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Advanced Design of Metal Laminated Coverings:
Recommendation for Tests, Guide to Use, Operational Feed Back

Working Group
B1.25

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Recommendation for tests

Guide to use

Operation feed back

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Foreword:

This brochure has been ordered by CIGRE study committee B1 to update the report: "Guidelines for tests on high voltage cables with extruded insulation and laminated protective coverings" WG 21.14 published in ELECTRA no141 [1] in April 1992. Further taken into account by IEC 60840 [3], 62067 [7] and the Technical Report 61901 [6] published in 2005. Numerous technical improvements appeared on laminated coverings since 1992 in parallel with service experience.

The present brochure replaces Electra 141.

The Terms of Reference are the following:

To review and update the tests on cables with extruded insulation and laminated protective coverings taking into account the system view, i.e. the installation of accessories. Tests on cable, on accessories and on the system itself should be addressed, including the short circuit one

- To issue a Guide to Use for non experts explaining what could be the different cable designs

Scope of work:

- Extruded cable systems only
- AC cable systems only with a focus above 36 kV
- Land cables

Deliverables:

The output should be an updated recommendation for tests on high voltage cables with extruded insulation and laminated protective coverings that includes a guide (for non-technical readers) with the aim to get customers to reference this guide. Moreover, the WG will provide an Electra article and a Tutorial for presentation at CIGRE conferences and workshops.

NOTE: Cables with traditional screen (extruded or corrugated) and plastic oversheath are excluded

Introduction:

The WG began his work by writing a questionnaire to perform a world survey of the use of laminated coverings. 13 countries answered, which gives a sound overview of the designs and operation feed back.

Three successful designs are today covering the market:

Combined Design - combined mechanical and electrical properties:

- XLPE 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 HDPE)

Additional wires can eventually be added to match the short circuit requirement

The metal foil is mainly aluminium; copper can be used as well.

Separate Design - separated mechanical and electrical properties:

- XLPE insulation system
- Copper or aluminium wires
- Water swelling 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 MDPE or HDPE)

Metal is mainly aluminium, copper or other metal laminated foils can be used.

Separate semi-conductive Design – separated electrical and water tightness properties with semi-conductive plastic coated foil.

- XLPE insulation system
- Round copper wires screen, non swelling semi-conductive tape below
- thin lead or Al foil (0,05 mm typical) with glue on one side, inner side (screen side) coated with typically 0,05 mm thick semi-conductive plastic
- Over-sheath (usually PVC)

The operation feed back relative to the use of these three designs as a function of the length to be laid, the installation method (ducts, directly buried…), the environment, the connection and grounding of the screen (single point, cross bonding, double point) made it possible for the WG to write the present brochure.

The First part is the recommendation for tests that replaces the one of ELECTRA 141 [1].

The Second part is a guide to use.

The Third part is the operational feed back.

A functional analysis of the laminated covering is given in the Appendix.

PART 1: RECOMMENDATION FOR TESTS

1 Definitions

1.1 Metal laminated covering:

A metal laminated covering consists of several layers of plain (not corrugated) metal and plastic materials bonded together to get a special set of properties: bending ability, radial water tightness.
It can be used to carry the capacitive, circulating and short circuit currents, according to the cable system design.

1.2 Design types:

The WG has identified three main cable designs:

1.2.1 Combined Design;

In the eighties power cables had a lead sheath. The first driver to introduce laminated covering instead of lead was to get lighter and cheaper cables. The first studies about the use of aluminium laminated screens started in the late eighties. Nowadays, also environmental reasons support this choice (CIGRE 2004).

Copper and other metal-plastic laminate are also used.

Combined Design (CD) - combined mechanical and electrical properties:

- XLPE 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 HDPE)

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

Note : In case copper wires are used in combination with a welded aluminium foil, it is recommended to put a non metal tape between them to avoid possible corrosion

A CD cable picture is shown in figure 1.

Figure 1: Combined Design 500kV cable

1.2.2 Separate Design:

This design was introduced in the eighties when the necessity of a radial moisture barrier became apparent in cables only having a wire screen and a PE and PVC jacket as water trees generated and led to cable faults. The principle of the laminated moisture barrier was taken over from telecommunication cables.

Separate Design (SD) - separated mechanical and electrical properties:

- XLPE insulation system
- Copper or aluminium wires
- Water swelling 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 MDPE or HDPE)

Metal is mainly aluminium; copper or other metal laminated foils can be used.

A SD cable picture is shown in figure 2.

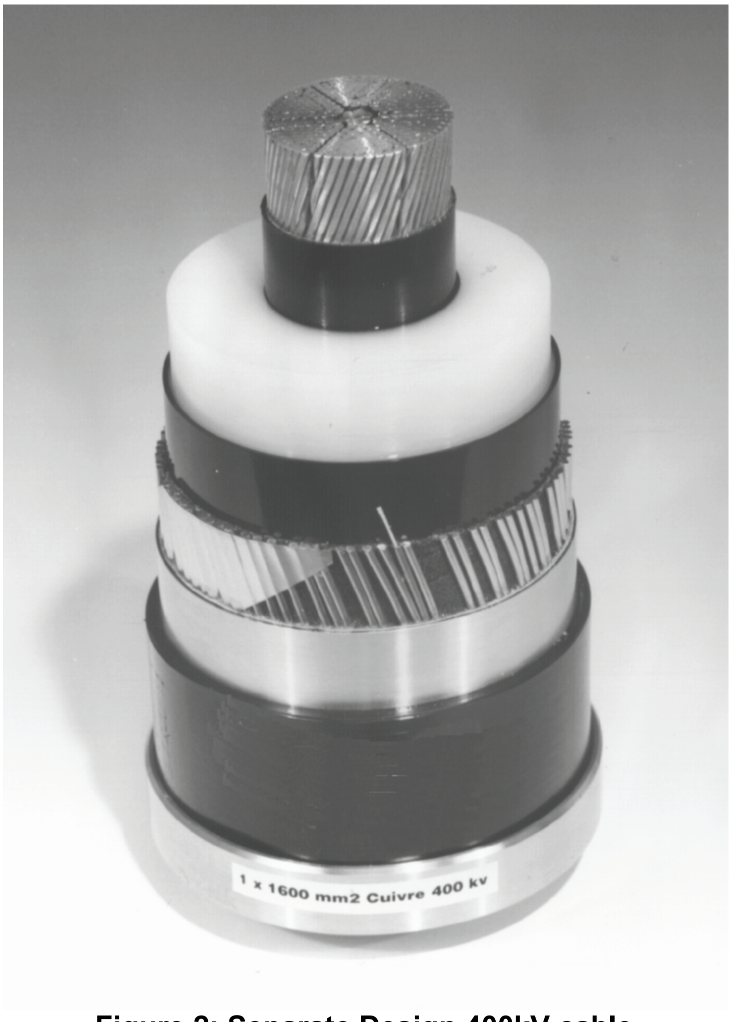


Figure 2: Separate Design 400kV cable

1.2.3 Separate semi-conductive Design:

This design was introduced in Japan in the eighties when the necessity of a radial moisture barrier became apparent in cables only having a wire screen and a PVC jacket as water trees generated and led to cable faults.
First cables used a lead laminated foil. Now Aluminium laminate is introduced as well.

Separate semi-conductive Design (SscD) – separated electrical and water tightness properties with semi-conductive plastic coated foil:

- XLPE insulation system
- Round copper wires screen, non swelling semi-conductive tape below
- thin lead or Al foil (0.05 mm typical) with glue on one side, inner side (screen side) coated with typically 0.05 mm thick semi-conductive plastic
- Over-sheath (usually PVC)

A SscD cable picture is shown in figure 3.

Figure 3: Separate semi conductive Design 275kV cable

Conclusion on laminated covering designs:

As compared to extruded sheaths, the use of laminated coverings (specially when using aluminium) decreases the weight and diameter of the cable, allows for improvement in pulling techniques, and also achieves longer delivery lengths on a drum, which, in turn, decreases the number of joints in a circuit link.

Potentially, a significant impact on cost reduction of the cable system can be achieved.

Since the late nineties, in many countries, the aluminium laminate screen bonded to the PE oversheath has progressively superseded the lead sheath and the PVC oversheath.

2 Recommendation for tests:

The tests are divided in several classes. They cover the needs of the functional analysis (see appendix A1), and the technical issues raised by utilities (see world survey 4.1.2):

Development Tests: Tests made during the development of a cable design.

Prequalification Tests: Tests made before supplying on a general commercial basis a cable design covered by the recommendations in this document. These tests demonstrate the satisfactory long-term performance of the complete cable system.

Type Tests: Tests that are conducted on cables and accessories, before they are supplied on a commercial basis, for a cable system covered by the recommendations of this document. These tests are conducted to verify the properties of a cable system prior to supplying that particular system.

Sample Tests: Tests that are conducted on samples of complete cables or components, at a specified frequency, to verify that the product meets the design and manufacturing specifications.

Routine Tests: Tests made by the manufacturer on every manufactured component (length of cable or accessory) to demonstrate the integrity of the manufactured component.

Tests after Installation: Tests made on a completed cable system, after installation and prior to use, to demonstrate system integrity.

2.1 Development tests

2.1.1 Tests on cable

2.1.1.1 Impact test

There are 3 classes for resistance of the cable sheath to mechanical impact depending on the design and installation conditions of the cable:

In case of the CD design the concern is that mechanical impact to the laminated covering could damage the metal component and alter the electric functionality of the screen; therefore, the impact resistance of the laminated covering must be the highest.

In case of the SD design there is not a concern that mechanical impact to the metal component of the laminated covering will alter the electric functionality of the screen. The cable can be operated with short circuit capability provided by the presence of the screen wires. However, the impact resistance of the laminated covering should be high enough to preserve the radial water tightness function provided by the laminated covering.

In case of the design SscD, In case of the design SsdD, there is no need for the impact test as the cable is designed to be installed in duct or tunnel, not directly buried, see 3.3.2.

