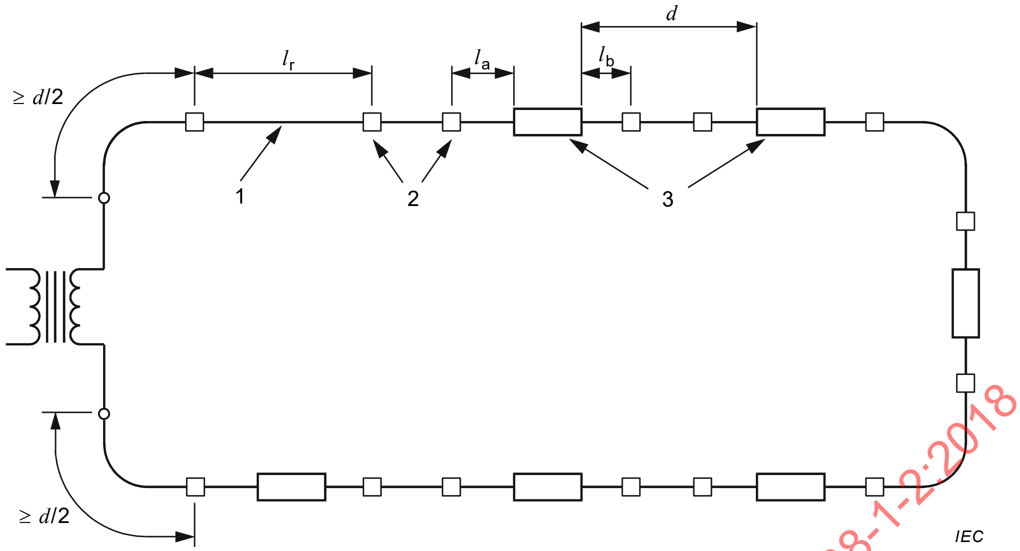
If more than one connector out of the six do not satisfy one or more of the requirements, no re-test is permitted and the type of connector shall be deemed as not conforming to this document.

Table 3 –Electrical test requirements

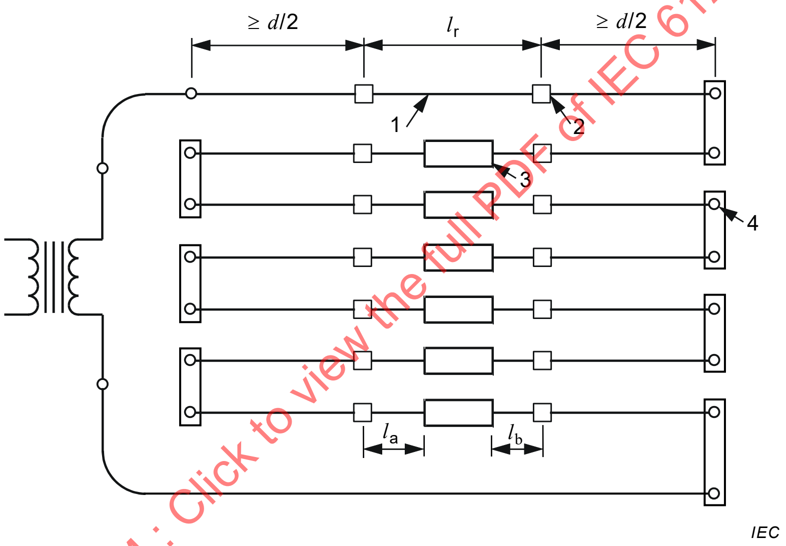
Parameter	Designation	Text reference	Maximum value
Initial scatter	δ	Clause F.4	0,30
Mean scatter	β	Clause F.5	0,30
Change in resistance factor	D	Clause F.6	0,15
Resistance factor ratio	λ	Clause F.7	2,0
Maximum temperature	θ_{max}	Clause F.8	θ_{ref}
NOTE Specified values are based on experience.			

6.7 Examples of electrical test loop configurations and associated parameters

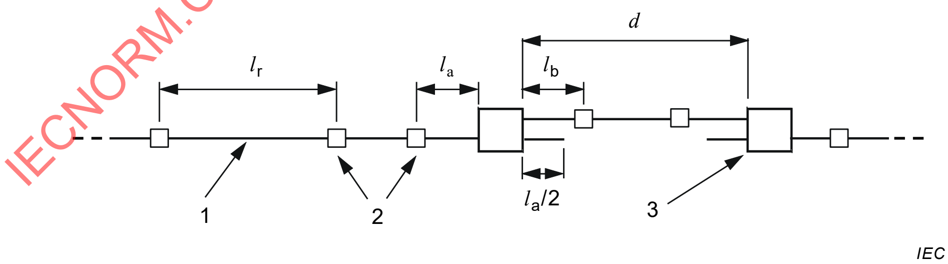
See Figures 3, 4 and 5.



a) **Through connectors – principle test loop**



b) **Through connectors with separable sections according to 6.1.1**



c) **Branch connectors to be tested as through connectors according to 6.1.3**

where:

$d \geq 80\ \sqrt{A}$ or 500 mm, whichever is the greater

A is the corresponding insulated conductor nominal cross-sectional area, in mm^2

$l_r \geq l_a + l_b + l_i$ (for l_i, see Figure 5)

For insulated stranded conductors:

l_a, $l_b \approx 15\ \sqrt{A}$ or 150 mm, whichever is the greater

Key

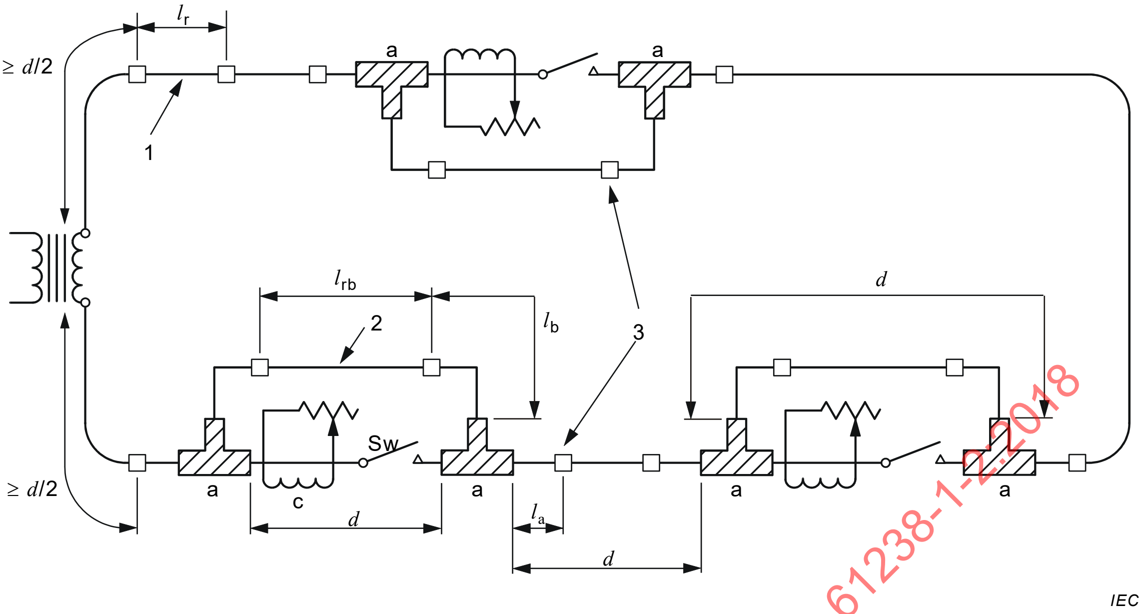
1 insulated reference conductor

2 equalizers (for insulated stranded conductors)

3 through connectors

4 disconnecting terminals

Figure 3 – Typical electrical test loop for through connectors installed on insulated conductors



where:

$d \geq 80\sqrt{A}$ or 500 mm, whichever is the greater

A is the main insulated conductor nominal cross-sectional area, in mm^2

l_r, $l_{rb} \geq l_a + l_b + l_j$ (for l_j, see Figure 5)

