BS EN 50343:2014

BSI Standards Publication

Railway applications — Rolling stock — Rules for installation of cabling

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National foreword

This British Standard is the UK implementation of EN 50343:2014. It supersedes BS EN 50343:2003 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/9/2, Railway Electrotechnical Applications - Rolling stock.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Foreword

This document (EN 50343:2014) has been prepared by CLC/SC 9XB "Electromechanical material on board rolling stock".

The following dates are fixed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2015-01-27
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2017-01-27

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 50343:2003.

EN 50343:2014 includes the following significant technical changes with respect to EN 50343:2003:

– references to other standards updated and harmonized;

– factor k_5 concerning sizing of multi core cables introduced;

– factor k_2 detailed, see Table 2;

– short time current detailed;

– mechanical aspects detailed;

– separation of cables due to safety reasons and EMC reasons harmonized;

– details added and changed concerning electrical and mechanical requirements for electrical terminations;

– cable lifetime considerations updated.

This document has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association.

1 Scope

This European Standard specifies requirements for the installation of cabling on railway vehicles and within electrical enclosures on railway vehicles, including magnetic levitation trains and trolley buses.

NOTE With respect to trolley buses, this European Standard applies to the whole electric traction system, including current collecting circuits, power converters and the respective control circuits. The installation of other circuits is covered by street vehicle standards for example those for combustion driven buses.

This European Standard covers cabling for making electrical connections between items of electrical equipment, including cables, busbars, terminals and plug/socket devices. It does not cover special effect conductors like fibre optic cables or hollow conductors (waveguides).

The material selection criteria given here are applicable to cables with copper conductors.

This European Standard is not applicable to the following:

– special purpose vehicles, such as track-laying machines, ballast cleaners and personnel carriers;

– vehicles used for entertainment on fairgrounds;

– vehicles used in mining;

– electric cars;

– funicular railways.

As the field of cabling in rolling stock is also dealt with in the cable makers’ standard, references are made to EN 50264 series, EN 50306 series, EN 50382 series and EN 50355.

This European Standard applies in conjunction with the relevant product and installation standards. Stricter requirements than those given in this European Standard may be necessary.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 45545 (all parts), *Railway applications – Fire protection on railway vehicles*

EN 45545-1, *Railway applications – Fire protection on railway vehicles – Part 1: General*

EN 45545-2, *Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behaviour of materials and components*

EN 45545-3 *Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers*

EN 45545-5, *Railway applications – Fire protection on railway vehicles – Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic levitation vehicles*

EN 50121-3-1, *Railway applications – Electromagnetic compatibility – Part 3-1: Rolling stock – Train and complete vehicle*

EN 50121-3-2, *Railway applications – Electromagnetic compatibility – Part 3-2: Rolling stock – Apparatus*

EN 50124-1, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*

EN 50125-1, *Railway applications – Environmental conditions for equipment – Part 1: Equipment on board rolling stock*

EN 50153, *Railway applications – Rolling stock – Protective provisions relating to electrical hazards*

EN 50200, *Method of test for resistance to fire of unprotected small cables for use in emergency circuits*

EN 50215:2009, *Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into service*

EN 50264 (all parts), *Railway applications – Railway rolling stock power and control cables having special fire performance*

EN 50306 (all parts), *Railway applications – Railway rolling stock cables having special fire performance – Thin wall*

EN 50306-2, *Railway applications – Railway rolling stock cables having special fire performance – Thin wall – Part 2: Single core cables*

EN 50355:2013, *Railway applications - Railway rolling stock cables having special fire performance - Guide to use*

EN 50362, *Method of test for resistance to fire of larger unprotected power and control cables for use in emergency circuits*

EN 50382 (all parts), *Railway applications – Railway rolling stock high temperature power cables having special fire performance*

EN 50467, *Railway applications – Rolling stock – Electrical connectors, requirements and test methods*

EN 50553, *Railway applications – Requirements for running capability in case of fire on board of rolling stock*

EN 60228, *Conductors of insulated cables (IEC 60228)*

EN 60423, *Conduit systems for cable management - Outside diameters of conduits for electrical installations and threads for conduits and fittings (IEC 60423)*

EN 60684-3-212, *Flexible insulating sleeving – Part 3: Specifications for individual types of sleeving – Sheet 212: Heat-shrinkable polyolefin sleevings (IEC 60684-3-212)*

EN 60684-3-216 , *Flexible insulating sleeving – Part 3: Specifications for individual types of sleeving – Sheet 216: Heat-shrinkable, flame-retarded, limited-fire hazard sleeving (IEC 60684-3-216)*

EN 60684-3-271, *Flexible insulating sleeving – Part 3: Specifications for individual types of sleeving – Sheet 271: Heat-shrinkable elastomer sleevings, flame retarded, fluid resistant, shrink ratio 2:1 (IEC 60684-3-271)*

EN 61180-1, *High-voltage test techniques for low-voltage equipment – Part 1: Definitions, test and procedure requirements (IEC 61180-1)*

EN 61386-1, *Conduit systems for cable management - Part 1: General requirements (IEC 61386-1)*

EN 61310-2, *Safety of machinery – Indication, marking and actuation – Part 2: Requirements for marking (IEC 61310-2)*

HD 60364-5-54:2011, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors (IEC 60364-5-54:2011)*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
cable
assembly consisting of

- one or more cores (screened or unscreened),
- their individual covering(s) (if any),
- assembly protection (if any),
- screen(s) (if any),
- sheath (if any)

[SOURCE: IEC 60050-461, 461-06-01, mod.]

3.1.2
conductor (of a cable)
part of a cable which has the specific function of carrying current

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

3.1.3
core
assembly comprising a conductor with its own insulation (and screens if any)

[SOURCE: IEC 60050-461, 461-04-04]

3.1.4
solid conductor
conductor consisting of a single wire

[SOURCE: IEC 60050-461, 461-01-06, mod.]

3.1.5
stranded conductor
conductor consisting of a number of individual wires or strands all or some of which generally have a helical form

[SOURCE: IEC 60050-461, 461-01-07, mod.]

3.1.6
busbar
conductor consisting of a rigid metal profile

3.1.7
screen (of a cable)
conducting layer(s) having the function of control of the electro magnetic field within the cable and/or to protect the cable from external electro magnetic influences

[SOURCE: IEC 60050-461, 461-03-01, mod.]

3.1.8
bundle
group of cables tied together

3.1.9
bolted connection
connection in which the pressure to the conductor is applied by bolting

[SOURCE: IEC 60050-461, 461-19-05]

3.1.10
crimp
cable termination in which a permanent connection is made by applying pressure, inducing the deformation or reshaping of a barrel part of the termination around the conductor

[SOURCE: IEC 60050-461, 461-19-01, mod.]

3.1.11
spring-clamp connection
terminal connection in which the pressure between the conductor and terminal is applied by a spring

3.1.12
penetration (connection)
terminal connection in which the contact with the conductor is achieved by jaws which penetrate the insulation

3.1.13
plug
connector intended to be coupled at the free end of an insulated conductor or cable, to be inserted into a matching socket, or readily removed when required

3.1.14
socket
connector intended to be mounted on a rigid surface and to hold a matching plug, such that the conductors contained within the socket make electrical contact individually with those in the plug

3.1.15
heat-shrinkable sleeve
tube that on exposure to heat during installation, will at a critical temperature, permanently reduce in diameter, while increasing in wall thickness

3.1.16
manufacturer
organisation that has the responsibility for the supply of vehicle(s), equipment or groups of equipment to the purchaser

3.1.17
purchaser
organisation that orders the vehicle or equipment or groups of equipment and has the responsibility for direct negotiations with the manufacturer

3.1.18
cable tie

mechanical construction needed for either keeping cables or assemblies of cables together, or for attaching them in a defined place.