Table 1: impact test requirements

Impact test	Design CD	Design SD	Design SscD
Height (m)	0,27	1	n/a
Weight (kg)	27	5	n/a
R (mm)	1	2	n/a
Number of impacts	4 at the same location	1 impact at 5 different points more than 100mm apart	n/a

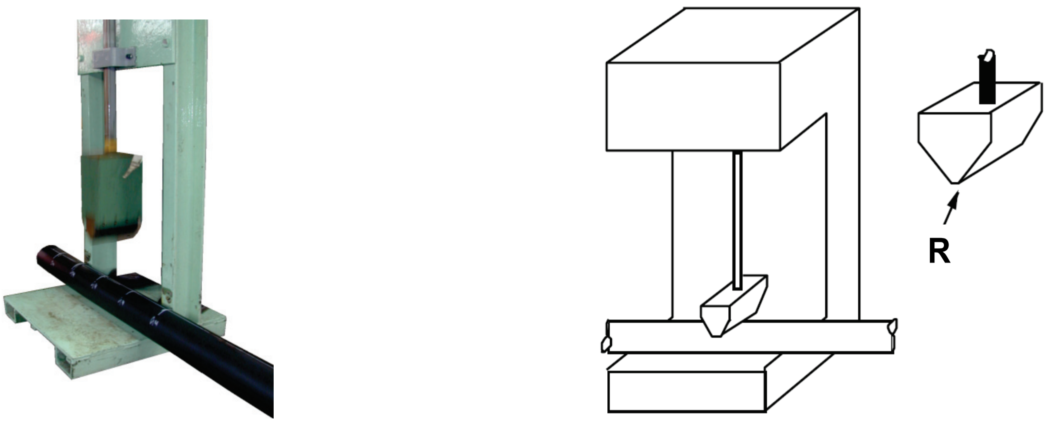


Figure 4: Test apparatus for the impact test

Sample:
A piece of cable, at least 1m in length

Test:

a) Test on CD design

The cable should be installed on a rigid metal base.
The test should be undertaken at 20±15 °C using a weighted metal of 27 kg wedge falling onto the cable from a height of 0,27 m. The wedge should have a radius R of curvature of 1mm at the point of impact and its axis should be perpendicular to that of the cable (figure 4).

The requirements for the impact test are presented in Table 1.
The impact test shall be performed at 4 locations along the cable, at 150 mm distance from each other. For investigation during development, one impact is performed at position 1, two at position 2, three at position 3, and for the test assessment four at position 4 (Figure 5).
The test shall be performed on the overlap or on the welded seam (Impact Point A) as on the opposite side of the cable (Impact Point B).

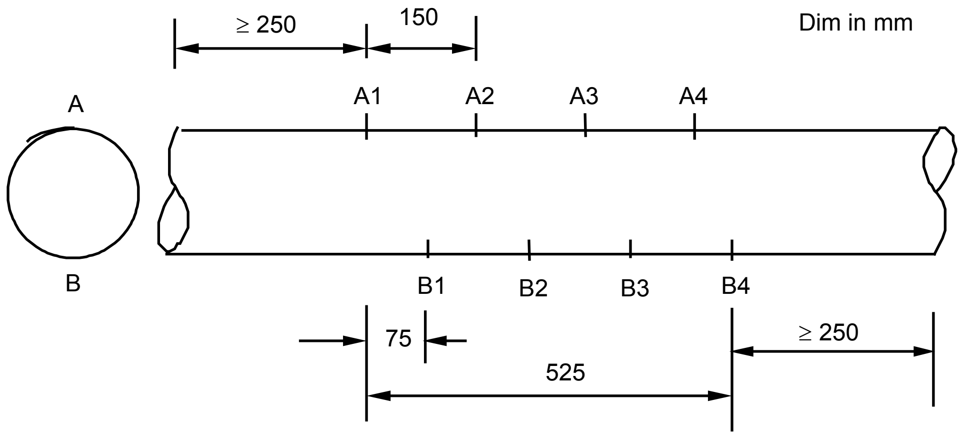


Figure 5: Positions of the points of impact

Result: Visual inspection and measurement of impact depth.
After the impacts the sample shall be cut longitudinally along two lines at 90° from the points of impact. The inner side of the metal screen or metal sheath shall be examined with normal vision.
- There should be no puncture at the points of impact A4 and B4.
- A longitudinal cut shall be made through the fourth points of impact, A4 and B4 (Figure 6). The semi-conductive screen should not be deformed by more than 1 mm and should not show a deflection having a sharp angle into the insulation at the point of impact. See distance d in the illustration of the impact point.

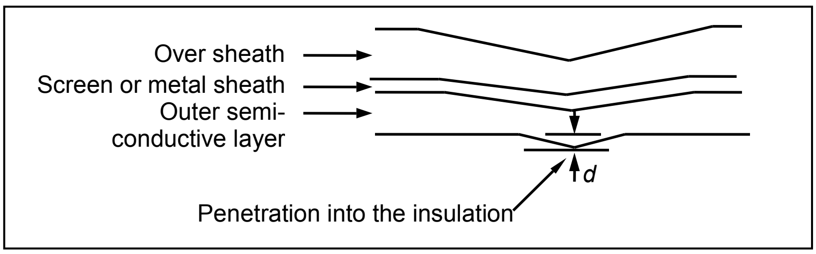


Figure 6: Deformation at the impact points to be examined

b) Test on SD design

The impact test on the SD design is carried out as per IEC 61901 [6]
The cable, at least 1 m in length, should be installed on a rigid metallic base. The test should be undertaken at 20±15 °C using a weighted metal wedge of 5 kg falling onto the cable from a height of 1 m. The 90° wedge should have a 2 mm radius of curvature at the point of impact and its axis should be perpendicular to that of the cable (figure 4).

An impact should be successively made at five different points along the cable; the distance between any two impact points should be at least 100 mm.

Result - visual inspection:
A 1 m sample should be dissected and visually examined. Examination of the samples with normal or corrected vision without magnification should reveal no cracks or separation of the metal foil of laminated protective coverings or harmful damage to other parts of the cable.

c) Test on SscD design
No test is needed due to the specific installation conditions (see part 2).

2.1.1.2 Abrasion test:

In the case of cables with laminated coverings, the over sheath has a function of preventing abrasion which could expose the metal component leading to corrosion of the metal foil. The abrasion test is considered of high functional importance as a first line of defence against corrosion.
The abrasion test shall be carried out if the oversheath material is not of type ST2 (PVC) or ST7 (MDPE – HDPE) of IEC standards 60840 [3] and 62067 [7], where the world survey (4.1.2) has provided feedback of satisfactory performance against abrasion.

The abrasion test should be performed on new materials, where satisfactory feed back on abrasion resistance from operation has not been provided.

The test procedure:

A complete piece of cable shall be tightly fixed to a metal base.

A conical test piece shall be applied to the upper surface line of the cable. The conical piece shall have a radius of curvature at its point of contact of 1 mm and the angle to the surface line of the cable shall be 90°. The mass of the piece shall be of 48 kg. The conical surface shall be smooth.

The conical piece shall be subjected to a motion to and fro, at constant speed, between the marks A and B as shown in Figure 7:

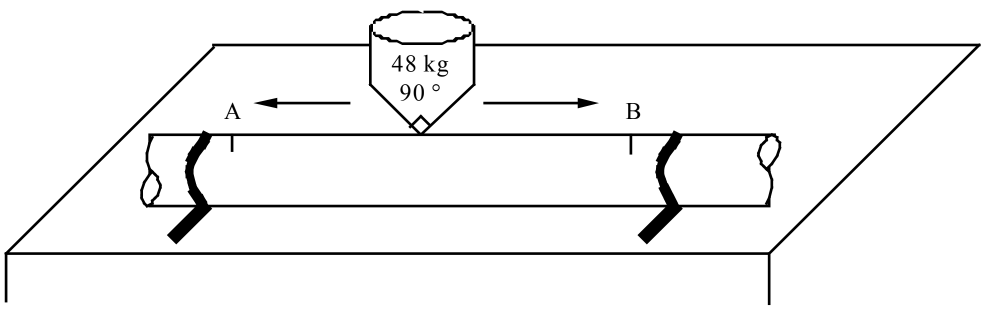


Figure 7: Test arrangement for the abrasion test

The characteristics of the test shall be:

- Distance between A and B: 50 cm ± 10 cm
- Speed of the conical piece between points A and B: 0,3 m/s with a tolerance of ± 15 %
- 4 motions to and fro of the conical piece

At the end of the test, it shall not be possible to see, with normal or corrected vision and without amplification, the metal screen under the over sheath between the A and B marks.

Case of SscD design
No test is needed due to the specific installation conditions (see part 2 paragraph 3.3.2).

2.1.1.3 Sidewall pressure test

The current installation practice allows for a sidewall bearing pressure test, according to the table below, when the over sheath materials are ST2 or ST7 as mentioned in 2.1.1.2.

The test shall be carried out if the designed value of sidewall pressure during installation is expected to be higher than the one indicated in Table 2, provided the cable has successfully passed the impact (2.1.1.1) and abrasion (2.1.1.2) tests (these tests govern the wall thickness of the oversheath).

Table 2: Maximum acceptable sidewall pressures

Design	CD/ST7	CD/ST7 + wires	SD/ST7	SscD/ST2
T/R (DaN/m)*	2500	1000	1000	750

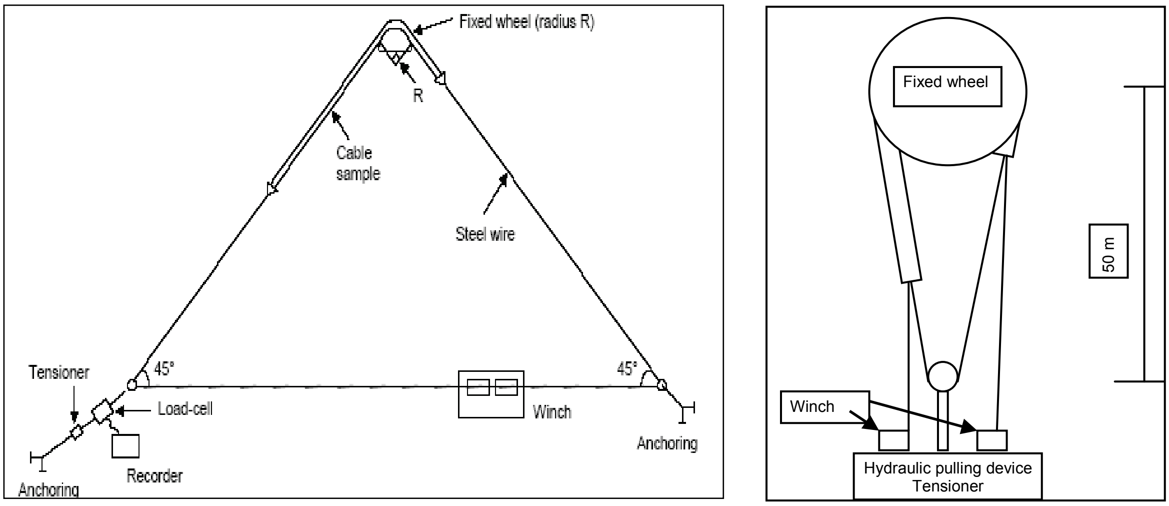
*T= tensile stress on the cable, R= Bending radius

In case of special cable design (i.e. where optical elements are integrated into the power cable structure), it is recommended to carry out the test even if the sidewall bearing pressure during installation does not exceed the above values in Table 2.