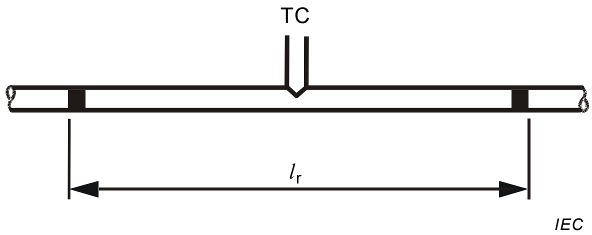
For insulated stranded conductors:

l_a, $l_b \approx 15\sqrt{A}$ or 150 mm, whichever is the greater

Key

1	main insulated reference conductor
2	branch insulated reference conductor
3	equalizer (for insulated stranded conductors)
a	branch connector
c	current control;
Sw	switch (for branch resistance measurement)
	a distance of d/2 between switch and connectors should be used

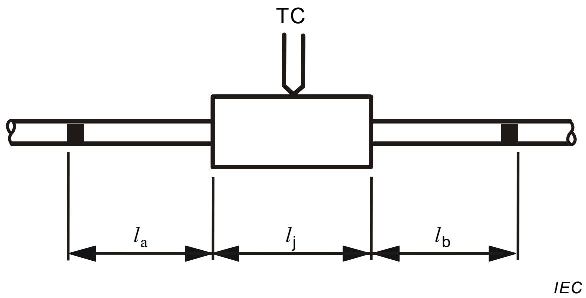
Figure 4 – Typical electrical test loop for branch connectors installed on insulated conductors



Formula:

$$R_r = \frac{U_r}{I_r} \times \frac{1}{1 + \alpha(\theta_r - 20)}$$

a) Insulated reference conductor



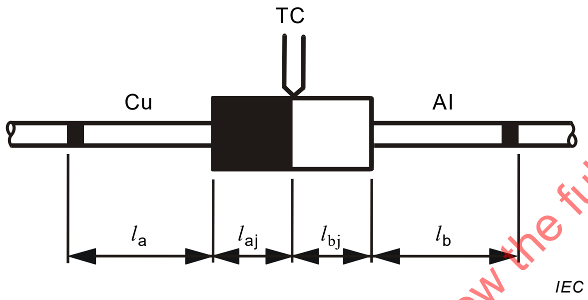
Formulas:

$$R_j = R - R_r \times \frac{(l_a + l_b)}{l_r}$$

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j}$$

Reference: same conductor on both sides

b) Through connector installed on insulated conductor



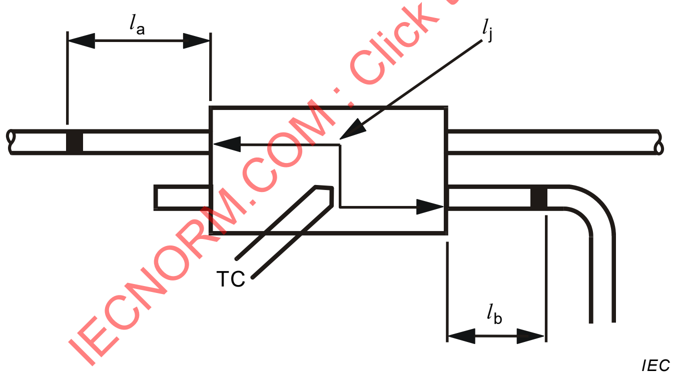
Formulas:

$$R_j = R - \left(\frac{R_r\text{Cu}}{l_r\text{Cu}} \times l_a + \frac{R_r\text{Al}}{l_r\text{Al}} \times l_b \right)$$

$$k = \frac{R_j}{\frac{R_r\text{Cu}}{l_r\text{Cu}} \times l_{aj} + \frac{R_r\text{Al}}{l_r\text{Al}} \times l_{bj}}$$

Reference: copper and aluminium conductors

c) Bimetallic through connector installed on insulated conductor



Formulas:

$$R_j = R - \left(\frac{R_r\text{main}}{l_r\text{main}} \times l_a + \frac{R_r\text{branch}}{l_r\text{branch}} \times l_b \right)$$

$$k = \frac{R_j}{R_r\text{branch}} \times \frac{l_r\text{branch}}{l_j}$$

Reference: main and branch conductors

d) Branch connector installed on insulated conductor

Key

TC = Temperature measurement positions, additional information is given in Figure 1.

Figure 5 – Typical cases of resistance measurements

7 Mechanical test

7.1 General

The purpose of this test is to ensure an acceptable mechanical strength for the connections to the conductors of power cables.

NOTE The mechanical test does not give any indication that the connector will be able to fulfill the electrical test requirements.

7.2 Method

The test shall be made on three additional connectors having the same combination of insulated conductors and installation procedure as used for the electrical test. The recommended insulated conductor length, between connectors or between connector and tensile test machine jaws, is ≥ 500 mm. The rate of application of the load shall not exceed 10 N per square millimeter of nominal cross-sectional area and per second up to 25 % of the value in Table 4 in order to mark the insulated conductor relatively to the connector, then up to the value in Table 4, which is then maintained for 1 min.

The applicable tolerance for applying the mechanical load shall be within ± 5 %.

When the axes of two insulated conductors are not aligned, the connector shall be fixed and the force applied in the axis of the clamping channel on each insulated conductor core. One sample of connector shall be used per tensile test.

For example, for a branch connector as shown in Figure 5 d), six connectors are needed, three samples are required for testing the main insulated conductor and three samples for the branch insulated conductor.

If the connector is tested electrically for insulated conductors of different nominal cross-sectional area, three connectors shall be tested individually with the same insulated conductor as used in the electrical test, in accordance with Table 4.

Table 4 – Selection of tensile force withstand values for the mechanical test

Class	Conductor material	Nominal cross-sectional area A (mm^2)	Tensile force (N)
Class 0	Aluminium	–	No test
	Copper	–	No test
Class 1	Aluminium	≤ 500	40 × A
	Copper	≤ 300	60 × A

7.3 Requirements

Not more than 3 mm slippage shall occur during the last minute of the test.

8 Test reports

8.1 General

The type test results according to this document may be presented in separate test reports.

8.2 Electrical tests

The test report shall include the following information:

– connector class (see 5.1);
– cable used (see 5.2);
– connector and installation procedure (see 5.3);
– temperature measurement method (see 6.2.3);
– current I_N at equilibrium temperature (see 6.3.2);
– for Class A the short-circuit test parameters (see 6.4);
– test loop configuration;
– values and graph of the connector resistance factor k versus the cycle number (see 6.5);
– values and graph of the maximum temperatures versus the cycle number (see 6.3.4);
– results of the electrical test (see Table 3).

It is advisable to show a graph of the temperature profile of the second cycle (see 6.3.3).

8.3 Mechanical test

The test report shall include the following information:

– connector class (see 5.1);
– cable used (see 5.2);
– connector and installation procedure (see 5.3);
– results of the mechanical test.

Annex A
(normative)

Equalizers and their preparation

A.1 Requirements for equalizers

For stranded and flexible conductors, the potential difference between the strands at measuring positions may cause errors in measuring electrical resistance.

Therefore equalizers are needed, the requirements for which are:

– achieve the electrical connection of all the strands to ensure accurate electrical resistance measurements;

– achieve thermomechanical strength throughout the electrical test including the short-circuit test if applicable (e.g. by avoiding excessive annealing or constricting of strands during preparation of equalizers and providing adequate current carrying volume);

– avoid thermal effect on the connector or the insulated reference conductor temperature readings during current heating (e.g. by using bulky equalizers).

Welded, soldered or crimped equalizers may be used to overcome this problem and to ensure uniform current distribution during resistance measurement. Welding equalizers is the recommended method for insulated stranded conductors to ensure reliable measurements.

Other methods may be used provided they give comparable results and do not affect the temperature of the connectors or the insulated reference conductor.

A.2 Recommendations for welding equalizers

The insulation on the conductor is removed for preparing the equalizers. After preparation of the equalizers, the insulation shall be rebuilt by adequate means (e.g. by using self-bonding tape, original insulation) to recover his original thermal properties and therefore not affect the temperature of the connectors or the insulated reference conductor.

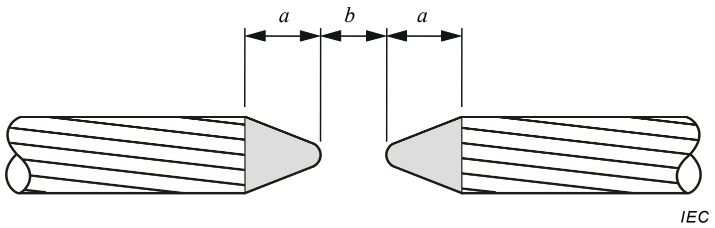
The welding material should be similar to the conductor material.