3.1.19
Short time current

Certain operation case where an electrical circuit carries a current that will introduce an amount of heat into the electrical circuit, which in general will increase its temperature. “Short time” means that the heat exchange against the surrounding material is not significant.

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

EMC	Electromagnetic compatibility
CSA	Cross sectional area
IP	Ingress protection
UV	Ultraviolet
rms	root mean square
DC	Direct current
AC	Alternating current

4 Technical requirements

4.1 General requirements

Cables and installation materials shall be type tested, selected for size and installed so as to be suitable for their function under their operating conditions. Size and installation of cables (including busbars and bare conductors) shall take into account the particular stresses to be expected in rolling stock. The materials used and methods of cabling shall be such as to prevent strain or chafing and excessive lengths of unsupported cable shall be avoided.

Cables on rolling stock shall not be used for any purpose other than for transmission, distribution and collection of electrical energy, electrical controls or monitoring systems. All components of cabling shall be selected, installed, protected, used and maintained so as to prevent danger (e.g. electrical or fire hazard, EMC problems).

The electrical connections shall be made in such a way that they can not be unintentionally disconnected or interrupted during service.

Effects that have impact on electrical connections and should be considered are at least:

– thermal effects

– dynamic loads as shock, vibration, car-body motions.

– material creepage

For consideration of environmental conditions, EN 50125-1 shall apply.

When considering operating conditions and environmental conditions, the locations as presented in Annex K (informative) should be taken into account.

For correct use of connectors, EN 50467 shall apply.

For protection against electrical hazard, the cabling installed shall be in accordance with EN 50153.

4.2 Selection of type and size of cables

4.2.1 General

When selecting cables or busbars the expected operating conditions should be taken into account. These should include but are not limited to the following parameters:

- voltage;
- current;
- overload current;
- short time current;
- voltage drop;
- short-circuit current;
- shape and frequency of current;
- fusing characteristic of the protection device;
- grouping of cables;
- ambient temperature and temperature due to load current;
- methods of installation;
- predicted cable lifetime;
- presence of rain or steam or snow or accumulation of condensing water;
- presence of corrosive, polluting or damaging substances;
- mechanical stresses;
- radiation such as sunlight.

Consideration should be given to the expected lifetime of the cabling compared with the expected lifetime of the vehicle.

The cable type (i.e. cable family) shall be selected in accordance with EN 50264 series, EN 50382 series or EN 50306 series, as applicable.

Once the cable type has been selected, the selection of conductor size if the cable is intended for power distribution shall be based on either load current and current carrying capacity calculated in accordance with 4.2.3 or based on protection device size in accordance with 4.2.4.

Short-circuit conditions and overload conditions should be checked with respect to the fusing characteristic of the protection device and the resistance of the chosen cable. See example in Figure 1.

Short-circuit conditions should be checked according to 4.2.7.

This short-circuit or overload case should be checked according to:

Normal load < nominal current rating of protection device ≤ current carrying capacity of the cable

(I_{corr} , see definition in 4.2.3 b)).

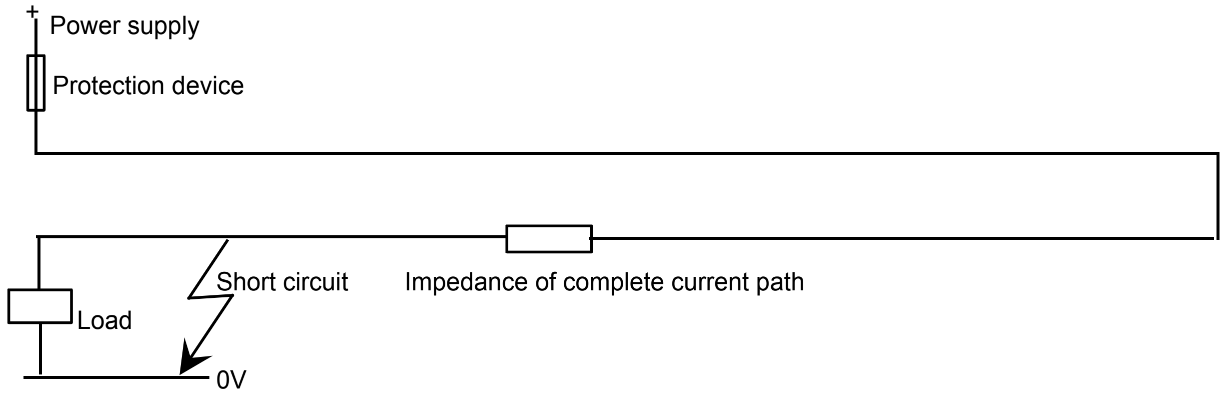


Figure 1 – Example of short-circuit condition where cable size will have influence on protection device behaviour

The cross-sectional area of any conductor shall be not less than the value specified in 4.5.

Cables and cabling shall be conform to the fire safety requirements specified in EN 45545-2, EN 45545-3 and EN 45545-5.

The number of different types of cables installed on any one type of vehicle should be minimized for practical reasons.

4.2.2 Selection of cable size for control cables

Control cables, which are intended to carry control signals only, shall have a minimum conductor cross-sectional area as specified in 4.5. This is also valid if the load current would make a smaller cross-sectional area possible.

NOTE It is not necessary for the conductor size of these cables to be selected according to 4.2.3.

4.2.3 Selection of cable size for cables for power distribution, on the basis of continuous load current

This subclause specifies a method for calculation of continuous maximum load current, of time duration longer than 5 s, of different cable sizes dependent on their method of installation and ambient temperature, to enable cables to be selected so as to ensure that the predicted lifetime is achieved.

For short time current, up to 5 s, see 4.2.7.

Correction factors from cable manufacturers should not be combined with correction factors given in this standard, in order to avoid miscalculation or oversizing.

The continuous maximum conductor temperature for the cable types defined in the various parts of EN 50264, EN 50306 and EN 50382 is either 90 °C, 105 °C and 120 °C or 150 °C. This is based either on proven experience and reliability over many years or in the case of newer, less well defined, insulations upon an acceptance test, using long-term thermal endurance ageing to demonstrate a lifetime of at least 20 000 h at 110 °C, 125 °C and 140 °C or 170 °C respectively (i.e. 20 °C above the continuous rating). Data from this thermal testing can, with care, be extrapolated to the conductor temperature to provide a predicted lifetime of the cable when continuously loaded. This predicted lifetime may be used in conjunction with the known duty cycle of the vehicle, and its predicted time out of service, to estimate the ability of the cable to function reliably for the predicted lifetime of the whole vehicle.

NOTE 1 Because the cable standards allow a variety of solutions for insulation type, it is important to confirm lifetime extrapolations with the cable manufacturer.

NOTE 2 A predicted lifetime of cable of 100 000 h may be used as a theoretical basis value for cables according to EN 50264, EN 50306 or EN 50382 series and their specific maximum conductor temperature at continuous operation.

This subclause only deals with thermal degradation of insulation material and it should be noted that mechanical stresses (bending, wear, etc.) and other environmental factors (such as presence of fluids such as cleaning detergents, aggressive atmosphere) may be the limiting factor determining predicted cable lifetime.

For cables intended for power distribution, the cable size shall be selected on the basis of the load current and the current carrying capacity in accordance with the following procedure (i.e. the three steps a), b) and c)).

a) The load current

The load current I_{load}, in amperes (A) which a cable has to carry for sustained periods during normal service shall be a basic value for cable sizing.