The test procedure:

The proposed test arrangement and procedure is according IEC TR 61901 [6], paragraph 5.2.

A cable sample 15 m in length should be tested using a test arrangement such as that shown in Figure 8 A.



A B

Figure 8: Sidewall pressure test arrangements

The cable should be subjected to one pass forward and one pass backward around a fixed wheel under the assigned sidewall pressure (T/R), calculated using the tension in the steel wire (T) and the wheel radius (R). The radius should not be greater than the radius used for the bending test (see IEC 60840 [3], 12.3.3). The cable should be in contact with the wheel for at least 90° during the test. Lubricant should be applied at the contact point on the wheel.

The test may be made by other means, for example by pulling a cable 180° around a fixed wheel (figure 8 B). A number of small diameter rollers (50 mm to 100 mm) can also be used.

The use of rollers may result in very high localised pressure. The amount of pressure depends on many parameters: diameter of the rollers, bending radius, distance between rollers, cable stiffness, etc. The method/rule to define the diameter of the rollers and the distance between the rollers has to be set according to the practice of the cable manufacturer and the information presented in CIGRE TB 194 [28].

Result - visual inspection:
A 1 m sample subjected to the sidewall pressure should be dissected and visually examined. Examination of the samples with normal or corrected vision without magnification should reveal no cracks or separation of the metal foil of laminated protective coverings or harmful damage to other parts of the cable.

2.1.1.4 Long term ageing of the adhesive bonds of the components of the laminated covering:

Temperature:
In close trefoil formation the actual sheath temperature in operation can reach 80 °C when the conductor temperature is 90 °C; so the recommended temperature for the long term ageing of the bonding is 80 ±3 °C[(1)].
The test has to be performed on the three cable designs.

Test conditions:

A 1 m sample bent in 2.2.1.1 shall be placed in a solution of 1 % NaCl, 1 % Na_2SO_4 with NaOH added to adjust a pH of 8,5 ± 0,5. The solution shall be maintained at (80 ± 3) °C during the test. The cable with both ends sealed shall be immersed at a depth of at least 0,5 m.
The cable sample shall be removed from the solution after 3000 h of immersion and shall comply with the following requirements.

Requirements:

The adhesion strength and peel strength of the metal foil shall be measured at room temperature in accordance with 2.3.1. The results should comply with the table 3 requirements.

A 1 m sample shall be dissected and visually examined. Examination of the sample with normal or corrected vision without magnification should reveal no cracks, no corrosion and no harmful damage to other parts of the cable.

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(1) As compared to 70 °C in case of the corrosion test of Electra 141.

2.1.1.5 Mechanical properties of the welding (case of CD design):

General :

The elongation at break of the welded metal should be checked as it indicates the quality of the welding process. This test has to be carried out in case of longitudinal welding as well as in case of transverse welding when two laminates are jointed together.

Test arrangement :

The test arrangement is described figure 9. The test samples are prepared by either by decreasing the sheath thickness down to 0,5 mm, so the metal surface is not altered and the mechanical contribution of the sheath remaining thickness is negligible as compared to the metal laminate, or taking the samples just before extrusion of plastic sheath. The edges of the samples must be smoothed or LASER cut to avoid initiation of cracks from a cutting defect.

The test shall be performed at ambient temperature. The distance between grips is about 100mm; the sample width is between 10mm and 50mm. The separation rate of the grips of the tensile testing machine shall be 20 mm/min. The test is performed on 5 samples including the welded zone and on 5 samples not including a welded zone. The break should be out of the welded zone.

Two marks are drawn on the sample, one on each side of the welding. Reference marks have to be taken at not less than 10 mm from the welding, at each side, as shown in Fig. 9.

Results
The median values of tensile strength and elongation at break are calculated.

The median elongation at break and the median tensile strength of the samples with the welding should be respectively more than 70% and 80% of that of the non welded samples, measured between the two marks.

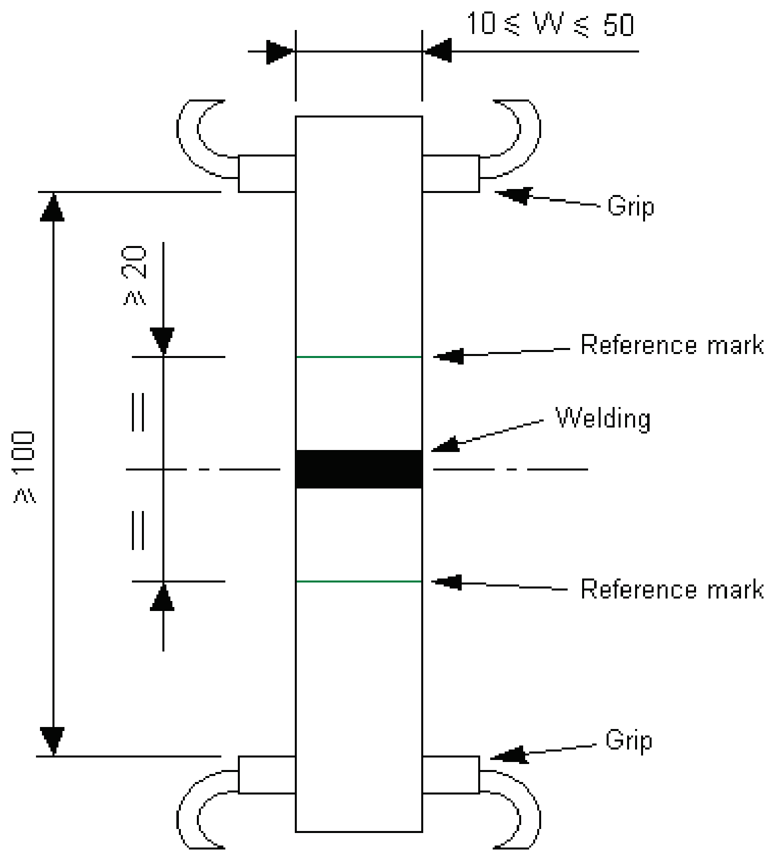


Figure 9: Test arrangement for the measurement of the mechanical properties of the welding, dimensions in mm.

2.1.2 Tests on cable system

2.1.2.1 Short circuit test

In the case of a single phase short circuit, the current can flow through the metal screen, the metal screen / accessory connection, the ground lead of the joint or the termination.

The following test has been designed to test these components and connections in a simple way. It simultaneously tests the cable, the connection to accessories, the accessories, the grounding connection, and the grounding cables.

The electric parameters of this test have been chosen to be such that the test capabilities are available in many laboratories at an acceptable cost.

If the requested short current is higher than 50 kA and no suitable equipment is available, the applied current may be minimum 50 kA and the time longer to reach the calculated temperature.

This test supersedes the short circuit test on cable previously recommended by ELECTRA 141 [1].

Sample:

The length of the sample of cable is about 5 m with a joint and/or the termination connection. There is at least 2 m of cable on each side of the joint and earth connection and ground connection.

If two different metal foils are connected together inside the cable length during manufacturing, such a metal foil connection should be included in the test.

Test arrangement

In figure 10, the short circuit test arrangement is given for three kinds of joints:

- Straight through joint
- Joint with earth connection
- Sectionalised joint

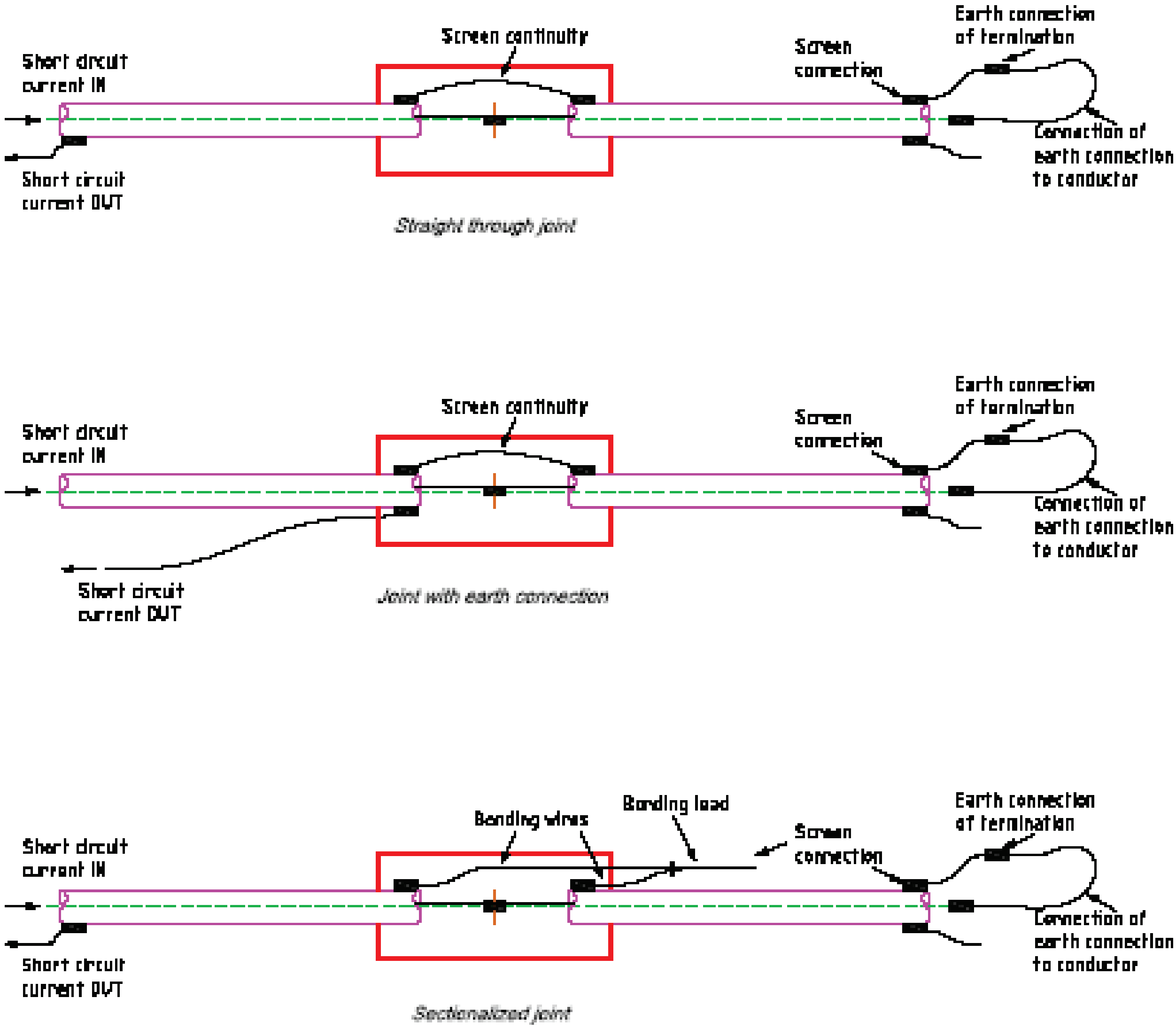


Figure 10: Short circuit test arrangement for three kinds of joints

<u>Rating:</u>

The short circuit rating has to be determined by calculation.
The maximum short circuit duration is 5 s.
Asymmetry is free.