Cut the conductors square, clean the ends, and melt them with the welding torch ensuring all strands are welded together. Build up the weld until the chamfer dimensions are achieved. The length of the chamfer is referenced as a, and the separation between the conductors for final welding is referenced as b.

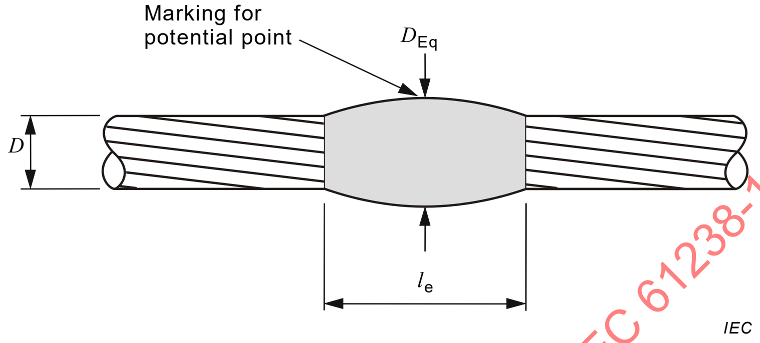
With the conductors supported and spaced by dimensions b, build weld metal up at the centre and turn the conductors so as to obtain a uniform circular weld profile.

Ensure that the conductor remote from the ends is kept sufficiently cool in order not to change the mechanical properties of the conductor in the region where the contact will be made.

The dimensions of the equalizer shall be as indicated in Figure A.1.



a) **Ends prepared**



b) **Welded/soldered equalizer**

where:

For circular shape

$D \leq D_{Eq} \leq 1{,}4 \times D$

$l_e \leq 1{,}5 \times D + 10$ mm

For sectoral shape

$H \leq H_{Eq} \leq 1{,}4 \times H$ and $W \leq W_{Eq} \leq 1{,}4 \times W$

$l_e \leq 1{,}5 \times H + 10$ mm

Key

a: chamfer length

b: conductor separation

D: conductor diameter

D_{Eq}: equalizer diameter

l_e: equalizer length

H: sector height

W: sector width

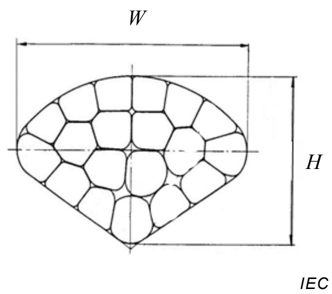


Figure A.1 – Preparation of equalizers

Annex B
(normative)

Measurements

B.1 Potential measuring positions for typical connectors

Potential measuring positions for the purpose of resistance measurement are shown in Figure 5. Potential measuring positions on insulated solid conductors shall be adjacent to the IPC, but a minimum distance of 10 mm shall be kept to the cable entrance of the IPC. For insulated stranded conductors, the potential measuring positions are the mid-point of the equalizers, which shall be 15 $\sqrt{A}$ mm or 150 mm, whichever is the longer, away from the connector. The actual lengths of l_a and l_b can vary in a real test set-up at each connector. It is therefore necessary to take into account these individual readings for the calculation of the resistance for every individual connector.

B.2 Temperature measurement

A good thermal contact between the thermocouple junction and the measuring object shall be established.

In the case of the insulated reference conductor (Figure 5 a)), the thermocouple shall be positioned at the mid-point and securely located either in a small hole drilled in a solid conductor, or by sliding it under the strands of the outer layer of a stranded conductor.

In the case of connectors (Figure 5 b) to Figure 5 d)), the thermocouple may either be inserted in a small hole drilled into the main body of the connector, or be secured to the outside surface using a thermally conductive adhesive or self-adhesive thermal tape. In the latter case, the amount of glue or tape used to install the thermocouple should not affect the heat dissipation in the connector.

B.3 Equivalent conductor resistance

It is necessary to measure the resistance of a known length of the insulated reference conductor and its temperature (Figure 5 a)), so that the actual connector resistance R_j may be calculated, by subtracting the resistance due to the conductor lengths l_a and l_b. The various lengths, which need to be recorded, are shown in Figure 5.

It should be noted that in the case of branch connectors, resistances of both the main and the branch insulated reference conductors are used when calculating the actual connector resistance (see Figure 5 d)).

It is necessary to measure the resistance of the insulated reference conductor on each occasion that the connector resistance measurement is made. All measured resistance values of the insulated reference conductor (corrected by temperature) shall be stable throughout the complete test to show that the equalizers are stable in principle. For the determination of the parameter k (see Annex F) it is essential that, during resistance measurement, the insulated reference conductor and all connectors are in the range of ambient temperature such as defined in 6.2.2.

Annex C
(informative)

Recommendations to decrease uncertainties of measurement

C.1 Handling the test loop

Bending or vibrations during transport and handling may give rise to mechanical forces, which affect the contact resistance of the test objects and should be avoided.

The same potential measuring positions should be used throughout the test, they should be clearly marked since calculation always refers to the initial situation. Verification of measuring positions, especially after the short-circuit test, is advised.

C.2 Measurements, instruments and readings

For insulated stranded conductors, the distances between any equalizer in the test set-up where no connectors are installed may be used for verification of resistance measurements.

All recorded values should show that the equalizers have acceptable stability throughout the test.

Check the validity of calibration or make a calibration of each instrument prior to the test. If possible, calibrate the whole measuring chain.

For measuring the current, a calibrated shunt may be introduced into the test loop.

If possible, use the same instrument for voltage (ΔU DC), current (ΔU DC of a shunt) and temperature (ΔU DC of thermocouple-voltage output) measurement.

A calibrated resistance with a value in the same order as the readings may be used for the calibration of the voltage measurement or a direct measurement of the resistance. A check should be made before, during and after the test.

It is recommended:

– to use the same instruments throughout the whole test;
– to avoid, whenever possible, the replacement of any instrument, since the change in the systematic uncertainty may influence the assessment of the measuring results;
– to use automatic storage of the measured values to avoid copy errors;
– to use a validated computer programme for the calculation to avoid errors by accident.

When calculating the k value, it is possible to use the measured resistance values of the insulated reference conductor and the connectors without any temperature correction, provided that the resistance of the insulated reference conductor does not change during the test and the temperatures of all parts of the test loop are the same and in stable conditions when resistance measurements are made.

Every effort should be made to avoid spurious readings.

Annex D
(normative)

Calculation of adiabatic short-circuit current

The general form of the adiabatic temperature rise formula which is applicable to any initial temperature is:

$$I^2_{AD}\ t = K^2 S^2 \ln\left(\frac{\theta_f + \beta}{\theta_i + \beta}\right)$$

where:

I_{AD}	is the short-circuit current (RMS over duration) calculated on an adiabatic basis (A)
t	is the duration of short-circuit (s)
K	is the constant depending on the conductor material (As$^{1/2}$/mm^2) see Table D.1 below for normative values of K
S	is the actual cross-sectional area of the conductor (mm^2) see below
θ_f	is the final temperature (°C)
θ_i	is the initial temperature (°C)
β	is the reciprocal of temperature coefficient of resistance of the conductor at 0 °C (K) see Table D.1 below for normative values of β
ln	is $\log_e$

Table D.1 – Material properties

Material	K (As$^{1/2}$/mm^2)	β (K)
Copper	226	234,5
Aluminium	148	228

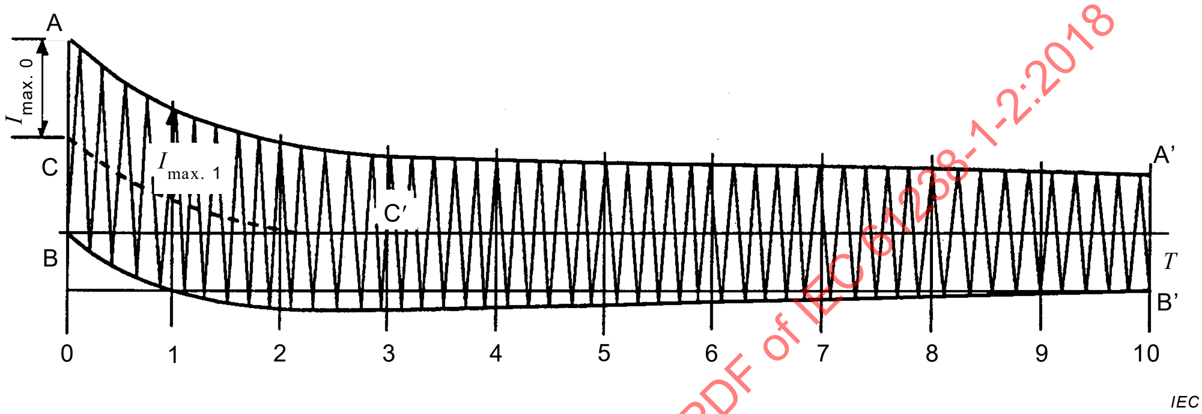
Although it is not required to measure the final temperature of an insulated conductor during the short-circuit test, experience has shown that the actual final temperature for some insulated conductor sizes is significantly higher when applying this calculation by using the nominal cross-sectional area. Therefore it is recommended to determine the actual cross-sectional area (S) to prevent over-heating. In this case, the preferred method is to weigh a fixed length of conductor and calculate the actual cross-sectional area (S) using the material density. The fixed length of conductor should not be lower than the reference length (l_r) used in the electrical ageing test or 1 000 mm, whichever is the greater.