When the circuit(s) being supplied by the cable is in continuous or sustained cyclic operation, I_{load} shall be calculated according to the following formula:

$$I_{\text{load}} = \sqrt{\frac{1}{t_1} \int i^2 \, \text{dt}}$$

where

t_1 is the duration of a typical duty cycle during service, in minutes (min);

i is the instantaneous current – including overload, if any - in amperes (A).

NOTE 3 For continuous direct current operation, the above formula has the simple form $I_{\text{load}} = i$.

When operation is not continuous or sustained cyclic, I_{load} shall be calculated according to Annex A.

b) The current carrying capacity

The permissible continuous current carrying capacity I_{cable} in amperes (A) of a single-core cable or a single core within a multi core cable being operated in free air shall be another basic value for cable sizing. A particular value of I_{cable} is valid for a particular reference ambient temperature T_{ref} and for a particular maximum conductor temperature in service, $T_{\text{c(max)}}$.

I_{cable} within the reference values T_{ref} and $T_{c(max)}$, shall be those provided by the cable manufacturer. Examples for I_{cable} for single core cables are presented in Annex B.

I_{cable} for maximum conductor temperatures other than $T_{c(max)}$ = 90 °C, shall be calculated according to Annex C.

The current carrying capacity of the cable in service, I_{corr}, in amperes (A) shall be calculated from I_{cable} using correction factors k_1, k_2, k_3, k_4, k_5, in accordance with the following formula.

$$I_{corr} = I_{cable} \times k_1 \times k_2 \times k_3 \times k_4 \times k_5$$

where

k_1 is a correction factor for the expected ambient temperature. It shall be calculated according to the following formula:

$$k_1 = \sqrt{\frac{T_{c(max)} - T}{T_{c(max)} - T_{ref}}}$$

where

$T_{c(max)}$ is the maximum conductor temperature, in degrees Celsius (°C), in service, which will allow the predicted lifetime of the cable to be achieved;

T is the estimated value of the actual ambient temperature, in degrees Celsius (°C) during operation, on the outside of the bundle or of the tube - if any. T is an average value;

T_{ref} is the reference ambient temperature, in degrees Celsius (°C), for which the I_{cable} value is valid.

Examples of k_1 values are given in Table D.1.

k_2 is a correction factor for installation type (grouping and installation conditions).

Values for k_2 given in Table 2 shall be used. Interpolation between the different numbers of cables in Table 2 is allowed.

k_3 is a correction factor to allow for a decrease in predicted cable lifetime, calculated according to the formula in Annex E. In all cases where the standard predicted cable lifetime shall be used, the value of k_3 shall be 1,0.

k_4 is a correction factor to take into account short time current when operation is not continuous, calculated according to the procedure in Annex A. When operation is continuous, the value of k_4 shall be 1,0.

k_5 is a correction factor for multi core cables; the correction factor k_5 is applicable for each individual core within a multi core cable. Values for k_5 are given in Table 1. Interpolation between the different number of cores in Table 1 is allowed. When single core cables are used, the value of k_5 shall be 1,0.

If single core cables and multi core cables are lying together on the same cable tray, open or close, by the correction factor k_5, different values for I_{corr} are obtained for single core cables and multi core cables.

Table 1 – Modification factor k_5 for individual cores within a multi core cable

Number of loaded cores	2	3	4	5	7	9	12	19
Correction factor k_5	0,91	0,78	0,63	0,59	0,51	0,46	0,41	0,38

c) Selection of cable size

The cable size shall be selected such that the current carrying capacity of the cable in service, calculated in accordance with item b) is greater than or equal to the predicted load current, calculated in accordance with item a) i.e.

$$I_{load} \le I_{corr}$$

The minimum cross-sectional area of the conductor shall be as specified in 4.5.

NOTE 4 Combining the formulae from 4.2.3 a) and b) and c), would lead to the following formula:

$$I_{cable} \ge \frac{I_{load}}{k_1 \times k_2 \times k_3 \times k_4 \times k_5}$$

This formula will in practice be more easy to use, because in cases with defined cable type and defined load conditions the last term will be constant and so it is easy to find the right cable size via I_{cable} in the current ratings table (see examples in Table B.1).

For a calculation example refer to Annex F.

Table 2 – Modification factor k_2 for installation type (grouping and installation conditions)

Number of cables being simultaneously loaded	Installation type							
	Cable in free air Type a)	Cables on trays, in one layer Type b)	Cables on trays, in two layers	Cables on trays, in several layers Type c)	Cables on the floor or on a wall Type d)	Cables on a ceiling or under floor Type e)	Cables in a closed tube, conduit or tray Type f)	Cables in a closed tube or conduit, thermally insulated Type g)
1 single cable	1,0	1,0	1,0	1,0	1,0	0,95	0,95	0,76
2 cables together	-	0,87	0,87	0,87	0,85	0,81	0,80	0,61
3 cables together	-	0,83	0,83	0,78	0,79	0,72	0,70	0,53
4 cables together	-	0,78	0,71	0,71	0,75	0,68	0,65	0,49
8 cables together	-	0,74	0,59	0,52	0,75	0,62	0,52	0,40
12 cables together	-	0,73	0,54	0,45	0,75	0,61	0,45	0,34
16 cables together	-	0,72	0,51	0,41	0,75	0,61	0,41	0,31
20 cables and more together	-	0,71	0,47	0,38	0,75	0,61	0,38	0,29

Details of installation types are as follows:

Type a) One single cable in free air with heat dissipation into the surrounding air ensured by all the following measures:

- distance between the cable and adjacent walls over, under or beside: At least equal to the cable diameter;
- distance between the cable and any other cable lying beside it in any direction: At least equal to the sum of its own cable diameter and the adjacent cable diameters;
- cable lying in an open tray or ladder support with perforations, the total area “A” in Figure 2 of the perforations being at least 15 % of the total supporting area in case of metallic tray or support with good thermal contact to car-body (otherwise at least 30 %), and without any cover.

Type b) Cables lying in one layer, touching each other, on an open tray or ladder support, with perforations as for type a).

Type c) As for type b) but cables in several layers over each other.

Type f) Cables lying in bundles in closed tubes, closed trays or boxes without significant air flow.

Type g) As for type f), but for thermally completely insulated closed tubes, closed trays or boxes.

Current flowing through the screen (e.g. motor cables and brake resistors) should be calculated as an additional conductor.

NOTE Installation types a), b), c), d), e) and f) are illustrated in Figure 2.