Calculation of the short circuit rating for design CD:

Calculations shall be performed following IEC 60949 [4]:

- For the calculation of the non adiabatic factor for over sheaths, the formula of paragraph 6.1 shall be taken.
- The factor F (factor to account for imperfect thermal contact) is 0.9.
- The maximum temperature during short circuit considered in IEC 61443 [5] is 200 °C (ST2) or 180 °C (ST7). However, higher temperatures have been specified in national standards or manufacturer's specifications.
- According to the operation and tests feed back, a temperature of 250 °C is acceptable. A higher temperature is not recommended.

Short circuit rating for design SD or CD + wires:

Calculations shall be performed following IEC 60949 [4]:

- The current share between the two different metal screen components is equal to the inverse ratio of their respective resistances.
- For the calculation of the non adiabatic factor for over sheaths, the formula of paragraph 6.1 shall be taken.
- The factor F (factor to account for imperfect thermal contact) is 0.9 for the laminated covering and 0.7 for the screen wires.
- The short circuit temperature considered in IEC 61443 [5] is 200 °C (ST2) or 180 °C (ST7) for the laminated covering. The most demanding limit shall be adopted. However, depending on the specific design, national standards or manufacturer's specifications might supersede these values.
- According to the operation and tests [31] feed back, a temperature of 250 °C at the screen wires is acceptable.

Note : when there is a layer thermally separating the screen wires from other materials in the cable, a temperature of 350°C is allowed

Short circuit rating for design SscD:

Calculations shall be performed following IEC 60949 [4]:

- The current share between the two different metal screen components is equal to the inverse ratio of their respective resistances.
- For the calculation of the non adiabatic factor for over sheaths the formula of the paragraph 6.1 shall be taken.
- The factor F (factor to account for imperfect thermal contact) is 0.9 for the laminate and 0.7 for the screen wires.
- The short circuit temperature considered in IEC 61443 [5] is 200 °C for the laminated covering. National rules or manufacturer's recommendations might supersede these values.

Test:

Five short circuits shall be applied successively to the assembly:

- Before the short circuit test, the cable conductor shall be heated and stabilised for at least 2 h at a temperature 90 to 95 °C.
- The short circuits are separated by an interval of time long enough to cool down the cable screen within 5 K of its initial temperature.

Result - visual examination and integrity of the laminate:

A 1 m cable sample including the metal foil connection if any, should be dissected and visually examined. Examination of the samples with normal or corrected vision without magnification should reveal no cracks or separation of the metal foil of laminated protective coverings or damage to other parts of the cable.
There shall be no sign of harmful deterioration of the cable / joint screen connection, neither at the cross bonding leads nor at the grounding connections.

The adhesion strength and peel strength should be according to 2.3.1 table 3.

Extension of qualification rule:

The cable system design will be qualified for other cross sections and voltages provided that the calculated temperature at the end of the short circuit and the maximum current, if lower than 50 kA, are both lower or equal to the one tested.

2.1.2.2 Corrosion at the accessories

This test was added as corrosion at accessories was a concern during the world survey. It has to be performed on the three cable designs.

The test has to be performed with the same equipment as the one defined in IEC 62067 [7b] or 60840 [3b], appendix G: "Test of outer protection for buried joint".

The test is carried out using natural or tap water. Deionised water is not allowed.

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. This may be achieved by using a header tank connected to a sealed-off vessel containing the test assembly.

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 diluting the water with water of higher or lower temperature. The minimum duration of each heating cycle shall be 12 hours 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.

Result – examination:
There should be no sign of corrosion of any metal part of the accessory: connection of the cable to the accessory, accessory screen, accessory bonding leads.

2.1.2.3 Thermal cycle test and Thermo-mechanical test

The thermal cycles and thermo-mechanical tests are addressed, if needed, in the relevant cable standards IEC 60840 [3] and IEC 62067 [7] and cover all the development requirements of advanced laminated coverings

2.2 Type tests

2.2.1 Tests on cables

2.2.1.1 Bending test

This test is a lead test for various tests, that is:

- long term ageing of the adhesive bonds of the components of the laminated covering
- electric tests

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:

- 20(D+d) for CD
- 25(D+d) for SD and CD + wires
- 10Ds for SscD

Where [2]
D is the nominal overall diameter of the cable,
d is the nominal diameter of the conductor.
Ds is the nominal diameter of the shielding layer

Result:
One sample of 3m length shall be examined. There shall be no delaminating, folding of the metal foil, radial buckling or crossing of the screen wires.
Adhesion and peel tests shall comply with the requirements of table 3 of paragraph 2.3.1.
In the case of SccD, no delamination shall occur.

2.2.2 Tests on cable system:

2.2.2.1 Type test following IEC standard:

The tests and sequence of tests are following the relevant IEC standard (IEC 60840 [3] or 62067 [7]) but the bending test is replaced by the one defined in 2.2.1.1.

The examination at the end of the type test should include a piece of cable, to show that there is no delaminating, folding of the metal foil, radial buckling or crossing of the screen wires.

[2] This definition is the same as the one in paragraph 6 of IEC 62067

2.3 Sample test

2.3.1 Adhesion and peel strength of the laminated metal foil

In case of the CD design the concern is that delaminating could damage the metal component and alter the electric functionality of the screen; therefore, the adhesion strength and peel strength of the laminated covering must be the highest.

In case of the SD design there is not a concern that delaminating will alter the electric functionality of the screen. The cable can be operated with short circuit capability provided by the presence of the screen wires. However, the adhesion strength and peel strength should be high enough to preserve the laminate from folding and buckling.

In case of the design SscD, the test cannot be performed because the metal foil is so thin that it breaks during the adhesion or peeling strength test.

Table 3: Minimum acceptable adhesion or peel strength forces

	Type of screen					
Adhesion or Peel Strength	**CD**		**SD**		**SscD**	
N/mm	Copper	1.5	Copper	1.0	Lead	NA*
N/mm	Alu	1.5	Alu	1.0	Alu	NA*
N/mm	Overlap	1.5	Overlap	1.0	Overlap	NA*

*test cannot be performed

Test: Adhesion strength

The test specimen shall be taken from the cable covering where the metal foil adheres 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 11.

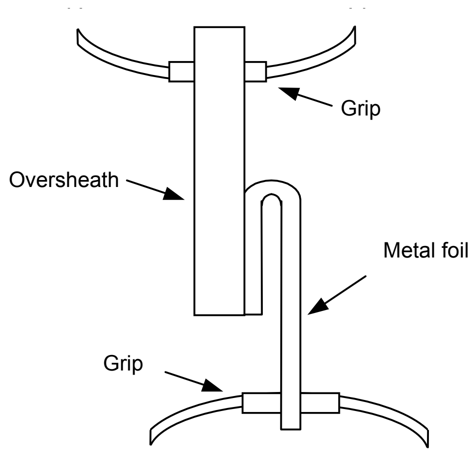


Figure 11: Adhesion of metal foil

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.

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

Test: 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 12.

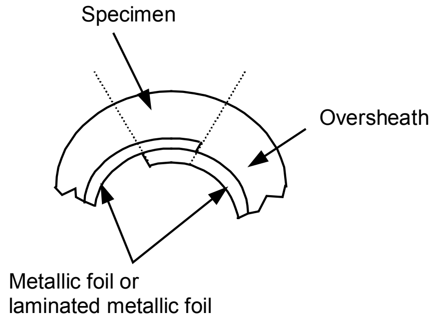


Figure 12 – Example of overlapped metal foil

The test shall be conducted in the same manner as described for the Adhesion strength. The arrangement of the test specimen is shown in Figure 13.

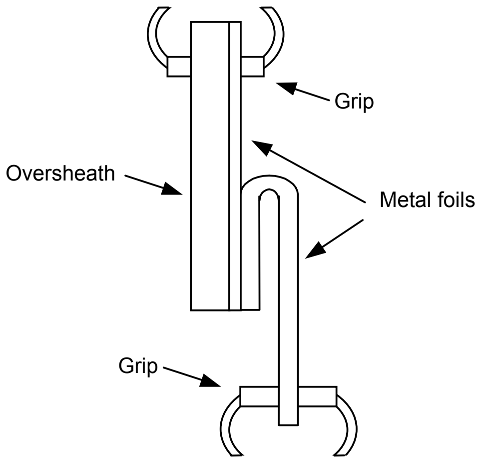


Figure 13 – Peel strength of overlapped metal foil

2.3.2 Electrical properties and dimension:

The DC resistance of the screen and the dimensions of the metal part of the laminated have to be checked in accordance with the relevant standards.

2.4 Routine tests

There is no specific routine test to be associated with advanced laminated coverings. The relevant standard is to be applied.

2.5 After installation tests

There is no specific after installation test to apply. The relevant standard is to be applied.

2.6 *Tests from earlier recommendation no more considered*

2.6.1 Tests on cables:

2.6.1.1 Fatigue (2.1.2 from Electra 141):

Aluminium based laminated coverings:
There has been a long experience with corrugated aluminium screen Self Contained Oil Filled cables. This design has given a satisfactory fatigue result for more than 30 years, ref JICABLE 07 B-44 [60].
It well known that the laminate design (bonding of layers together) improves the fatigue properties of the metal foil.
Experiments have been carried out on cables with advanced laminated covering of SccD design (JICABLE 03 A-1-5 [45]). They confirmed that no issue about fatigue was to be feared for conventional laying distances (< 13km), and state of the art installation design.
No fatigue issue was reported from the world survey.

The successful completion of a type test (including the examination of the cable after the bending test and at the end of the type test, looking to delaminating, folding of the metal foil and radial buckling or crossing of the screen wires) should assess the quality of the cable design and consequently the absence of fatigue issue during installation and operation.

Other metals:
Copper is known to be as good as aluminium. For other metals, an investigation should be performed.

2.6.1.2 Radial moisture penetration (1.1 from Electra 141):

This test was "under development" in Electra 141 [1].