Annex D is based on Clause 3 and Table I of IEC 60949:1988 and IEC 60949:1988/AMD1:2008 wherein the complete calculation method can be found. This method shall be used for alloys.

Annex E
(informative)

Determination of the value of the short-circuit current

In the case where there is no constant symmetrical RMS value during the short-time current, the equivalent RMS value can be determined from an oscillogram, using the method described below (see Figure E.1).



Key

AA' and BB'	Envelopes of current waves
CC'	Displacement of current-wave zero line from normal zero line at any instant
$I_0 \ldots I_i$	RMS value of the AC component of current at any instant calculated from normal zero: DC component (CC') is neglected
I_{max0}	Peak value of the AC component of current at the instant of initiating short circuit
BT	Duration of short circuit.

Figure E.1 – Determination of equivalent RMS value of current during the short-circuit test

The total time BT of the test is divided into 10 equal parts by verticals 0 to 1…10 and the peak value of the AC component of the current is measured at these verticals.

These values are designated: I_{max0}, I_{max1}, I_{max2}, ……… I_{max10}.

The effective values are then: $I_i = I_{max\,i} / \sqrt{2}$.

The equivalent RMS current during the time BT is given by:

$$I_{RMS} = \sqrt{\frac{1}{30}\left[I_0^2 + 4\left(I_1^2 + I_3^2 + I_5^2 + I_7^2 + I_9^2\right) + 2\left(I_2^2 + I_4^2 + I_6^2 + I_8^2\right) + I_{10}^2\right]}$$

NOTE Annex E is consistent with Annex G of IEC 62475:2010.

Annex F
(normative)

Calculation method

F.1 General

This statistical evaluation shall follow IEC 60493-1.

F.2 Measurements made

To the cycles listed in Table 2, the following measurements with the test loop at ambient temperature shall be taken (see 6.2 and Annex B):

U potential difference between measurement positions spanning each connector;

I direct current at the moment of measuring U;

θ temperature of each connector at the moment of measuring U;

U_r potential difference between measurement positions on the reference conductor;

I_r direct current at the moment of measuring U_r;

θ_R temperature of the reference conductor at the moment of measuring U_r.

The above is the recommended method. Direct measurements of resistance R and R_r may, alternatively, be used for any of the above U/I values.

In addition, temperature measurements θ on each connector and θ_R on the reference conductor during heat cycling on the cycle prior to, or following the resistance measurements shall be recorded.

Distances l_a, l_b, l_j, l_r defined in Figure 5, are measured and are applicable for the whole test. The distances shall be measured with a tolerance of ±2 mm for lengths ≥ 40 mm, or ±5 % for lengths < 40 mm.

F.3 Connector resistance factor k

The resistance, referred to 20 °C, between measuring positions spanning a connector is as follows:

$$R = \frac{U}{I} \times \frac{1}{1 + \alpha(\theta - 20)}$$

Where the temperature coefficient of resistance α, for the purposes of this document, is regarded as equal for copper and aluminium:

$$\alpha = 0{,}004\ \mathrm{K}^{-1}$$

The resistance of the reference conductor, referred to 20 °C, is as follows:

$$R_r = \frac{U_r}{I_r} \times \frac{1}{1 + \alpha(\theta_r - 20)}$$

The connector resistance R_j is then:

$$R_j = R - R_r \times \frac{(l_a + l_b)}{l_r}$$

and the connector resistance factor k:

$$k = \frac{R_j}{R_r} \times \frac{l_r}{l_j} \qquad \text{(F.1)}$$

F.4 Initial scatter δ

The scatter between the six values of k_0 (one value for each connector) at cycle no. zero is calculated as follows:

Calculate the mean value:

$$\overline{K}_0 = \frac{1}{6}\sum_{1}^{6} k_0$$

then the standard deviation:

$$s_0 = \sqrt{\frac{1}{5}\sum_{1}^{6}(k_0 - \overline{K}_0)^2}$$

and finally the scatter:

$$\delta = \frac{1}{\sqrt{6}} \frac{s_0}{\overline{K}_0} t_s$$

where:

t_s is the Student coefficient;

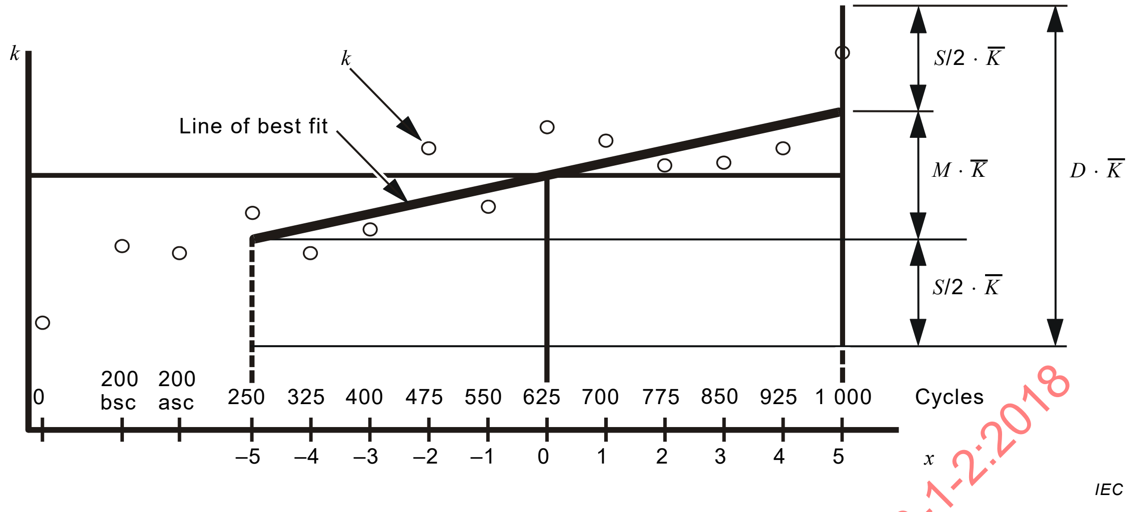
$t_s = t_{5;0,995} = 4,032$ for 99 % two-sided confidence level and five degrees of freedom;

hence:

$$\delta = 1,65 \frac{s_0}{\overline{K}_0} \qquad \text{(F.2)}$$

F.5 Mean scatter β

This scatter shall be determined using the last 11 measurement readings of resistance. These 11 readings start at the 250th cycle point, and then every 75 cycles up to 1 000 cycles. A tolerance of ± 10 cycles is permitted on the timing of any reading, and in this case, the statistical formulae listed in this document are applicable. Outside this tolerance, a detailed statistical treatment is necessary. For convenience of calculation, the origin is transferred to the mid-point of the 11 readings and the statistical variable x is introduced (see Figure F.1). The symbol x has the values 0, ± 1, ± 2, ... , ± 5.



Key

bsc = before short-circuit test

asc = after short-circuit test

Figure F.1 – Graphic example of assessment of a Class A individual connector

For each connector, its mean value over the interval $x = -5$ to $+5$ shall be calculated.

$$\bar{k} = \frac{1}{11}\sum_{-5}^{+5} k \qquad \text{(F.3)}$$

Hence six values are obtained. The mean of these six values is then:

$$\bar{K} = \frac{1}{6}\sum_{1}^{6} \bar{k}$$

The standard deviation:

$$s = \sqrt{\frac{1}{5}\sum_{1}^{6}(\bar{k}-\bar{K})^2}$$

and the scatter:

$$\beta = \frac{1}{\sqrt{6}}\,\frac{s}{\bar{K}}\,t_s$$

Where t_s = 4,032 as before.