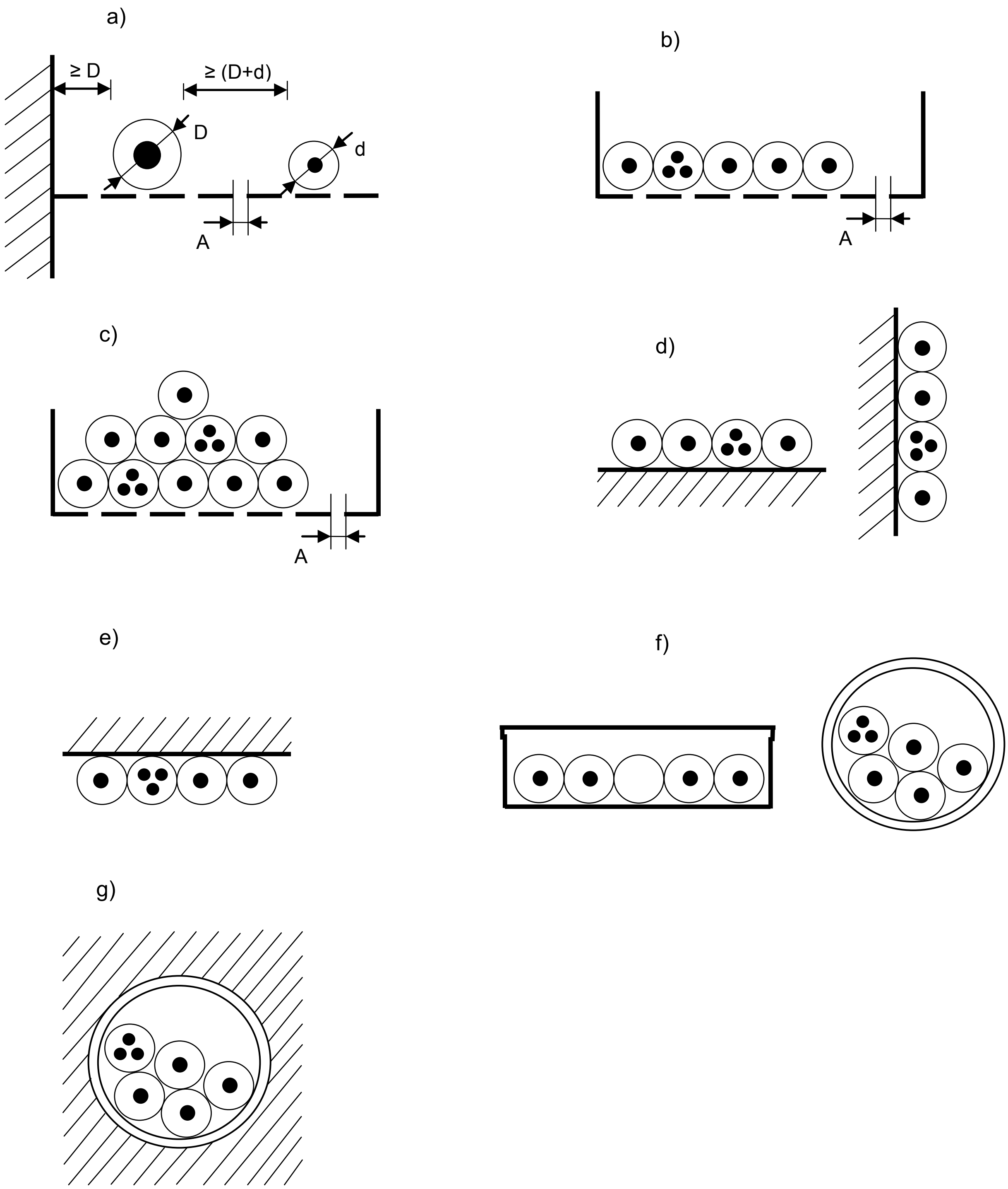


Figure 2 - Cable grouping and installation conditions

4.2.4 Selection of cable size for cables for power distribution, on the basis of rating of protection device

In cases where the load current I_{load} is not exactly defined, the rating of the protection device may be chosen according to the maximum load current that can be expected. The conductor size shall then be selected according to the rating of protection device in accordance with Table 3. This applies to all cable types with $T_{\text{c(max)}}$ of at least 90 °C, at an ambient temperature of maximum 45 °C.

NOTE This method is simple but has disadvantages (weight, required space and costs of cables may increase).

Table 3 – Selection of cable conductor size on the basis of rating of protection device

Rating of protection device A	**Nominal cross-sectional area of conductor** mm²	
	Up to 4-core cables, or bundles of max. 4 cables, on open trays or in free air	**Up to 4 cables in a closed tube**
6	1,0	1,0
10	1,0	1,5
16	1,5	2,5
20	2,5	4,0
25	4,0	6,0

4.2.5 Motor cables

Traction motor cables shall be sized according to the procedure specified in 4.2.3. For cables in motion during operation, higher flexibility of cables should be considered when selecting cable type (i.e. class 6 in accordance with EN 60228).

4.2.6 Cables for protective bonding

Cables for protective bonding shall be sized and installed according to the rules described in HD 60364-5-54:2011, Section 543. This standard is dealing with general rules for electrical equipment. The requirements of EN 50153 shall be fulfilled.

In HD 60364-5-54, section 543.1.2, a formula for minimum cross-sectional areas of protective conductors applicable for disconnecting times not exceeding 5 seconds is given.

4.2.7 Cables used under short time current (below 5 s)

For cables loaded with a short time current (below 5 seconds), CSA shall be sized such that the end temperature does not exceed a temperature of 20 °C over the conductor operating temperature of the insulation as defined in EN 50355. Lifetime, in this case, is reduced to at least 20 000 h of cumulated operation.

For dimensioning of cables for short time current within the scope of this European Standard, the formula given in HD 60364-5-54:2011, 543.1.2 should also be used.

EXAMPLE Conductors for thermal engine starters.

k factors for bare conductors are given in HD 60364-5-54:2011, Table A.54.6.

k factors and short-circuit ratings for rolling stock cables are given in EN 50355.

For any other material of the conductor, the insulation and other parts and the initial and final temperatures, the k factor shall be calculated or be given by the cable manufacturer.

For calculation of k, see Annex A in HD 60364-5-54.

NOTE The k factor referred to in 4.2.7 and in the formulae in HD 60364-5-54 section 543.1.2 and in EN 50355 have a different meaning than the k factors used in EN 50343.

For a calculation example in EN 50343, refer to Annex F.

4.3 Bundling of cables

If several cables are to be laid together as a bundle, the following factors shall at least be taken into consideration:

– thermal requirements (see 4.2.3);

– EMC requirements (see 5.2);

– rated voltages (see 4.11);

– mechanical aspects, such as strength of bundle, weight of bundle, available space and relative movement;

– fixing points (see 4.15).

If cables with different cross-sectional area are to be bundled together, the mechanical stresses should be considered.

4.4 Flexibility of cables

If high flexibility is required, stranded conductors of class 6 in accordance with EN 60228 should be used. In all other cases, stranded conductors of class 5 in accordance with EN 60228 shall be used (see also 4.7).

High flexibility is required in case of car-to-car or car-to-bogie cabling, i.e. locations 5, 6 and 7 in Annex K and for equipment which may have relative cabling movements between internal parts, e.g. doors, shoe gears.

NOTE Internal connections of, for example, electronic devices, may use single solid conductors of class 1 in accordance with EN 60228 (e.g. for wire wrap connections) if there is no risk of fatigue failure or if precautions have been taken to avoid this risk.

When higher flexibility of a bundle is required, the nominal cross-sectional area of each individual cable should be selected with respect to its individual load current. In many cases, the smaller the cross-section of a conductor, the more flexible the cable is.

4.5 Minimum cross-sectional area of conductors

Single-core cables laid separately, or cables laid side by side, connecting electrical components in different locations inside rolling stock vehicles (e.g. for connections between locations A, B and C as shown in Figure 3) shall have a nominal conductor cross-sectional area of at least 1,0 mm².

Higher minimum cross-sections may be necessary due to e.g.:

- voltage drop;
- load current;
- mechanical strength.

Special care should be taken on minimum cross-sectional area in order to achieve the necessary mechanical strength for car-to-car or car-to-bogie cabling i.e. locations 5, 6 and 7 in Annex K.

It is permitted to use smaller cross-sectional areas under the following conditions:

- for internal wiring in racks or assemblies or in electronic equipment or precabled devices, if the circuit is protected against overload and if the mechanical strength is given (e.g. inside A or B or C as shown in Figure 3);
- for multi-core cables, bundled cables, databus connections etc., if the mechanical strength is provided and if the load current in all operational cases allows this;
- for devices specified and tested as a complete unit for use in rolling stock.