A simple test, adapted from ASTM E 96 by Tokyo Electric Power Company has been included in some specification and performed in France, Japan, Korea, and Taiwan.
Results showed that there is no detectable radial penetration of water in the case of metal laminated coverings. Ref JICABLE 07 C5111 [59]
.

A high sensitivity test was reported at "Power Technology International 1993 [61] **»:**
A piece of 24 kV hollow cable with overlapped aluminium foil bonded to over-sheath was introduced in a carefully closed steel chamber filled at 50 °C with water containing hydrogen isotope tritium. Exposed length was 246 mm. Water permeates into the centre of the cable and is collected in a vial. The quantity of tritium is detected by liquid scintillation analysis, which is 10^9 times more sensitive compared to classical method.
The measured permeation rate of the laminated covering, SD type, was around 1,5 ng $m^{-2} s^{-1}$, i.e.1000 times less than what permeates through a 2 mm thick PE sheath without metal barrier.

The long term ageing test of 2.1.1.4 validates the cable design in reference to the moisture penetration.

2.6.1.3 Spike test (6.3.3 and appendix E from BS 7970):

This test proves that the cable can transit the short circuit current during the required time in case of internal failure.

It has been prescribed in British Standard 7970 [12].

Results have been published in Jicable 1999 A2-6 [37]. No problem was reported.

The WG is not aware of any problem in operation.

This costly test has then been removed from the recommendation.

2.6.1.4 Thermal cycle test (2.1.2 from Electra 141):

In ELECTRA 141 [1], 100 cycles were to be performed, then the cable examined.

Two alterations could happen:

- The fatigue, that has proven to be not an issue see 2.6.1.1.
- The decrease of the peeling strength, which could happen in case of bad design, and is checked in 2.1.1.4.

Moreover, a system test, as recommended in CIGRE brochure TB 303 [29], is included in the IEC 62067 [7a and b], and is likely to be included in IEC 60840 [3b],. This test requires 180 load cycles. It will give credibility to the system design.

Note : In the case there is not a system test in IEC 60840 (cond screen stress < 8kV/mm or ins. screen stress < 4kV/mm), the sheath shrinkage could be measured over 80 load cycles according to CIGRE brochure 303.

2.6.1.5 Screen contact resistance (1.1 from Electra 141):

The issue was the contact between the copper wires and the aluminium foil.
This test was under development in ELECTRA 141 [1]
No specific test has been proposed since then.

The problem has been solved through the system design.

2.6.2 Tests on cable system

There was no test on cable system in ELECTRA 141 [1].

2.7 Conclusion:

The recommendation for tests has been written taking into account:

- The cable designs as pointed out by the world survey
- The tests of ELECTRA 141 [1] that are considered as relevant to evaluate the quality of the system by the cable manufacturers.
- The cable system design.
- The questions raised by the operation feed back. New tests are proposed when needed.

Cable systems validated in reference to the recommendation should be sound.

PART 2: GUIDE TO USE

3 Guide to use:

The Guide to use section is dealing with the specificities of cables with laminated metallic coverings. For a general guidance

- on the selection of high voltage cables, refer to IEC 60183 [2],
- on laying practices, refer to CIGRE TB 194, (2001) [28].

3.1 Purchasing:

The cables with laminated coverings are lighter and smaller in diameter than the ones with extruded screen.
A longer length between joints can be achieved.
Depending on the circuit characteristics the most adequate design (CD, SD or SscD) is to be selected.

3.2 Storage:

Cables with aluminium laminated coverings are sensitive to moisture ingress. A special attention, as for other high voltage cables, must be paid to the protection of the cable ends during storage and installation works.

3.3 Laying conditions:

3.3.1 Sidewall pressure:

When the cables are pulled from one end of the span, the sidewall pressure should be lower than the one of the table in 2.1.1.3, depending on the cable design. If not, the acceptable level should be measured.

3.3.2 Direct burying:

Design SscD should be avoided.

The direct burial of cables is described in the CIGRE brochure TB 194 [28], paragraph 3.2.2.
There is no special limitation regarding the use of design SD or CD.
A special attention must be paid to the homogeneity of the soil properties, as for any directly buried HV link.

3.3.3 Ducts and Tunnels, galleries and shafts:

All designs can be used.
A semi-conductive layer over the sheath is highly recommended to be able to perform the after installation sheath integrity test (DC test between screen and outer semi-conductive layer).

3.4 Electrical design vs. Circulation current:

3.4.1 Connection of copper wires with the laminate:

The good electrical contact between the copper wires and the metal foil should be effective during the complete life of the cable.
It can be achieved either at accessories, either by design along the cable length.

In the case of SD design, the contact with the metal foil may be distributed over the full length of the cable depending on the cable detailed design.

The WG recommends connecting the metal foil to the accessories metal screen whatever the particular realisation of the SD design (so called open and closed design).

3.4.2 Long spans:

When there are long spans with circulating currents, a particular attention has to be paid to the endurance of the screen contact at the accessories (see 3.5).

Pressed contacts have led to negative feedback in this condition, while their performance is satisfactory when single point grounding is used.

For voltages equal or higher than 150kV, due the expected high short circuit current and time, pressed contacts are not recommended whatever the circuit electrical design.

3.5 Installation:

3.5.1 Stiffness of the cables

No reported problem regarding the Stiffness of any of the designs DC, SD, SscD. The bending diameters are lower than the ones recommended for the extruded jackets.

3.5.2 Designs to be avoided

3.5.2.1 Cable construction

When a design with two metal elements, e.g. Cu wire screen and Al foil is used, there must be a good electrical contact between the Cu wires and the Al foil. A semi-conductive tape between Cu wires and Al foil is not good enough because in case of short circuit, the short circuit current will flow only over the Cu wire screen and will induce a voltage difference between Cu wire and Al foil. Depending on the cable length the voltage can be high enough to create a breakdown through the semi-conductive tape. The resulting electric arc will damage the outer semi-conductor of the cable core and destroy the cable (see Elektrizitätswirtschaft, Jg. 89 (1990), Heft 11 [62]). For this design it is necessary to have either:

1. an electrical connection between Cu wires and Al foil at each end of each cable section (i.e. at joints and terminations).
2. direct electrical contact between Cu wires and the Al foil in the cable: no tape, partly no tape or special tape e.g. Cu woven tape etc, (see Elektrizitätswirtschaft, Heft 7/92, Seiten 353 – 356 [63]).

3.5.2.2 Screen connection at the accessories

Spring rolls can give rise to hot spots in connection zone at high currents. They should therefore be avoided when the designed screen current is above 200 A. Welding gives no hot spots in connections between Al foils and screen strands and should be used. Screen wires should be spread out, as when bunched together, they lead to higher temperatures.

3.5.2.3 Direct burying of SscD

There is no experience of direct burying of SscD. In case direct burying of this design is considered, an evaluation similar to the ones performed for design SD will be performed.

3.6 Repairing:

The laminated coverings are very robust (see requirements of paragraph 2.1.1.1 impact test, 2.1.1.2 abrasion test, 2.1.1.3 sidewall pressure test) and a repairing work is seldom needed when state of the art laying techniques are used.

If there is damage to the outer sheath only, the repair works must rebuild all laminated layers i.e. glue and oversheath.

If there is a puncture in the metal foil:

- When the cable is still dry (for instance the accident happens during the installation), it can be repaired and all layers have to be rebuilt. This is a delicate work that needs training and qualification of the operator. The functionality of the laminated covering (metal and plastic layers) has to be checked during the repair works.

- When there is moisture in the cable (for instance the accident happen during the operation and the cable is directly buried), the cable has to be changed over the length submitted to moisture ingress.

The after installation test of the sheath should be performed after the repair.

3.7 Maintenance:

No special action as compared to extruded metal sheath is required. A periodic test of the sheath integrity is to be performed once a year as recommended by contribution B1 PS1 Q6 from CIGRE 2004 by K. Bjorlow-Larsen [64].

PART 3: OPERATION FEED BACK

4 The experience with cables with laminated coverings:

4.1 World survey:

In addition to the 9 countries contributing to the WG, The group has prepared a questionnaire to assess the feed back of the use of the laminated coverings:

Question 1: Identification of the utility
Question 2: Installed circuit length by voltage range of designs D1, D2, D3 and traditional extruded cable designs.
Question 3: Trends in volume in the different designs by voltage range
Question 4: Issues regarding cable quality
Question 5: Issues regarding installation and accessories

This questionnaire has been sent to all CIGRE B1 members, they have handed over to their respective utilities.

We got answer from a total of 13 countries

There are 3 times more SD than CD circuit lengths, mainly due to the large experience of Germany, and larger than that of SscD. The trend is to increase the number of circuits with laminated coverings as compared to other designs.

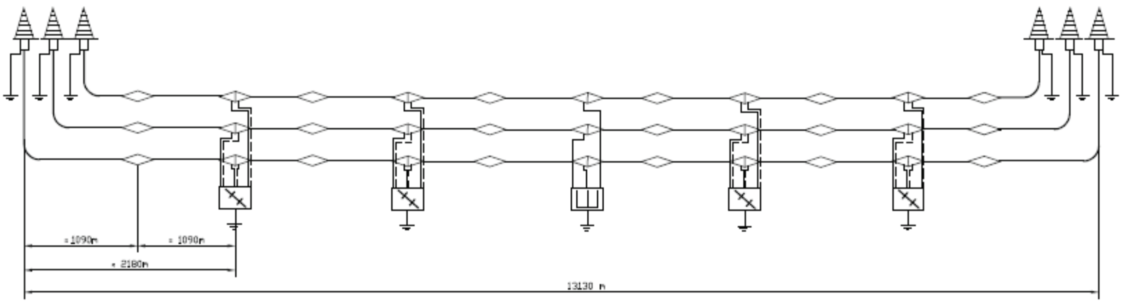
4.1.1 Use of cables with advanced laminated coverings:

Installation:
The survey showed that designs CD and SD are installed in all conditions: tunnels, ducts, surface through, directly buried.

4.1.1.1 Examples of CD design installation:

4.1.1.1.1 Elancourt France RTE 225kV 2000mm² aluminium:

Description of the route:



Transmitted power: 530 MVA

The route is 11.7km long and includes 7 horizontal drillings.