Hence:

$$\beta = 1{,}65\,\frac{s}{\bar{K}} \qquad \text{(F.4)}$$

F.6 Change in resistance factor of each connector

F.6.1 General

To calculate the possible variation in the resistance factor of a connector over the last 11 measurement readings, the method of least squares shall be used to determine the line of best fit. To the change in resistance factor of this line is added a quantity, the magnitude of which depends upon the confidence interval of scatter of resistance factor values about the line of best fit.

F.6.2 Line of best fit

The slope of the line of best fit over the range x = -5 to +5 is given by:

$$b = \frac{\sum_{-5}^{+5} x\,k}{\sum_{-5}^{+5} x^2}$$

Hence, the per-unit change in resistance factor is:

$$M = 10\ \frac{b}{\bar{k}} \qquad \text{(F.5)}$$

Where $\bar{k}$ has the value given by Equation (F.3).

The parameter M is evaluated for each of the six connectors.

F.6.3 Confidence interval δ_i

The confidence interval δ_i for the change in resistance factor is:

$$\delta_i = t_s\ \sigma$$

where:

t_s is the Student coefficient;

$t_s = t_{9;0,95}$ = 1,833 for a 90 % two-sided confidence level and (11 – 2) = 9 degrees of freedom;

σ is the standard error estimated from the line of best fit at x = +5 or x = -5.

It can be shown that σ, for 11 measurements, is:

$$\sigma = 0{,}564 \times \sqrt{\sum_{-5}^{+5} \frac{(k - \bar{k} - b \cdot x)^2}{9}}$$

$$\sigma = 0{,}564 \times s_j$$

The expression under the root sign is the standard deviation of the connector from the line of best fit. We define this value s_j since it relates to an individual connector and it should not therefore be confused with the standard deviation of the six connectors, s, calculated at the mean measurement position x = 0 and used for determining the scatter β.

It should be noted that the above expression for s_j can also be determined by simplifying to:

$$s_j = \frac{1}{3}\sqrt{\left|11\left[(\bar{k^2}) - (\bar{k})^2\right] - 110\,b^2\right|}$$

Where $\bar{k}$ has the value given in Equation (F.3)

and
$$(\bar{k^2}) = \frac{1}{11}\sum_{-5}^{+5} k^2$$

The total per-unit deviation from the line of best fit is then:

$$S = \frac{2 \cdot t_s \cdot \sigma}{\bar{k}} = \frac{2 \cdot 1{,}833 \cdot 0{,}564 \cdot s_j}{\bar{k}} = \frac{2{,}07 \cdot s_j}{\bar{k}}$$

The parameter S is evaluated for each of the six connectors.

F.6.4 Change in resistance factor D

From F.6.1 and F.6.2, the estimated change in the value of k for each connector over the last 11 measurements is

$$D = |M| + S = \frac{|10b|}{\bar{k}} + \frac{2{,}07\ s_j}{\bar{k}} \qquad \text{(F.6)}$$

F.7 Resistance factor ratio λ

$$\lambda = \frac{k}{k_0}$$

where:

k is the connector resistance factor for each connector found at any stage of the measurement series;

k_0 is the connector resistance factor of the same connector measured at cycle no. zero.

F.8 Maximum temperatures θ_{max}

For each connector, the value of θ_{max} shall be recorded. This is the maximum value of the connector temperature reached during any stage of the test. Simultaneously, the value of θ_{ref} shall also be recorded.

Annex G
(informative)

Explanation on assessment of results of electrical tests on connectors

G.1 History

The wide divergence between different national test methods for electrical connectors made it difficult for the user to compare, evaluate and accept results from tests according to different standards. When introducing new products, it was sometimes necessary for the manufacturers to present test reports according to all relevant standards. To overcome these problems, a decision was made to establish a working group to develop an internationally accepted standard with a well defined testing procedure and an assessment that was reproducible. The result of this work, IEC 61238-1, was presented in 1993.

The various testing standards considered during the preparation of IEC 61238-1 were based on temperature cycles and most of them included the application of short-circuit currents. The requirements and acceptance criteria were for the resistances to be stable. Different methods were used to define the stability during the short period of testing.

The statistical method of assessing test results described in IEC 61238-1 is mainly based on a compromise between the Italian standard CEI 20-28 and the British standard BS 4579-3. Early in the discussions it was agreed to adopt a statistical method of evaluating the trend of electrical resistances instead of the more traditional deterministic methods. Several tests were carried out to find the similarities and differences between the two standards. The aim was to find a method of statistical assessment that would be relevant for a test with 1 000 heat cycles. The Italian standard requires 1 500 cycles with resistance measurements every 60 cycles during the last 600 cycles and six short-circuit current tests after 500 cycles, while the British standard requires 2 000 cycles with resistance measurements every 100 cycles and three short-circuit current tests prior to heat cycling.

G.2 Short examination of the assessment methods of IEC 61238-1 compared with the Italian standard CEI 20-28 and the British standard BS 4579-3

The different statistical evaluations should be viewed as a part of the complete assessment procedure. All three standards require six identical specimens to be installed in a test loop and 11 resistance measurements constitute the basis for the statistical assessment. It should be noted that the formula symbols in each standard may have different meanings. Table G.1 lists the various connector characteristics examined for IEC 61238-1.

The main difference between the Italian and the British regression analysis is that the former, except for temperature requirements, assesses the six specimens as a group whereas in the British standard each specimen is assessed individually.

The individual regression analysis, which is incorporated in BS 4579-3 and also adopted in IEC 61238-1, is essential to provide adequate sensitivity to the change of resistance for a single sample. The analysis looks at the scatter of measurements about the line of best fit. However, the method is sensitive to anomalous readings, which may be a merit of the test as it can detect the onset of deterioration. The possibility that incorrect readings may affect the analysis should also be considered.

Group regression analysis as specified in the Italian standard CEI 20-28 is a sensitive indicator of scatter and has the advantage of taking into account all 66 measurements. The method responds to differences between samples and to the change of resistance for particular samples. However, the method is less sensitive to the instability of a single specimen.

This formula in IEC 61238-1 for mean scatter is a group regression analysis based on the standard deviation between the mean of the six groups of specimen values averaged over 11 measurements. The Italian regression method is based on the calculation of mean values of the six specimens obtained for each of the 11 measurements.

The group regression analysis is a verification of whether or not the tested connectors belong to the same family.

G.3 The IEC 61238-1 method of assessing test results

It was considered advantageous to introduce the “relative resistance” k so that the analysis would be independent of the absolute value of connector resistance. k is the relationship between the resistance of a connector and an equivalent length of the conductor. The adoption of k is also expected to give improved measurement reproducibility.

Other parameters that shall be calculated include:

– the initial scatter δ between the initial six values of k_0 before heat cycling;

– the mean scatter β between the six values of k averaged over the last 11 measurements. The assessment verifies that the connectors behave in the same way and that they belong to the same “family”;

– the change in resistance factor D, which shows the change of the resistance factor k for each connector over the last 11 measurements. Statistical methods are used to assess the probability that the change of resistance will not exceed the specified value;

– the resistance factor ratio λ, which shows the relationship between the resistance at any stage of the measurements and the initial resistance;

– the maximum temperature θ_{max} of the test objects.

The selection of assessment criteria and values was made after evaluating test results and experience from different laboratories and countries.

At an early stage during the development of IEC 61238-1, k itself was included as one of the acceptance criteria together with the change in k due to the short-circuit test. To reduce the number of acceptance criteria, a decision was taken to exclude these parameters.

Table G.1 – Summary of assessed behaviour of a tested connector

General requirements **Type tested connector shall show the same behaviour regarding the following aspects:**	**Assessment in IEC 61238-1** **Related test parameter and limit values covering the general requirement:**
All tested connectors of a specific design shall be similar in resistance after installation.	The initial scatter δ between the six values of k_0 before heat cycling shall not exceed the value 0,30 as given in Table 3.
The resistances of each tested connector shall remain stable during the entire electrical test, including the short circuit test, if applicable.	The resistance factor ratio λ of each tested connector shall not exceed 2,0 as given in Table 3.
The resistance of each tested connector shall not rise excessively during the last 750 heat cycles and all connectors shall show similar behaviour.	The mean scatter β shall not exceed the value 0,30 and the change in resistance factor D shall not exceed 0,15 as given in Table 3.
The connectors shall never overheat during any phase of the electrical test.	For each specimen the temperature of the connector during current-heating shall not exceed that of the reference conductor when measured as given in Table 3.
If applicable, the connector shall withstand a specified pull-out force related to conductor size and conductor material to guarantee the required basic mechanical tensile strengths occurring in service.	Mechanical tensile strength for all connectors except of Class 0: no slipping shall occur at the entrance of installed connectors after applying the related mechanical tensile force given in Table 4.