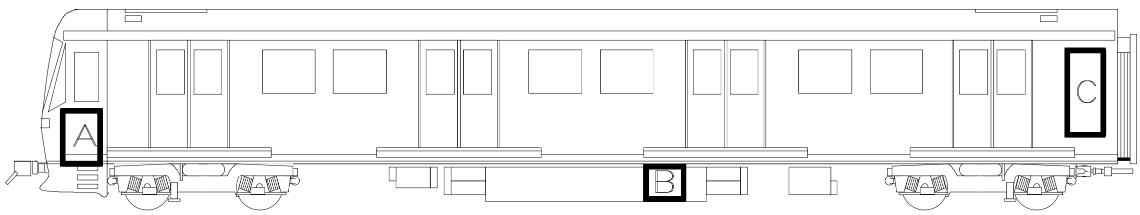


Figure 3 – Locations in rolling stock, concerning use of minimum cross-sectional areas for conductors

4.6 Use of green and yellow colour

Conductors of a protective equipotential bonding system whether insulated or bare, shall be readily distinguishable by shape, location, marking or colour. If identification by colour is used, it shall be the bicolour combination green-and-yellow.

NOTE If the use of a conductor for protective equipotential bonding is obvious, e.g. at bogies, it is allowed to identify protective equipotential bonding by other means than colour.

The green/yellow core of a multi-core cable - if any - shall not be used for purposes other than protective equipotential bonding.

Individual cores in multi-core cables not used for protective equipotential bonding may be either green or yellow.

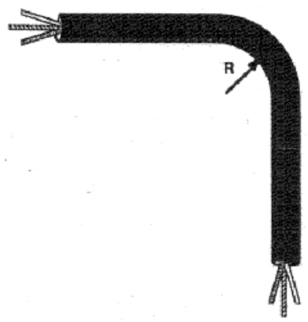
4.7 Bending radii and other mechanical requirements

Cables shall be installed so that the minimum bending radii for fixed-installation cables and cables which are flexing during service are not less than those given in the relevant product information or cable standard.

In a bundle, e.g. consisting of cables having different diameters, the minimum bending radii for the bundle shall be that of the cable having the highest bending radii.

Examples for bending radii are given in Table 4.

The definition of the internal bending radius is as given in Figure 4.



Key

R internal bending radius

Figure 4 – Definition of internal bending radius

Table 4 – Minimum internal bending radii R for static applications

For cable diameter (mm)	≤ 12	> 12
Unscreened cables	4D	5D
Screened cables	10D	10D
Minimum bending radii given by the cable manufacturer shall prevail. NOTE 1 D is the overall cable diameter. NOTE 2 Values based on EN 50355:2013, Table 16.		

The cable material should be considered carefully with respect to its ability to resist the effects of dynamic movement. Excessive forces on the installation devices used – e.g. fastening clamps and termination points - should be avoided as far as possible, for example by using extra fixing means or more flexible cables.

In high vibration environmental conditions (e.g. in the diesel engine compartment or location 6 and 7 in Annex K) thin wall cables according to EN 50306-2 should not be used inside a non-metallic flexible conduit if they are not additional mechanically protected by sleeves, braided hoses, etc.

NOTE 1 Mechanical stresses are detailed in EN 50355.

NOTE 2 The bending radius can have influence on the EMC effects of screened cables.

All cabling mechanical fixing elements shall be free of any kind of sharp edges to avoid possible damage of the cables during installation by penetrating the insulation or due to chafing and vibrations in service conditions.

Sharp edges which are able to cause damages on cable insulation, shall be covered by edge protectors. See example in Figure 5. Cabling mechanical fixing elements may be shaped according to the cabling installation curvature. Fixings should be added in the proximity of the edge.

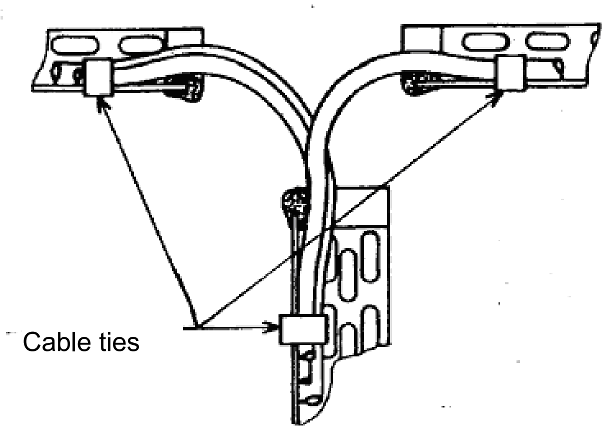


Figure 5 – Examples of mechanical protecting of cabling

When slight relative movement is expected, then the cabling installation should be designed to withstand all possible movements. In this case, forces imposed to the terminations and frictions caused by these movements should be minimized and avoided by adequate fixing.

In addition, when considerable relative movement is expected, the ends of cabling installation should be vertical or present a minimum angle to the vertical, reducing the bending effect of gravity.

Adequate protection against impact of objects, e.g. ballast stones, at under car-body locations should be considered (e.g. locations 4, 5, 6 and 7 according to Annex K).

4.8 Re-termination

Single- and multi-core cables with a nominal conductor cross-sectional area of 16 mm² or less installed on rolling stock should have sufficient spare length at each termination to allow for at least 3 re-terminations.

NOTE When cables are terminated by a plug, it may be impractical to provide any spare length.

For requirements regarding refurbishment and repair, refer to 4.12.

4.9 Busbars

Busbars should be made of copper, brass or aluminium. On contact surfaces, precautions shall be taken to prevent contact resistance values from increasing with time in particular due to corrosion effects or material creepage.

Busbars shall conform to the relevant international, European or national standard. The selection of the type and dimensions of busbars shall be at the discretion of the vehicle manufacturer. The sizing procedure shall include the influence of ambient temperature.

4.10 Connections to busbars

Electrical connections between busbars and equipment or between different bar sections or between different devices shall be flexible if relative movement can be expected.

If bolted connections are used, they shall have suitable locking arrangement, which will retain their mechanical forces nearly constant over the lifetime of the equipment, including any material creepage.

4.11 Separation of cables with different voltage levels and for safety reasons

Measures in order to prevent electrical hazards to persons shall be according to EN 50153.

EN 50153 specifies the use of measures like equipotential connection for protective purposes, insulation, prevention of access, automatic disconnection of power supply in hazardous cases, car protective bonding, warning labels with respect to different voltage bands and possible occurrence of direct and indirect contact.

As methods of cabling are not mentioned in EN 50153, this will be detailed in the following.

When grouping cables, cables carrying different voltage levels shall be separated as far as practicable.

Separation shall be by distance, insulating barriers or earthed metallic barriers (see Figure 6 and Figure 7).

Separation barriers or screens or sleeves shall have the same mechanical strength and resistance to fire and insulation properties as the insulation of the cables in the higher category.

If cables e.g. on the roof are touched by a broken overhead line, the dangerous voltage shall lead to short-circuit detection in the trackside power substation before endangering any person, see EN 50153.

Further requirements for separating cables for safety reasons may be:

– regarding running capability in case of fire according to EN 50553
– power supply train line (e.g. 800 A 1 kV/1,5 kV/3 kV) which has the ability to start a fire in case of failure of insulation.

NOTE 1 EMC considerations may require a larger distance than that shown in Figure 6. See 5.3.