Accessories:

- 6 outdoor terminations
- 18 straight joints
- 15 cross bonding joints (12 with SVL and 3 directly grounded)

Pulling of the cables

Installation in ducts

Controlled backfill (weak concrete)

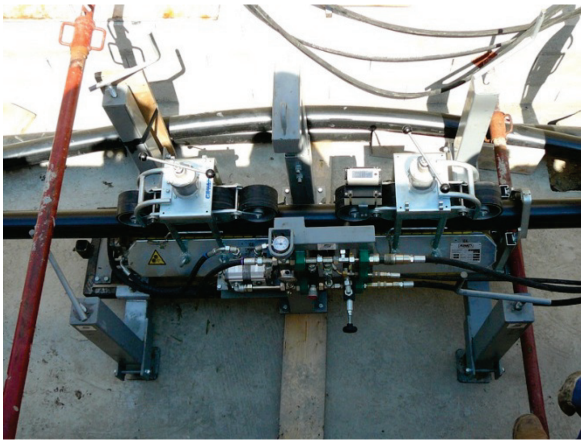
Warning lattice

4.1.1.1.2 Nanterre Nourotte RTE 225kV 1600mm² copper:

Transmitted power: 470 MVA

The route is 21km long and includes 3 horizontal drillings.

60 joints and 6 outdoor terminations

 Cable pulling	 Pushing caterpillar (push and pull laying)

***4.1.1.1.3** Turbigo-Rho 2000mm² copper 400kV Italy:*

Technical details

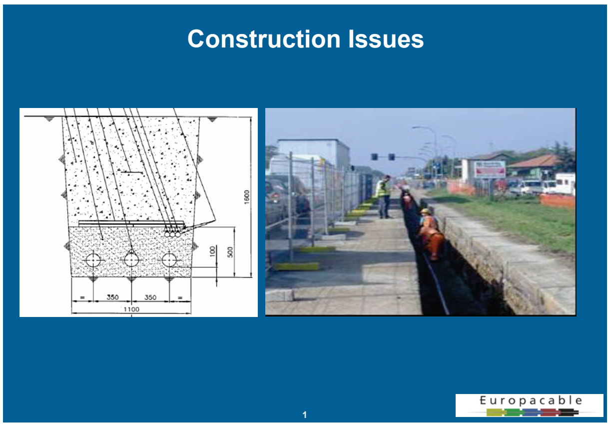
Transmitted power: 1050 MVA per circuit.

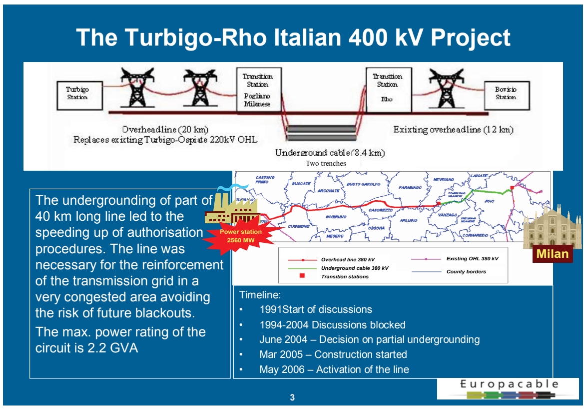
In order to make crossing of some villages possible and to obtain quick permission in an area having important natural reserves, the under grounding of the last 8.4 km of the total 28 km long line was necessary. To fulfil the thermal power rating of the overhead line, it was necessary to install two underground 380 kV cables per phase having a 2000 mm² copper conductor.

The two cable circuits were directly buried in trench at a depth of 1.5 m, one circuit per trench with cables laid flat spaced 350 mm and a distance between trenches of 6 m, to provide a continuous rating of each circuit of 1600 A. Each circuit was composed of 12 cable spans and 4 cross bonding sections.

Outdoor terminations were installed in the overhead/underground transition compound. Continuous temperature monitoring with a DTS system and continuous partial discharge monitoring at joints was also applied.

Special magnetic field shielding has been provided where necessary for some part of the route in order to comply with Italian legal requirements.





4.1.1.1.4 Madrid Airport "Barajas" 400 kV 2500 mm² copper:

Madrid Barajas airport has been re-developed in 2003 with the construction of two new runways and terminal and satellite areas. Intrusion of a nearby double circuit 400 kV overhead line on airport operations and possible radio interference with automatic navigation systems has led to under-grounding of part of the line. The underground cables are laid in a 12.8 km long prefabricated tunnel. Cable and GIL solutions were compared and XLPE cable selected as the most competitive solution. The overhead line rating per circuit (1390 MVA summer / 1720 MVA winter) can be met using one cable per phase equipped with forced cooling. The two cable circuits are in the same tunnel.

Thermal requirements

The high rating of the circuits requires a 2500 mm2 copper conductor and a forced cooling system, which includes 5 fan stations, distributed temperature sensing (DTS) to measure circuit and tunnel temperatures and a real-time thermal rating (RTTR) system that commands and integrates all subsystems. The forced cooling system is designed for a summer air intake temperature of 35 ºC, maximum tunnel air temperature of 50 ºC and maximum air speed of 5 m/s. The limiting parameter is the temperature of the 400 kV cable joints. The tunnel temperatures (air at the top of the tunnel and hottest cable) are continuously monitored by the fibre optic DTS system. The RTTR interfaces with the DTS and controls the cooling fan speeds. Circuit parameters, such as load, temperatures, surrounding environmental conditions, etc. are continuously monitored by the RTTR system to calculate in real time the maximum loads (steady state and short term overload) that could safely be applied to the circuits. Cable sheath bonding consists of a combination of 5 x 3 cross-bonded sections 810 m long and two single point bonded lengths at the ends (300 m at one end and 400 m at the other). This configuration ensured the manufacturing of 90 drums of identical length and eventual route changes adopted during civil works construction have been absorbed by these cable ends.

Installation details

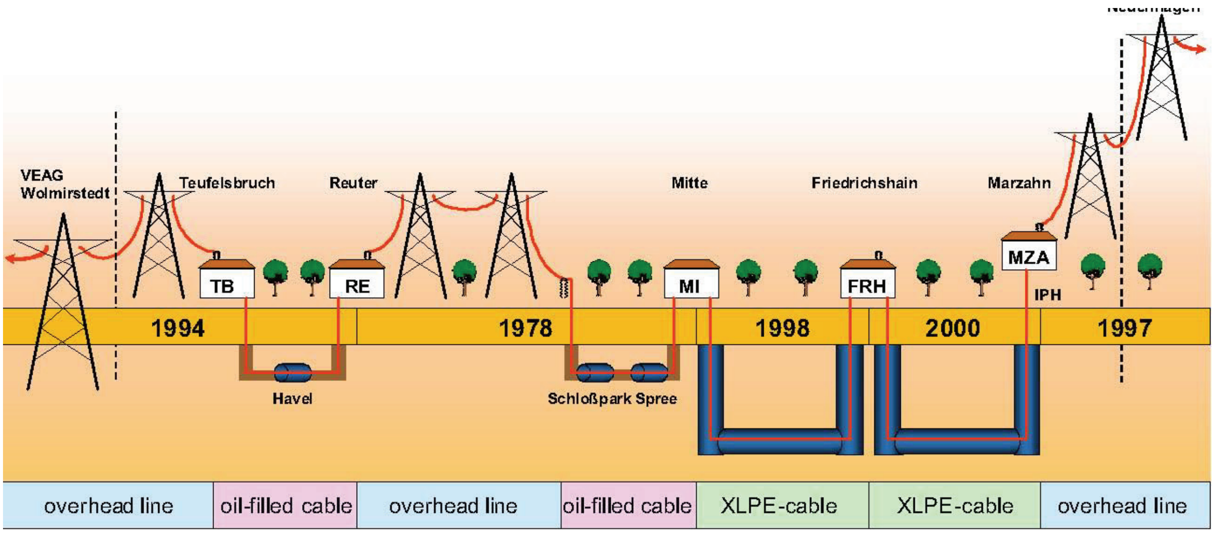
The technical solution that meets project electrical and thermal requirements consists of a 2 m x 2.25 m tunnel buried at an average depth of 2 m. The cable circuits, supplied by two manufacturers, are laid in a vertical configuration, one at each tunnel side with a phase separation of 0.5 m. Due to high mechanical stresses present in the cables with load variations, a flexible cable laying (snaking system) was chosen to minimize longitudinal and radial stresses on cable and accessories. Cables are fixed on metallic supports fixed to tunnel walls every 6 m. The cables rest on saddles and brackets and are tied together by means of three phase spacers at the 3 m intermediate point between two supports. Spacers are used to reduce electro dynamic forces generated during a short circuit. Sag applied to cables after laying is equal to 0.25 m. All metallic supports used for cable laying have been designed to resist maximum electro dynamic forces during a short circuit.

4.1.1.2 Examples of SD design installation:

4.1.1.2.1 Diagonal BEWAG Berlin Germany 400kV 1600mm² copper:

In 1994, Bewag's insular existence came to an end when it was connected to the supra-regional interconnected grid (VEAG Wolmirstedt). Part of this connection consists of a new 380 kV overhead power transmission line and a new 380 kV oil-filled cable system which was used to provide an inner city link-up with the Reuter substation in Spandau district. A 380 kV connection (overhead line and oil-filled cable) between the Reuter and Mitte substations, which had come into operation as early as 1978, enabled power to be supplied from the grid to the city centre of Berlin.

The entire 380 kV diagonal link



The extension of the 380 kV cable network to connect Mitte and Friedrichshain substations was originally to be carried out by analogy with conventional cut-and-cover methods, as had been the case with the 380 kV grid link-up. The envisaged extension route ran mostly along public highways and cuts across various major construction sites (Potsdamer Platz, new government precinct, Friedrichstraße) and urban development areas at several points. For all these reasons a feasibility study was carried out to establish whether it would be possible to have the planned 380 kV cable system installed in a tunnel linking the two substations. The position of the tunnel was then determined on the basis of geological reports, existing test drills and realized depth drills. The tunnel runs at a depth of approx. 25 to 30 metres beneath the land surface. Its outside diameter is 3.6 metres and the inside width 3 metres. The tunnel is approx. 6.3 km long. The run is approx. 1.1 km shorter than it would have been if conventional construction methods had been used.

380 kV connection between Friedrichshain and Marzahn substations

The fourth section of the 380 kV diagonal connection between the 380 kV substation in Friedrichshain and the new substation in Marzahn stretches over a distance of approx. 5.2 km.

The new connection, which completed the diagonal link-up, went into operation in autumn of the year 2000.

4.1.2 Cable designs and market share

Table 4 is limited to the answers received and it shows that the feedback is significant..