NOTE Electrical and mechanical tests of connectors are performed with separate samples in this type test which is sufficient to cover cable applications described in Clause 1. Other combined mechanical and electrical tests performed on the same samples are under consideration for special applications for example to verify the aptitude of a connector design to handle possible displacements in cable installations.

Annex H
(informative)

Tests on multicore connectors

H.1 Principle

H.1.1 Electrical tests

Annex H gives some testing arrangements that may be used to test multicore connectors for specific cable designs subjected to specific cable network operation conditions. Because of different designs, different use and different test experience in various countries, no common standard requirements can be considered for these applications at the moment. Therefore two test recommendations are presented, the choice of which will be agreed between manufacturer and customer.

Multicore connectors (e.g. ring connectors) are usually insulation piercing through- and branch-connectors used in accessories on multicore low voltage distribution cables with conductor nominal cross-sectional areas up to and including 240 mm^2.

A preconditioning test on each test specimen used in the electrical type test may be performed to cover stresses during installation for example coming from live load-pickup as described in Annex I.

One aim of these test recommendations is to create maximum load stresses during heat cycling and short-circuiting by passing the same current through almost all involved cores of the multicore cable in parallel and by subjecting the multicore connector to the highest possible thermomechanical stress without changing the properties of the involved insulation material of the cables adjacent to the installed multicore connector.

The other aim is to assess each connection inside a multicore connector individually. The existing assessment criteria in this document can only be applied on statistical independent connectors. In multicore connectors where clamping devices are acting simultaneously on adjacent core-connections this rule is not fulfilled due to the proximity effect between specimen. The note in Table 3, which contains electrical test requirements, says that the values given in this document are based on experience. For multicore connectors there is however a lack of experience. Users are invited to collect and share test experience to improve the recommendations and work on common requirements for the next edition of this document.

H.1.2 Mechanical tests

Usually these connectors can be classified according to Class 0, because the accessory withstands the mechanical loads. If the connector is classified according to Class 1, then the branch connections can be individually tested as per Clause 7.

H.2 Test recommendations for electrical tests based on test experience in the UK and in France

H.2.1 General

Subclause 6.1 is taken as reference with the following modifications:

– The number of multicore connectors shall be two therefore the number of phase’s connections shall be six.

– Upon the customer's requirement, the installation can be done with the complete cable (all the phases are to be used) in order to perform the test in the "field configuration". The test conditions are to be agreed with the customer.
– When the connector is used as through connector, Figure H.1 a) or Figure H.1 b) have to be used.
– When the connector is used as branch connector, Figure H.2 a) or Figure H.2 b) have to be used.
– When there are more than one branch conductor to be connected Figure H.2 a) or Figure H.2 b) have to be taken as reference.
– The neutral conductor should be heated in order to maintain a homogenous temperature in the multicore connector. The main conductor is connected without the branch conductor. In any case, the neutral conductor should be only monitored and should not be part of the test.
  - When the nominal cross-sectional area is the same as the phases (see Figure H.1 a) or Figure H.2 a)), the main conductor is connected without tap.
  - When the nominal cross-sectional area is not the same (see Figure H.1 b) or Figure H.2 b)), an additional circuit can be connected in order to adjust the temperature of the neutral conductor.
– If additional tests on neutral connectors are performed separately, the specific test conditions should be mentioned.

H.2.2 Measurement

Subclause 6.2 is taken as reference with the following remarks.

– l_j measurement has to follow Figure 5 d),
– thermocouple positioning has to follow Figure 1.

H.2.3 Heat cycling test

Subclause 6.3 is taken as reference with the following remarks.

– In addition to the actual temperature adjustment for main and tap phases, the neutral needs to be monitored with a larger tolerance (i.e. $\theta_{ref}\ {}^{+0}_{-15}$ K). The aim of the larger tolerance is to allow different possibilities of adjusting the temperature in the neutral conductor. Furthermore, the neutral is not part of the test.

H.2.4 Short-circuit test (only for Class A)

Subclause 6.4 is taken as reference with the following modifications.

– In order to highlight the thermal effect on the multicore connector, two setups are proposed, the first one through the branch conductor and second one through the main conductor.

Then, for each combination, three short circuits should be applied, in total six short circuits should be applied:

– connector 1 phase 1 and connector 2 phase 1 with branch conductor as reference for current setting;
– connector 1 phase 2 and connector 2 phase 2 with branch conductor as reference for current setting;
– connector 1 phase 3 and connector 2 phase 3 with branch conductor as reference for current setting;
– connector 1 phase 1 and connector 2 phase 1 with main conductor as reference for current setting;

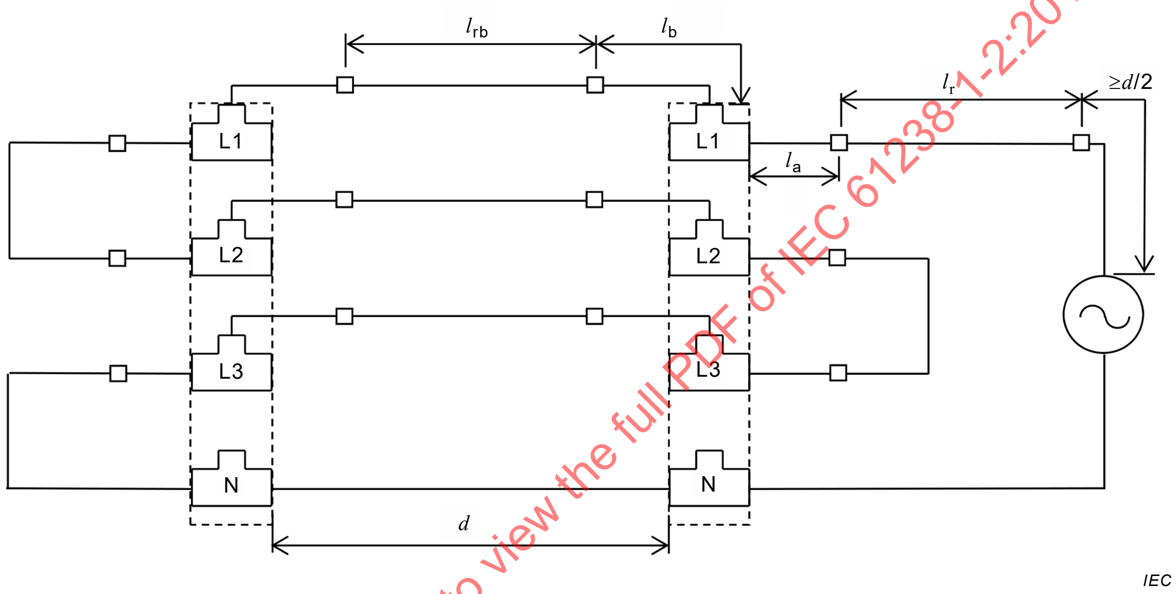
– connector 1 phase 2 and connector 2 phase 2 with main conductor as reference for current setting;
– connector 1 phase 3 and connector 2 phase 3 with main conductor as reference for current setting.

In the case of connectors used as through connectors, only one setup is applicable.