NOTE 2 The separation is necessary for safety reasons, in order to minimise, in case of accidents, fire, chafing of cables etc. the probability of introducing higher voltages or higher power into cables intended for carrying lower voltages/power

Where separation by distance can not be achieved, for example because of restricted space available, the cables shall be separated by a partition or by insulation (see Figure 7). Exceptions shall be limited to cases where no practical solutions are possible (close to terminal strips, at crossings, etc.).

When possible, the individual return cables should be treated in the same way as their matching forward supply cables in all categories.

The unprotected parts of circuits shall be as short as possible, this shall be achieved by ensuring that protective devices and transducers for protective devices are installed as close as possible to the source of supply.

If high voltage cables (circuits within voltage level IV according to EN 50153) have to be laid in a passenger compartment or driver’s cab, they shall be installed in closed earthed metallic tubes or behind earthed metallic enclosures.

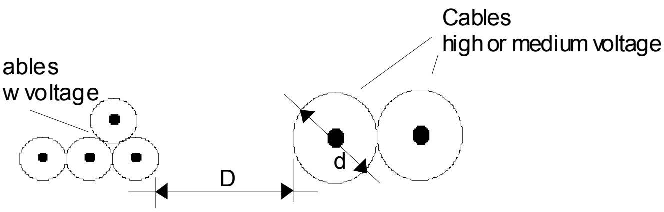


Figure 6 – Separation of cables by required distance: D > 2 d and D > 0,1 m

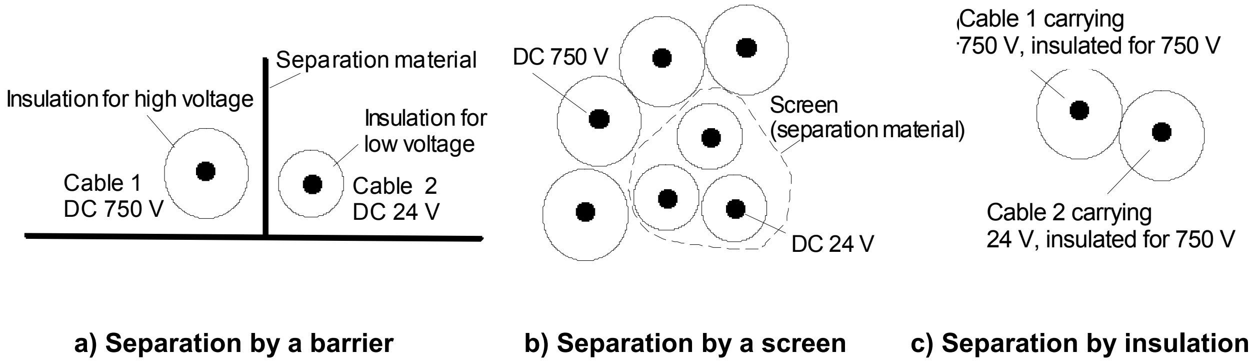


Figure 7 – Examples of separation of cables by barriers or by insulation

NOTE 3 Drawings used in Figure 7 are examples only. Separation material suitable to insulate for 750 V. Normally cables for 750 V and cables for 24 V would not be laid closely together due to EMC reasons.

For additional cabling requirements regarding avoiding of fire hazards, EN 45545-5 shall apply.

4.12 Provisions for refurbishment and maintenance, including inspection and repair

Modifications to electrical equipment shall not adversely affect the original fire safety specification, according to 6.2 of EN 45545-5:2013.

The design of a new vehicle should take into account the fact that on average once in its lifetime it is likely to undergo a major refurbishment (redesign or extensive modifications) or be extensively repaired.

The design shall include the following provisions for this:

– Cables, cable conduits, equipment, terminals, etc., should be accessible as far as possible.

  NOTE 1 This is also necessary for inspection purposes.

– Provision should be made as far as possible to allow replacement and repair of cables (provisions for pulling new cables through conduits etc., ensuring space is available for splicing). Concerning spare cable length for the purpose of re-termination, refer to 4.8.

– When replacement of cables would be difficult, spare cables should be provided. Also refer to 4.14.

  NOTE 2 These provisions are also necessary to allow for repairs and changes during commissioning.

In order to make rearrangements of cables installed in tubes easier, the bending radius and the cross-sectional area of the tubes should be as large as possible. Discontinuous tubes (tubes with holes, breaks etc.) may be required in order to increase accessibility.

NOTE 3 Bundling of cables in tubes may have advantages and disadvantages. It could support easier use of the spare space for later additional cabling, but in cases where the existing cabling is changed, it could become necessary to draw out and change the complete bundle.

Cables which are exposed to flexing and bending stress during service should have good accessibility (e.g. locations 5, 6 and 7 in Annex K and for equipment which may have relative cabling movements between internal parts, e.g. doors, shoe gears). The transition between the flexing and the fixed parts of the cabling should be as smooth as possible.

For cables lying in tubes or conduits the ratio between the actual amount of cables including spares and the maximum possible amount of cables lying in a tube or conduit should not exceed 60 %, to allow replacement/refurbishment.

For cables lying in trays or cable ducts the ratio between the actual amount of cables including spares and the maximum possible amount of cables lying in a tray or cable duct should not exceed 80 %, to allow replacement/refurbishment. Refer also to section 4.3

If the concerned cables are fixed (i.e. not being moved, bent or flexed during service), insulated splicing connectors may be used during repair and refurbishment for cross-sectional areas up to 6 mm². Refer to 4.17 concerning requirements for terminating conductors.

For new vehicles, splicing shall not be used in the original design, or manufacture.

Disconnection points should be selected so that the need for dismounting of cabling because of repairs or planned maintenance is minimized. Cables with low life time expectancy (for instance flexible car-to-car cables) should be easy to renew with minimum need for dismounting.

If using spare cores and cables, an insulation test should be made before commissioning.

At location 4, 5, 6 and 7, according to Annex K, resistance to cleaning agents should be considered.

4.13 Fire prevention, cable laying and cabling behaviour in case of fire

For details about cable concerning fire propagation, resistance to fire and reaction to fire (e.g. smoke contents), see Clause 4 of EN 50355:2013.

For details about cabling materials (such as fixings, heat-shrinkable sleeves, tubes) concerning fire propagation, resistance to fire and reaction to fire (e.g. smoke contents), see EN 45545 series.

For requirements regarding running capability in case of fire, EN 50553 shall apply.

For certain critical functions (emergency light control, door operation, emergency brake application, fire extinguisher control etc.), it may be necessary to use cables, supporting, protecting and connecting elements with special construction that retain their integrity for a defined time in case of fire. Regarding this, EN 50200 and EN 50362 shall apply.

Separate routing of such cabling may be required.

NOTE The properties of these cables may conflict with other requirements (e.g. toxicity, content of halogens).

4.14 Provision of spares

4.14.1 Provision of spares for control cabling

For interface cables connecting electrical components in different locations inside rolling stock vehicles, 10 % or at least 2 spare cores shall be provided in every multi-core cable or bundle of cables containing more than 10 cores. An appropriate number of spare terminals or contacts in connectors (male and female contacts in the plugs, coupler contacts etc.) or space available for additional terminals or connectors should be provided.

NOTE 1 This is not applicable to cables for specific purposes (e.g. door open push-button, lighting control cabling, screened databus or other communication system cables).

The number of spare cores shall be that amount provided at the date of completion of assembly of the first vehicle.

This number of spare cores needed depends on the construction of the cables and connectors and on the method of laying the cables. In cases where the cables are inaccessible (when they are installed in tubes etc.) the number of spare cores should be increased.

Not connected ends of spare cores shall be rolled up and fixed in an accessible place. Connected spare cores shall be tested.