Table 4: summary of installed lengths of CD, SD and SscD design in the countries that gave an answer to the questionnaire

Voltage Range	**XLPE cable with metal laminated covering**			**XLPE cables with extruded metal screens**
U (kV)	installed circuit (km)			installed circuit (km)
	Combined Design	Separate Design	Separate SC Design	E.g. corrugated metal sheaths, lead sheaths
	IT – IR – Be – AU – MEX – NL – NZ – NO – SE – CN - FR	IT – IR – Be – DE - AU – DK – MEX – NL – NZ – NO – SE – CN – FR – USA	JP	IT - IR - Be - AU - JP DK – MEX – NL – NZ – NO – SE – CN - FR
50 - 109	355	92	6178	8629
110 – 219	286	2573	571	790
220 – 314	109	38	27	1881
315 - 500	33	48	0	167
TOTAL	**783**	**2660**	**6776**	**11467**

The global trend is an increase of the market share of the laminated coverings, and a decrease of traditional screens extruded lead, and corrugated metal screens.

Special cases:
Germany, all cables with metal laminated covering are of SD design; this adds 400 km a year of this type of cable.
In France, all cables are of CD design; this adds 200 km a year of this type of cable.

4.1.3 Questions and feed back received from utilities

4.1.3.1 Experience in service

All types (CD + SD + SscD):

Nothing to report

4.1.3.2 Question to CD Design:

Q: Risks of damage to insulation when soldering or welding during installation of the Al tube.
A: When it is performed by qualified fitters, there is no issue. No reported problem up to now

Q: Detection of seam defects.
A: The welding seam is monitored during the manufacturing process, the monitoring must be recorded. The repair of defects in the manufacturing process is part of the quality procedures of the supplier.

Q: Sealing against moisture at joints
A: this point is addressed with a specific test in section 2.1.2.2

Q: Occurrence of wrinkles and creases of laminates because of a bad adhesion in the overlap of the laminate, and bad quality of glue.
A: The quality procedures of the supplier, from the purchasing of the materials, through the production process, to the final tests, should consider these points. An adhesion and peel strength of the laminate has been introduced as sample test 2.3.1.

4.1.3.3 Design SD and CD:

Q: Corrosion of aluminium foil
A: In spite of the extensive use of the SD design since the 80's in Germany and the CD design since the 90's in France, no corrosion problem has been reported up to now.

In Germany, Sweden, Austria, Denmark, the corrosion, if any, of the aluminium foil is not considered to be an issue as it does not alter the electrical functionalities of the cable.

A good bonding, as checked in 2.1.1.4 and 2.3.1, guarantees a corrosion free operation.

4.1.3.4 Design SD and SscD:

Q: Sliding at the overlap
A: When the cable has successfully passed the "Long term ageing of the adhesive bonds of the components of the laminated covering" ref to paragraph 2.1.1.4, this phenomenon does not occur.

Q: Fatigue performance
A: this is not reported as an issue and is addressed at paragraph 2.6.1.1 of this document

Q: Proving continuity of foil in installed cable.
A: This cannot be measured after installation in a proper way. During the manufacturing process, if there is a metal foil break, the production is immediately stopped. The cable length has to be re-covered. When the design has been properly checked, there is no break during the installation phase, as reported by the world survey.

Q: Mechanical robustness
A: This is addressed by the bending, impact, abrasion and sidewall pressure test see 2.2.1.1, 2.1.1.1, 2.1.1.2, 2.1.1.3.

Q: Interruption of metal barrier at the transition from cable to joint.
A: A similar design as the one of the overlap of the metal foil along the cable is used to provide the continuity of the moisture barrier properties at the joint and cable interface.

Q: Interruption of metal barrier at the transition from cable to termination.
A: Terminations are not in submersed areas. A moisture continuity of the properties is not compulsory, but the sealing against moisture at the end of the metal foil has to be included in the termination design.

Q: Necessity to get **adaptation joint** between traditional cables with extruded screen and cables with a laminated covering
A: Adaptation joints are proposed by manufacturers. The way to qualify them is out of the scope of the WG B1.25.

4.1.3.5 All types (CD + SD + SscD):

Q: Repairing of the laminate: Twice, during installation, a heavy tool fell on the cable and damaged the outer sheath and then the Al screen. After survey, RTE changed parts of the cable.
A: Repairing of the laminate has been addressed in 3.6
The abrasion test of 2.1.1.2 and impact test of 2.1.1.1 make the cable robust enough for a normal installation practice.
The repairing of the metal laminate has been addressed in the guide to use section 3.6

Q: Are large bending radii necessary?
A: The bending radii as prescribed in 2.2.1.1 are equal or less than the one prescribed for extruded metal screen designs.

A.1. Functional analysis

Functional analysis of the screen and outer protection of accessories to cables with laminated coverings:

A detailed functional analysis can be found in TB 303 [29], ANNEX 5.4 pp 72 & 73 for the joint and 78 & 79 for the termination

Key properties of the metal covering:

	Function	Specification / threat	Comment
Metal	1 **Electrical function**	-a. Transfers currents circulating in cable screen, transfers short circuit current. -b. Current sharing between double screens if present	a. Currents in the screen may be important and the ability of the screen connection not to overheat during cycling should be checked (not in cycling tests in IEC)
	2 **Mechanical properties**	-a. No hot spot at connection -b. No harmful deformation of cable or joint insulation -c. No cracking near the connection	Cracking may need more than 180 cycles to appear (180 cycles: long term test following IEC 62067 ed1). Severity depends largely on the installation environment and conditions.
	3 **Chemical properties**	-a. Compatibility with cable and joint materials	
	4 **Screen disconnection (for cross-bonding)**	-a. Withstands dielectric transients	
	5 **Water tightness**	-a. Avoid water ingress to the insulation	
Outer protection	1 **Electrical function**	-a. Isolation of joint from earth -b. No degradation of dielectric function with ageing and during short circuit	
	2 **Thermal-Mechanical function**	-a. Mechanical protection of joint	
	3 **Water tightness**	-a. Avoid water ingress into the cable	
	4 **Chemical properties**	-a. Compatibility with inside material, resistance against soil aggression (if cable installed in ground) or other surroundings	
	5 **Interface with cable over-sheath**	-a. Possible shrinkage of cable over-sheath and/or shrinkage of joint outer protection to be taken into consideration when designing the outer protection	This effect may be not visible during a short period
Cable system	1 **Overall properties**	-a. No degradation because of interactions between all components and of components themselves -b. No water penetration before and after heat cycling into the cable system	

Table 4.1.3.1 Functional Analysis of a High Voltage Cable and cable components
Abbreviations: Routine… R, Sample test… S, Type test….T, Development…. D, Pre-Qualification…. PQ

Here after the part related to screen functions and the parts below and above. It is an update of the TB 303 [29] table.
IEC 60840 and IEC 62067 are under revision and will be published in a near future.The paragraph numbers will be harmonised between the two specifications. In this brochure the paragraphs are taken from the draft documents of IEC 60840 and 62067

Cable's component	**Function or Property**	**Specification/Threat**	**Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§**	**Comments**
Layer over Semicon	**1 Electrical properties**	-a. Low resistivity to avoid PD at interface with screen	-a. PD measurement (**R: §9.2,** and **T: §12.4.4**)	
	2 Thermal-mechanical properties	-a. Resistance to mechanical bending during manufacturing and installation - b. Prevent deformation of the semicon and the insulation… -c. Water-blocking tapes possibly avoid the longitudinal water penetration (if required)	-a. Bending test before type test (**T: §12.4.3**) Examination after completion of the type tests (T: §12.4.8) -b. 20 cycles (**T: § 12.4.6**) + PD test (**T: § 12.4.4**) +examination (**T : §12.4.8**) -c. Water penetration test (**T: §12.5.14**)	
	3 Chemical properties	-a. Compatibility with semi-con and screen -b. Stability of electrical resistivity after heat cycles	-a. Compatibility test. Ageing on complete cable (**T: §12.5.4**) -b. 20 cycles (**T: § 12.4.6**) + measurement of resistivity after ageing (**T: 12.4.9**)	

Cable's component	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
	4 **Interface with semi-con and metal screen**	-a. Compatibility test (see above) -b. Avoid deformation of insulation (see above)	-a. Ageing on complete cable (**T**) but no measurement on tape (see above) -b. 20 cycles (**T: §12.4.6**+ examination (**T: §12.4.8**)	
Metal Screen/ Sheath	**1** **Electrical properties**	-a. Satisfy the short-circuit conditions -b. Collects capacitive current and induced currents -c. Electrical connection when more than one metal screen is applied -d. Current sharing in two metal layer constructions -e. Good contact between metal screen/sheath and semicon layer below -f. Electrical continuity of the screen in case of welding between two adjacent foils in one cable length	-a. Calculation of cross section needed (following IEC 60949 and 61443) and (**D: TB § 2.1.2.1**) -b. Resistance measurement as for conductor (**S, T: §10.5**) and dimensions of the screen (**S: §10.7**) -b. Calculation of losses in screen (depending on installation conditions – see IEC 60287) -c. T: Heat cycling and temperature measurements **(D: TB § 2.1.2.1)** -d. Current sharing following conductivities. - e. PD test + cycles +PD (**T: 12.4**) -f.: Resistance measurement (**S: §10.5**)	d. Missing in IEC. CIGRE WGB1-03 has made a report TB 272 on this subject in 2005

Cable's component	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
	2 Mechanical properties	-a. Supports mechanical bending	-a. Bending test before type test (**T: §12.4.3** TB § **2.2.1.1**) -Examination after completion of the type tests (**T: §12.4.8**)	
		-b. Limited deformation of insulation and outer semicon in case of short circuit temperature rise	-b. Thermal short-circuit test on screen (**D:** TB § **2.2.1.1**)	b. No official thermal short-circuit test in IEC specifications concerning HV cables
		-c. Supports radial pressure during heating	-c. Thermo-mechanical test with heat cycles and ageing test (**D: TB § 2.1.1.4)**	c. needed in special cases see **2.1.1.3**.
		-d. Radial water tightness in case of composite metal foil screen	-d. No need to check, see **TB § 2.6.1.2**	
		-f. Fatigue in case of composite metal foil screen when installed in non buried conditions	-f. No need to check, see **TB** § **2.6.1.1**	f. The operation feed back shows that no special test is needed when the design complies with the requirements of this brochure
		-g. Side wall pressure in case of composite metal foil screen	-g. See **TB § 2.1.1.3**	
		-h. Correct welding between adjacent foils in the cable length	-h. mechanical tests (**TB § 2.1.1.5)**	

Cable's component	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
	3 **Chemical properties**	-a. No corrosion of the metal -b. Compatibility with layers or semi-con	Ageing test **(D: TB § 2.1.1.4)** -b. Compatibility test	
	5 **Interface with semi-con or layer over semi-con and over-sheath** **and interface with accessories**	-a. Compatibility (see above) -b. Correct connection with accessories screens -c. Radial water tightness in case of metal laminated covering	-a. Compatibility test: -Ageing of complete cable (**T: §12.5.4** with visual examination) -b. Heat cycles: -20 cycles (**T: §12.4.6**) or 180 cycles (**PQ: §13.2.4**) And thermal short-circuit test, this brochure (**D: TB § 2.1.2.1)** -c. Ageing test following this brochure (**D: TB § 2.1.1.4)**	a. See electric contact properties after compatibility test b. Long term PQ test not in IEC 60840 ed3