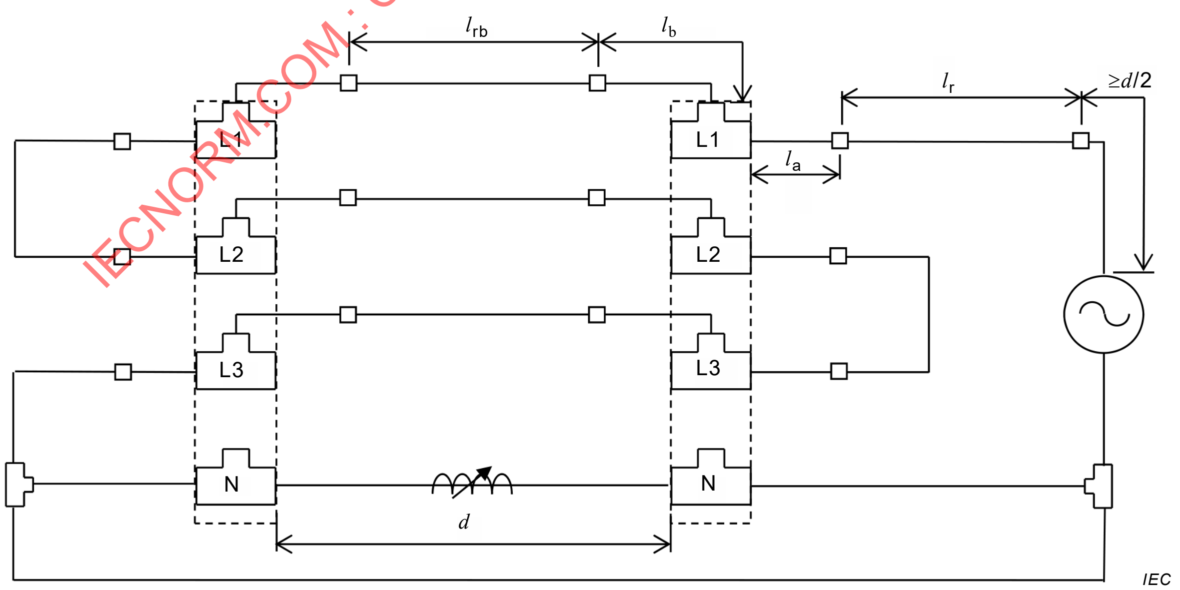
H.2.5 Results evaluation

Subclauses 6.5 and 6.6 are taken as reference with the following modification:

– The maximum value of initial scatter δ could be increased to reflect the interaction between each connection (to be determined after investigation).

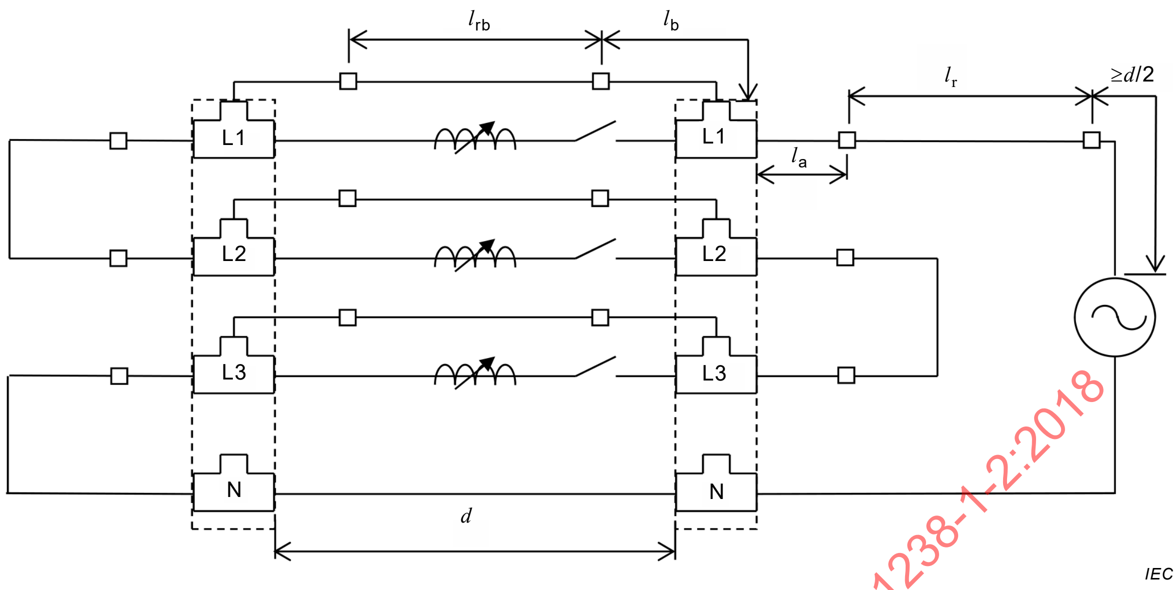


a) Typical test loop for multicore connector with identical nominal cross-sectional area and shape for phases and neutral

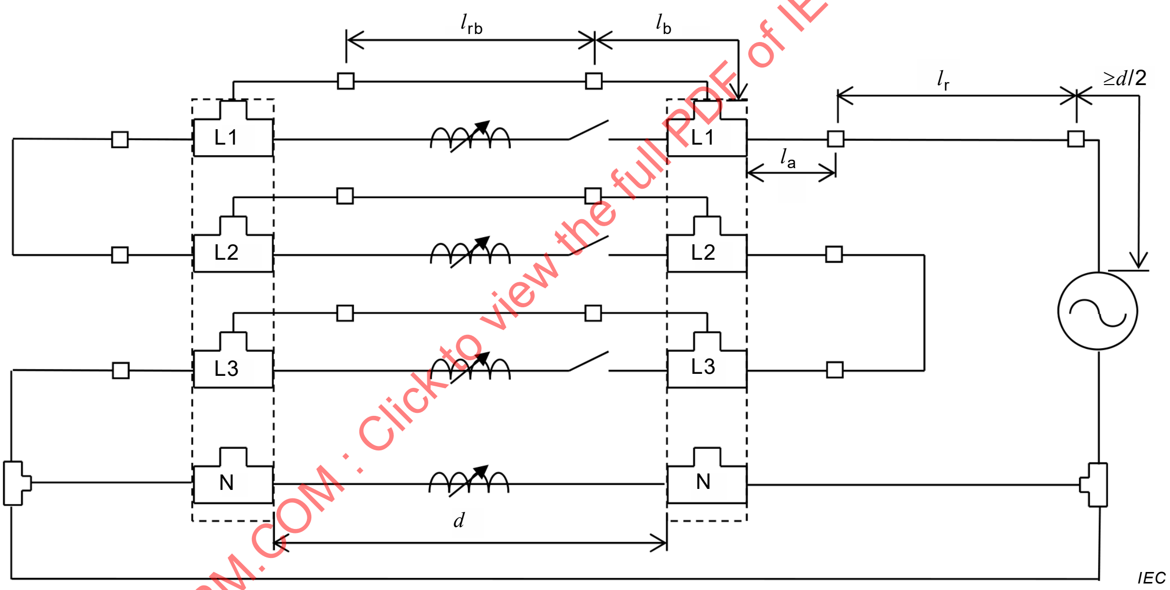


b) Typical test loop for multicore connector with different nominal cross-sectional area for phases and neutral

Figure H.1 – Test loops for through connectors



a) Typical test loop for multicore connector with identical nominal cross-sectional area and shape for phases and neutral



b) Typical test loop for multicore connector with different nominal cross-sectional area for phases and neutral

Figure H.2 – Test loops for branch connectors

H.3 Test recommendations for electrical tests based on German standard DIN VDE 0220- 3

H.3.1 General

A different assessment of the test recommendations is proposed in this document based on DIN VDE 0220-3. The advantage is that the test results are comparable to test- and field-experience which has been collected for more than 30 years with multicore cable applications in Germany.

Test results based on this document and test results based on DIN VDE 0220-3 are not comparable. The test recommendations described below are not identical to that of

DIN VDE 0220-3 but are expected to create comparable assessment results by using measuring methods and temperature profiles for heat-cycling as described in this document.

If multicore connectors are designed to be used for a range of cross-sectional areas of conductors in through and/or branch cables, the tests should be carried out in two combinations:

– maximum main size and maximum branch size,
– minimum main size and maximum branch size.

The test recommendations for multicore connectors are applicable to designs used on three- and four-core low voltage distribution cables. In cable designs where the neutral and/or shield cannot be subjected to the same nominal current as the phases, these current carrying parts may not be heat-cycled and may not be assessed.

H.3.2 Test setup for electrical test

The test setup consists of several test branches, each of them containing one multicore connector installed on multicore cables fixed to a mechanically rigid test frame with disconnecting terminals installed at the ends of each cable conductor to allow the electrical interconnection of different cable cores to pass test currents during different test sequences.

The recommended test sequence makes it necessary to change current flow through different cable-cores of the test setup from time to time for example for heat-cycling, for short-circuiting and for resistance measurement. To avoid excessive mechanical movement on the tested connectors it is recommended to use a rigid frame where all terminals on cable conductors are mechanically anchored and the interconnection between different terminals can be set and changed without any additional mechanical impact on the tested connectors. To avoid additional thermal influence, a minimum installation distance of d according to Figure 3 and Figure 4 between specimen and disconnecting terminals should be used. As disconnecting terminals, bare cable lugs mechanically fixed to a rigid electrically insulated test frame may, for example, be used. The current carrying capacity of the linking-cables or -parts attached to the anchored terminals should be almost equal to the tested cable conductors to avoid heat sources or heat sinks.