NOTE 2 Other treatments of the ends of spare cores may be agreed, for safety reasons or for EMC purposes. These include insulating the ends or connecting them to earth.

4.14.2 Provision of spares for auxiliary power distribution cabling

In installations where spare provisions are functionally required, i.e. electrical cabinets or cubicles, a minimum amount of 10 % spare terminal connections or space available for additional terminal connections should be provided at the date of completion of assembly of the first vehicle.

4.15 Requirements for fixing

Cables other than those running in tubes or conduits shall be secured by mechanical fixings or fastenings.

Cables should be secured at maximum intervals as follows, unless the cable manufacturer has specified other values:

a) power cables, multi-core cables and cable bundles

   – 300 mm when cables are running in the horizontal direction, also between a termination point and the first fixing.

   – 500 mm when cables are running in the vertical direction, also between a termination point and the first fixing.

b) single-core cables for low power, laid singly

   – 150 mm between fixings when cables are running in the horizontal or in the vertical direction, also between a termination point and the first fixing.

NOTE 1 Typically, exceptions to this are made for thick cables and jumpers between parts which make relative movements.

The fixings shall be selected to take into account the cross-sectional area of the conductors or cable bundles, and the expected operational and environmental conditions during the operational lifetime of the vehicle, such as shock and vibrations and cable temperature.

NOTE 2 During a short-circuit, higher electro-mechanical forces could be generated between cables, which may have impact on the cable fixing systems.

If the cables are covered by a metallic or non-metallic sleeve, these sleeves shall have fixings which conform to the requirements specified by the sleeve manufacturer.

Cable ties shall conform to the relevant international, European or national standard, and their selection shall be at the discretion of the vehicle manufacturer.

Cable ties shall be selected in accordance with the following:

- cable ties shall be selected with respect to the fact that they do not damage the cables or deteriorate their properties;
- cable ties shall be selected which are resistant to the conditions in which the cables are installed (e.g. exposure to diesel oil and UV radiation);
- the fire performance of cable ties shall conform to EN 45545 series.

When another mounting place is available, cable fixings shall not be mounted on parts that will regularly be moved or replaced during maintenance. Cable fixings shall be separate from fixings of mechanical equipment.

When cables are exposed to flexing and bending stress during service cable fixings shall be provided close to terminations in order to avoid flexing at the point where the conductor emerges from its insulation and where the core emerges from any sheath (e.g. locations 5, 6 and 7 in Annex K and for equipment which may have relative cabling movements between internal parts, e.g. doors, shoe gears).

See section 4.13 for further advice.

4.16 Clearances and creepage distances

For the uninsulated parts of electrical installations, in particular cable lugs and busbars, clearances and creepage distances shall be in accordance with EN 50124-1.

4.17 Requirements for electrical terminations

4.17.1 General

For connectors, refer to EN 50467.

All conductors - except spares, but including non current carrying conductors provided for protective earthing - shall have terminations on both ends. Each termination point shall have a specific preparation of the cable end and shall have a matching part on the terminal or device side, if applicable for the termination technology. Both the current rating and the temperature rating of both sides of the termination point shall be not less than the maximum load to be expected in service.

The termination point shall produce a permanently reliable connection between the conductors of the cable and the parts of the terminal or device which are intended to carry the current.

At least the following conditions should be taken into account:

- fire behaviour;
- thermal resistance of all involved components;
- mechanical behaviour (taking into account creep of materials and avoidance of plastic deformation, resistance to fatigue and corrosion and the ability not to disconnect unintentionally);
- electrical behaviour (voltage withstand, current density, voltage drop, thermal and mechanical effects from short-circuit conditions);
- safety against persons touching electrically live parts;

– ability to meet the specific railway environmental conditions (shock and vibration, temperature, corrosion, moisture, dust, etc.);

– use of appropriate tools;

– electrochemical potential difference of the material combination;

When applicable, terminations should at least have been mechanically tested for:

– shock and vibration,

– tensile strength,

– torque control,

– insert and extraction forces,

– retention forces,

and should at least have been electrically tested for:

– contact resistance,

– voltage drop,

– withstand voltage,

– temperature rise,

– current load

4.17.2 Electrical terminations at the cable ends

Examples of methods of terminating cables at the conductor end side and their main mechanical and electrical aspects are given in Table G.1.

4.17.3 Electrical terminations at the terminal or device side

The terminations used at the terminal or device side shall conform to the relevant international, European or national standard, and their selection shall be at the discretion of the vehicle or enclosure manufacturer.

Examples of terminations used at the terminal or device side and their main mechanical and electrical aspects are given in Table G.2 to Table G.5.

In order to prevent temperature rise at terminal points, the following measures shall be taken:

– Except supplementary conductive elements in order to avoid galvanic corrosion e.g. in a protective earth connection, washers or any intermediate parts shall not be used between the conducting components

– except specific constructions being calculated and tested as current carrying components, bolts and studs shall not be used as conductors

– the metal surface materials of the two parts shall match and shall be cleaned and prepared;

– when cable lugs are connected to busbars, current carrying studs or protective earthing studs, the construction shall be such as to ensure the flow of current

  • with a maximum of 2 terminal lugs at each bolted connection for power,

  • with a maximum of 3 terminal lugs at each bolted connection for protective earthing,

  - with a maximum of 3 terminal lugs at each bolted connection for control.

– when cable lugs are connected to isolators or insulated terminal studs, the construction shall be such as to ensure the flow of current

  - with a maximum of 3 terminal lugs at each bolted connection for power,
  - with a maximum of 3 terminal lugs at each bolted connection for protective earthing,
  - with a maximum of 4 terminal lugs at each bolted connection for control.

Means to avoid galvanic corrosion should be provided between the conducting components if the material combination results in an electrochemical potential difference exceeding 300 mV. Refer to Annex J for examples.

NOTE 1 The quality of an electrical contact depends on

- the surface texture and the materials of the conducting parts involved. (The surface texture should be better than 3,2 μm in the same sense as used in EN ISO 1302);
- the dimensions of the contact surface in relation to the current (i.e. current density) (see below);
- the clamping pressure (see below).

Regarding factors having influence on fire hazard in general, EN 45545 series shall apply. Especially the additional requirements of EN 45545-5:2013, Clause 5 shall apply.

The current density in a copper contact shall not exceed 1,4 A/mm², using the load current I_{load} for this calculation (see 4.2.3). For aluminium, this maximum value shall be 0,8 A/mm².

For calculating the effective area of contact, see procedure below and Figure 8.

NOTE 2 This procedure is also applicable when two busbars are connected to each other (the pressure on both bars will be applied by a bolt connection).

The effective area of contact, *A*, in square millimetres (mm²) shall be the area of a square of sides equal to the outside diameter of the thrust washer, *D*, in millimetres (mm), less the area of a circle of diameter *d*, in square millimetres (mm²), where *d* is the inside diameter of the washer (see Figure 8). The value of *A* shall be calculated using the following formula:

$$A = D^2 - \frac{\pi \times d^2}{4}$$

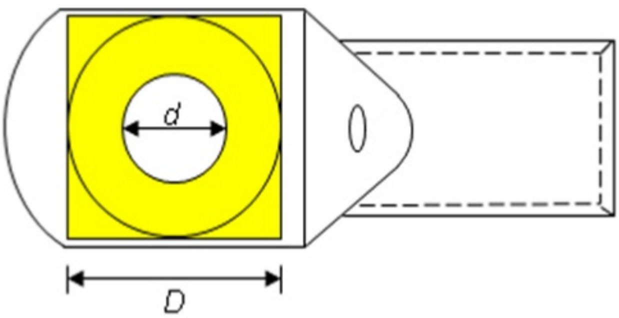


Figure 8 – Dimensions for calculating the effective area of a contact (example for a cable lug)

The effective contact area shall be within the geometrical limits of the contact area of the conducting element. In case it exceeds the outside geometrical limits, then the effective contact area is equal to the contact area of the conducting element.