Cable's component	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
Over sheath	**1 Electrical properties**	-a. Electrical insulation of screen from earth if required -b. Insulate for AC and impulse voltages in case of cross bonding or single point bonding -c. No degradation of this property -d. Correct behaviour in case of short-circuit on outer screen	-a. AC/DC test on sheath (**R: §9.4**) or a spark test during manufacturing -b. Test combined with test on outer protection of joints -c. 20 cycles (**T: §12.4.6**) + AC and impulse test on sheath -d. Short circuit test on screen, this brochure **(D: TB § 2.1.2.1)**	
	2 Thermal-mechanical properties	-a. Supports mechanical bending during installation -b. Resistance to mechanical impact during and after installation -c. Resistance to abrasion during installation -d. Good mechanical qualities before and after ageing e.g. no cracking of the outer sheath -e. Resistance to fire if required	-a. Bending test this brochure (**D: TB § 2.2.1.1)** -b. Mechanical impact: this brochure (**D: TB § 2.1.1.1**) -c. Tests according this brochure (**D: TB § 2.1.1.2**) -d. See the different tests on the different types of materials in IEC (**T: §12.5**) -e. Tests under fire following the relevant tests in IEC (**T: §12.5.13**)	

Cable's component	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 */62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
	3 Chemical properties	-a. Compatibility with screen -b. Resistance to UV -c. Resistance to the chemicals in ground -d. Resistance to termites and rodents where needed (special additives or design)	-a. Compatibility test: -Ageing on complete cable (**T: §12.5.4**) -b. Carbon black content in PE oversheaths: (**T: §12.5.12**) -UV stabilizer in other materials: accelerated weathering test -c. Choice of material depending on the application -d. Special tests depending on type of termites and rodents: **D**	
	4 Interface with screen, accessories or external aggression	-a. See above -b. Shrinkage of over-sheath may give problems with accessories	-b. Long term cycling in presence of accessories: (**PQ: §13.2.4**) or **D** (**T: §12.5.16 of IEC 60840**)	- b. Included in long-term pre-qualification test of IEC 62067 (§ 13.2.3) but not in IEC60840 ed3. Shrinkage, if any, is not necessarily finished after 20 cycles.
Complete cable	**1 Different electrical and mechanical needs**	-a. No degradation because of interactions between all components and of components themselves -b. No ingress of water to avoid insulation degradation and dielectric problems with accessories	-a. Examination after completion of the type tests (**T: §12.4.8**) -b. Short circuit test as **D** depending on the network conditions (to be decided with the network engineers); this brochure (**D: TB§ 2.1.2.1**) -b. Water penetration test (**T: §12.5.14**)	

Table.4..1.3.2 Functional analysis of High Voltage cable joint and joint components

Abbreviations: Routine… R, Sample test… S, Type test….T, Development…. D, Pre-Qualification…. PQ

Here after the parts related to joints and screen connection. It is an update of the TB 303 [29] table.
IEC 60840 and IEC 62067 are under revision and will be published in a near future.The paragraph numbers will be harmonised between the two specifications. In this brochure the paragraphs are taken from the draft documents of IEC 60840 and 62067

Joints components	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
Metal screening, connection to cable screen	**1 Electrical function**	-a. Transfers currents circulating in cable screen, transfers short circuit current.	-a. Thermal cycles with current circulating in the screen: **D.** This brochure (**TB § 3.5.2.2**) Thermal short circuit test following this brochure (**D: TB § 2.1.2.1**)	a. Currents in the screen may be important and the ability of the screen connection not to overheat during cycling should be checked, or a design according to this brochure § 3.5.2.2 .No such short circuit test in IEC 62067 ed1 nor IEC 60840 ed3
		-b. Current sharing between double screens if present	-b. Development test D: Thermal cycling with current circulating in the screen and temperature measurement in the screen area + examination	
	2 Mechanical properties	-a. No hot spot at connection	-a. 20 Thermal cycles (**T: §12.4.6**). Thermal short circuit test following the needs of the network would be useful as a development test D	a. No short circuit test in IEC 62067 ed1 nor in IEC 60840 ed3
		-b. No harmful deformation of cable or joint insulation	-b. 20 Thermal cycles (**T: §12.4.6**). and examination (**T: §12.4.8)**	

Joints components	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /62067 in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
	3 Chemical properties	-a. Compatibility with cable and joint materials -b. Avoid corrosion at the connections	-a. Thermal cycles (**T: §12.4.6**) -b. this brochure (**TB § 2.1.2.2)**	
	4 Screen disconnection (for cross-bonding)	-a. Withstands dielectric transients	-a. AC and impulse tests on outer protection of joints **(Annex G)**	
	5 Water tightness	-a. Avoid water ingress to the insulation	-a. Water tightness test Long term heat cycles with joint immersed or in ground followed by a sheath voltage test This brochure (**D: TB § 2.1.2.2)**	
Eventual filling	**1 Filling of housing**	-a. Avoid high thermal resistance		a. Design aspect
	2 Chemical properties	-a. Compatibility with surrounding material	-a. Development test to check the good behaviour of materials in contact with additives: check of mechanical properties of cable materials and joint materials after ageing in air oven	
	3 Water tightness	-a. Avoid water ingress to the insulation	-a. This brochure (**D: TB § 2.1.2.2)**	
	4 Thermal-Mechanical properties	-a. Eventually rigidifies the joint		a. Design aspect

Joints components	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
Outer protection	**1 Electrical function**	-a. Isolation of joint from earth -b. No degradation of dielectric function with ageing and during short circuit	-a. Test on outer protection (T: Annex H /Annex D) -b. Long term test (PQ: §13.2.3 + §13.2.4) Short circuit test on metal screen this brochure (**D: TB § 2.1.2.1)**	
	2 Thermal-Mechanical function	-a. Mechanical protection of joint		a.. Design aspect of system
	3 Water tightness	-a. Avoid water ingress into the cable	-a. Test in water on outer protection (**T: Annex G)**	
	4 Chemical properties	-a. Compatibility with inside material, resistance against soil aggression (if cable installed in ground) or other surroundings	-a. Long term test (**PQ: §13.2.4**) + voltage withstand test on outer protection after long term test	
	5 Interface with cable over-sheath	- a. Possible shrinkage of cable over-sheath and/or shrinkage of joint outer protection to be taken into consideration when designing the outer protection	-a. Check the shrinkage of the cable sheath and joint protection after heat cycling of 20 cycles (**T: §12.4.6**) or 180 cycles (**PQ: §13.2.4**)	a. May be 20 cycles are not enough to see the long term behaviour of the shrinkage effect

Joints components	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
Complete joint	**1** **Overall properties**	-a. No degradation because of interactions between all components and of components themselves -b. No water penetration before and after heat cycling into the cable system	-a. Examination after completion of the type tests (**T: §12.4.8**) -b. Test in water on outer protection (**T: Annex G**) or better: Long term test (**PQ: §13.2.4**) + insulation resistance test on outer protection after long term test	

Table.4..1.3.3 Functional analysis of High Voltage terminations and components of terminations

Abbreviations: Routine… R, Sample test… S, Type test….T, Development…. D, Pre-Qualification…. PQ

Here after the parts related to screen connection with cable. It is an update of the TB 303 [29] table.
IEC 60840 and IEC 62067 are under revision and will be published in a near future. The paragraph numbers will be harmonised between the two specifications. In this brochure the paragraphs are taken from the draft documents of IEC 60840 and 62067

component of termination	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
Screen/Earth connection	**1 Electrical functions**	-a. Fixation of earth potential		a. Engineering problem, to be considered when installing the system. Bimetal connections to be considered with special care
		-b. Evacuates short circuit current and circulating currents with both ends earthed	-b. Short circuit test following this brochure (**D: TB § 2.1.2.1)** Thermal cycles with current in the screen (**D**) or design according to (**D: TB § 3.5.2.2**)	b. No short circuit test in IEC 60840 ed3 nor in IEC 62067 ed1 Currents in the screen may be important and the ability of the screen connection not to overheat during cycling should be checked (not in cycling tests in IEC)
		-c. In case of disconnection from earth, electrical withstand between earth and screen	-c. Impulse and DC/AC test between earth and screen as a type test	
		-d. Suppression of screen currents with single end earthing or special bonding		d. Engineering problem: -Single end earthing High frequency waves at GIS ends to be solved by coaxial connections to earth

component of termination	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
	2 **Thermal-mechanical properties**	-a. No degradation of connection and surrounding with thermal short circuit	-a. Thermal short circuit test of the earth connection following the needs of the network would be useful as a development test **D** with visual examination This brochure: (**D: TB § 2.1.2.1**)	
	3 **Interface**	-a. No entry of humidity underneath the outer protection of the cable -b. Possible shrinkage of cable over-sheath and/or shrinkage of joint outer protection to be taken into consideration when designing the outer protection	-a. -b. Check the shrinkage of the cable sheath and joint protection after heat cycling of 20 cycles (**T: §12.4.6**) or 180 cycles (**PQ: §13.2.4**)	a. Visual inspection on installed system b. May be 20 cycles are not enough to see the long term behaviour of the shrinkage effect. Long term PQ tests missing in IEC 60840 ed3
	4 **Chemical**	-a. No corrosion of contact points		a. Design: choice of metals and protection
Base plate	**1** **Mechanical properties**	-a. Supports the weight of termination and cantilever forces on termination		a. Design aspect
	2 **Chemical properties**	-a. No corrosion of the base plate	-a. Examination when making climatic tests	a. Design aspect
	3 **Base plate insulators**	-a. Withstand AC/DC/Impulse in specially bonded systems	-a. AC/DC and impulse test on screen connection versus base plate	a. Design aspect

component of termination	Function or Property	Specification/Threat	Test to check the functionality (Relevant paragraphs of draft IEC 60840 /*62067* in brackets) In blue relevant paragraphs of this brochure: TB+§	Comments
Complete termination	**1** **Overall properties**	-a. No degradation because of interactions between all components and of components themselves -b. Correct sealing and no fluid leakage	-a. Examination of deterioration after completion of the type tests (**T: §12.4.8**) and short circuit test This brochure (**D: TB § 2.1.2.1**)	a. Leakage may come up with time in service and, may be, will not be detected during long-term development tests. It needs regular inspection or special protection if no inspection is possible

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