Cores in multicore cables might be manufactured by using conductors not made out of the same production length, even when from the same size, shape and material. Therefore it is recommended to build all test branches using the same cables in each parallel test branch taken out of one continuously produced length. Then only one reference conductor for each main core and one for each branch core can be used and identified by having the same color of insulation.

One multicore connector is placed per test branch. The installation of the multicore connectors should be made by the manufacturer. The preparation of the required installation window in the multicore main cable and the preparation of cable ends for branch cable cores should be made according to the manufacturer's installation instruction, which should be part of the type test report. Adjacent to the cuts of the outer cable protection, the complete cables should be kept in the original shape at least at a distance of 100 mm and should be fixed by cable cleats to the rigid test frame to avoid movement on the specimen during handling of the complete test setup during the type test. For stranded conductors, equalizers should be installed, preferably located between cable cleats and anchoring clamps. As a result, the lengths of l_a and l_b will be longer than given in Figure 3 for the main conductor but should be minimized by placing the equalizers close to the cable cleats. The preferred test method is to have the branches not bended up to the equalizer and to fix the branch cores individually to a mechanical fixed structure of the test setup near the equalizer, not necessarily representing the real installation of a branch in joints.

One possibility when installing the branches of the multicore connector is to dismantle the multicore branch cable in single insulated conductors, place the equalizers to create the same distances on each core from the limit-mark at the end of l_j where the cable will be clamped to each equalizer. Afterwards the cores should be bended to fit into the clamp.

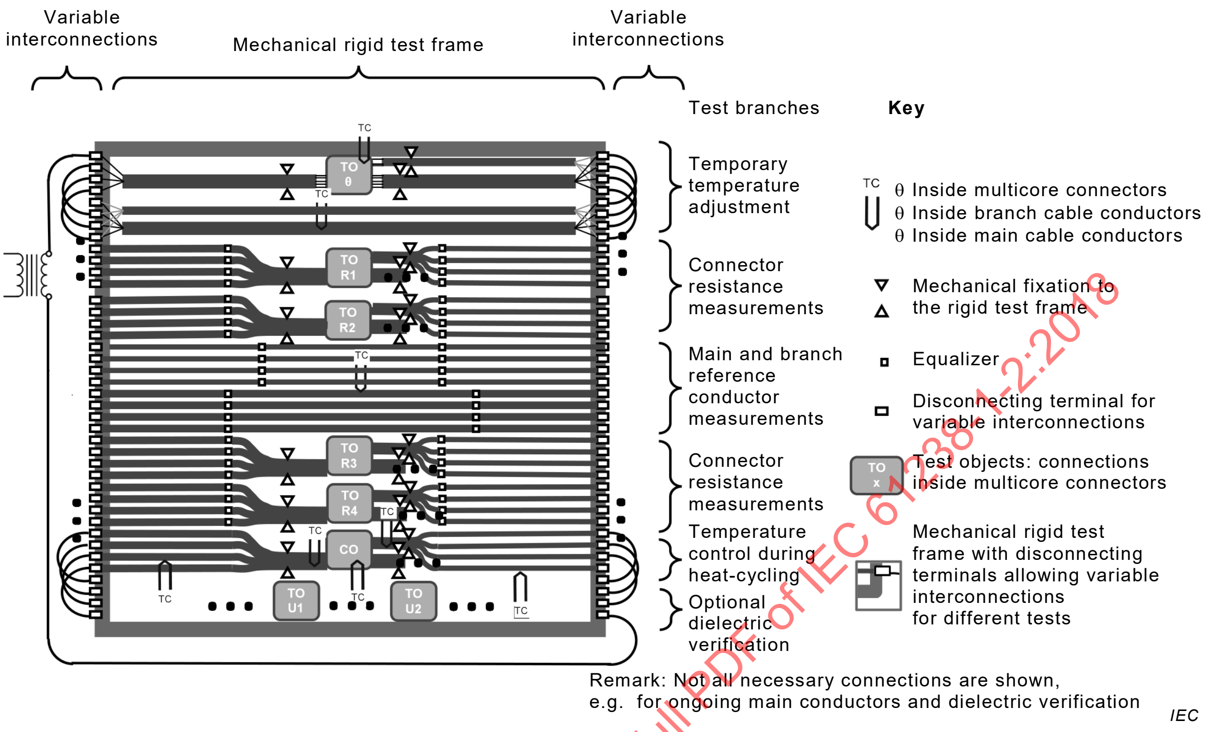


Figure H.3 – Example of test setup for multicore branch connectors on a four-core cable consisting of several test branches

In this example, the preparation for the ongoing main cable is not shown but should be made in the same way as for the feeding main, if the short circuit test should also be performed or if the main and branch cables should run in parallel during heat-cycling.

H.3.3 Resistance assessment branches of the test setup

Test branches for resistance measurement should use equalizers in the case of stranded conductors or potential measuring positions in the case of solid conductors placed adjacent to the spot where the accessible cable core insulation meets the connector insulation, as described in this document, by keeping a minimum distance of 10 mm.

H.3.4 Temperature measurement in a separate test branch during the first and second heat-cycle

While the insulation is an integral part of the installed multicore connector which may influence its performance behaviour, the prepared test objects for resistance stability assessment should not be modified because there is a certain risk that manipulated specimen might be damaged by applying temperature measurement equipment inside the connector.

It is recommended to use an additional test branch in the test setup for temperature measurement of each metal part used for the conductor-connection inside the multicore connector and for the temperature and current control of each conductor in the main and branch cables. All metallic contact parts in this multicore connector installed in the temperature measuring branch should be equipped with thermocouples. Multicore connectors may have more than one metal piece to connect two conductors. As the uncertainty in temperature measurement of small metal parts depends very much on the correct installation of the thermocouples, more than one thermocouple may be applied in different ways. It is recommended to record and use the maximum measured temperature value as the connector temperature.

For temperature measurements of reference conductors, a thermal equivalent configuration compared to the real cable should be tested by keeping the cores in the original position inside the cable and rebuilding the insulation layers of the cable where thermocouples are applied. No equalizers should be used in this branch of the test setup and no installation of resistance measurement equipment should require further separation of conductors and further removal of cable insulation.

Test branches for resistance measurement and/or the arrangement with the single core reference conductors should be interconnected and serial loaded in the same way as the test branch for temperature measurement.

The heat-cycling current during the first heat cycle is actuated to control and respect the following temperature conditions:

– The temperature of each core conductor adjacent to the multicore connector should not exceed θ_{max} + 15 K to avoid damage of the penetrated core insulation, which is an integral part of an IPC.

– The temperature of any metallic contact part in multicore connectors should not exceed 100 °C.

– The conductor temperature of any insulated cable core in its original position inside the multicore cable should not exceed 140 °C.

As soon as one of these temperature conditions is met, the temperature recorded in the reference conductor measurement branches will be used as control parameter for the following heat cycle as described in 6.3.3.

The temperatures of conductors inside the insulated multicore cable are expected to be higher than in the case of the single core IPC test when passing the same current due to the adjacent placed current carrying conductors. The original cable position is also kept in some parts of the resistance measuring branches where the cable is cleated. It should be controlled, that the temperature in these parts will not exceed 140° C because then material properties of aluminum conductors may change and may have an impact on resistance readings if these parts are located between connector and equalizers.

The following values should be recorded in the test report:

– equilibrium current I_N;

– median value of maximum temperatures in main reference conductors while I_N is applied;

– median value of maximum temperatures in branch reference conductors while I_N is applied.

While serial loaded, this equilibrium current I_N will create certain end temperatures in every main and branch reference conductor used for resistance measurement. These temperatures should be measured and a median reference conductor should be determined which should then be used for regulating all following subsequent heat-cycles.

IPC systems are sensitive to the temperature exposure times because of the insulation material creepage. The DIN VDE test is using only on and off regulation of the current to get a heating profile. To get comparable results, using current regulation as described in 6.3.3 is recommended when determining the heating profile during the second heat cycle. Alternatively t_1 should be maximum 30 min and t_2 minimum 30 min to limit the energy input.

The temperature test branch is only used temporarily during the first and second heat cycle and should then be removed, as the necessary heating currents may overheat and damage the installed main and branch cable in its original shape and as the installed multicore connector may lose mechanical stability during subsequent heat cycles because of the applied thermocouples.