4.18 Use of heat-shrinkable sleeves

Heat-shrinkable sleeves may be used on railway equipment for two purposes:

- for identification (by their colour, or by carrying the marking itself, or by keeping extra markings in place);
- for electrical and mechanical protection (e.g. prevention of water ingress and permanently maintaining a particular clearance or creepage distance).

Such sleeves should only be used in addition to appropriate insulation.

If heat-shrinkable sleeves are used for insulation they should be carefully selected to ensure

- the mechanical and electrical performance is comparable with the insulation it is replacing,
- the installed wall thickness is comparable to the core or cable insulation it is replacing.

Heat-shrinkable sleeves should be installed in accordance with the manufacturer's or the supplier's instructions and in particular, it should be noted that when shrinkage is restricted some properties may be impaired, e.g. wall thickness, mechanical and electrical performance.

When covering uninsulated parts by sleeves, only short lengths should be used. Otherwise the flexibility of the cable could be lost, fire behaviour changed and cooling conditions affected.

At the moment of using heat for shrinking the sleeves, the maximum allowed short time temperature (short-circuit temperature) for the cable material should not be exceeded.

If the use of heat-shrinkable sleeves needs to be restricted – e.g. owing to fire behaviour - to certain operating categories of vehicle, according to EN 45545-1, this shall be stated by the purchaser in the contract.

Heat-shrinkable sleeves shall conform to EN 60684-3-212, EN 60684-3-216 or EN 60684-3-271 except that test fluids may be changed by the sleeve manufacturer in order to determine whether the sleeves meet the requirements for specific applications (for example test fluids mentioned in Table H.1 or according to national standards).

4.19 Connections for return current

The requirements of EN 50153 shall be fulfilled.

4.20 Storage of cables

Storage of cables before installation on the vehicles should bear witness to good workmanship.

Where necessary, the drums and reels shall be protected against detrimental climatic environmental influences (rain, UV radiation, etc).

Where necessary, special care shall be taken into account when cables are stored externally:

- watertight protection by means of end caps
- protection against UV radiation protection by means of e.g. a foil around the cables on the drum

– for drums stored for a longer period in colder temperatures, the cables should be kept for at least 12 h at the installation conditions before they are used.

Cables installed on new vehicles should not exceed the manufacturing date by more than 5 years.

The cable manufacturer may recommend other storage requirements.

4.21 Cable conduits

The cable conduits and accessories should comply with EN 60423 and EN 61386-1.

Non metallic conduits and accessories shall comply with the fire requirements within EN 45545 series.

When selecting type of cable conduit the expected operational and environmental conditions for the different locations as per Annex K should be taken into account. These should include but are not limited to the following parameters:

– interior,

– exterior,

– static,

– dynamic,

– flexibility

– on roof (UV),

– fuel,

– oil,

– cold impact,

– current de-rating of cables due to thermal effect in close conduits,

NOTE 1 Metric thread sizes are required for conduit adaptors.

NOTE 2 In exterior applications the conduit adaptors need to fulfill IP 65 at minimum, according to EN 60529.

4.22 Electrical bolted connections

Unless torques are specified by the manufacturer, the pressure applied to copper conducting parts shall be initially between 10 MPa and 20 MPa. These values apply to both half hard and soft copper. Unless otherwise specified by the manufacturer, the pressure applied to aluminium conducting parts shall be initially between 7,5 MPa and 15 MPa.

The maximum stress of metallic nuts and bolts shall not exceed 75 % of the elastic limit of the material.

Additionally, the following parameters should at least be taken into account:

– prevention of lug movement (cabling fixings);

– sequence order of elements belonging to the bolted connection (washers, nuts, bolts, studs, etc.);

– relative dimensional definition of the fixing elements (washer inner and outer diameter, bolt or stud diameter, etc.);

– extra-length for studs or bolts allowing correct nut fitting;

– enough length to allow 3 lugs for power cabling or 4 lugs for control cabling;

– environmental influence (corrosion, vibration, temperature, etc.), surface finish requirements and material combination (see 4.17);

– washer types (conical spring washers, flat washers, etc.);

– possibility to use lock nuts.

To avoid relative movements between elements belonging to a bolted connection (i.e. cable lug and washers), the cable should be fixed.

Figure 9 and Figure 10 show typical examples of sequence orders on a bolted connection.

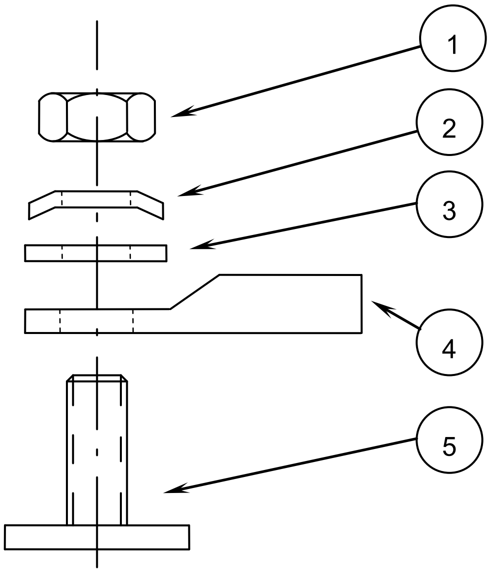
NOTE 1 Regarding restrictions to current flowing through threads, see 4.17.3.

When a conical washer is used, then the diameter of it shall be smaller than the diameter of the flat washer after tightening with the correct torque.

When terminal studs are used in bolted connections, then sufficient excess length of, at least, two thread turns shall be visible after tightening with the correct torque.

NOTE 2 Maximum number of cable lugs may be taken into account for the length of the stud.

Inner diameter of washers and cable lugs shall be suitable to the outer diameter of the bolt and the outer diameter of the washer shall be suitable to the cable lug.



Key

1 nut

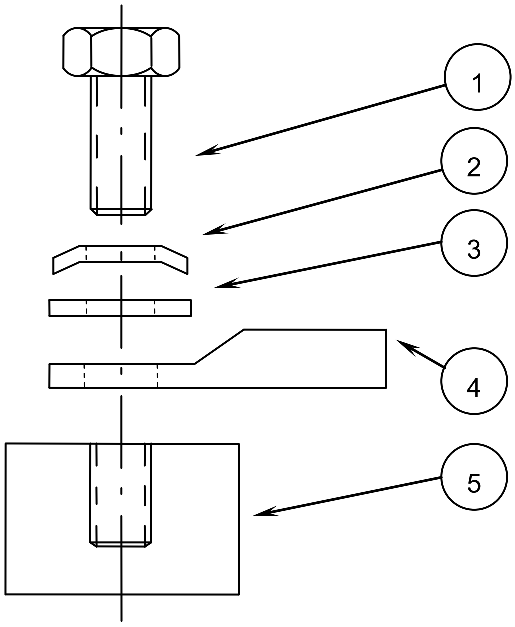
2 conical spring washer

3 flat washer

4 cable lug

5 terminal stud

Figure 9 – Example of sequence order of elements belonging to a bolted connection (nut)



Key

1 bolt

2 conical spring washer

3 flat washer

4 cable lug

5 boss

Figure 10 – Example of sequence order of elements belonging to a bolted connection (bolt)

5 EMC requirements

5.1 General

The requirements specified in Clause 5 are based on the assumption that the car-body is conductive. When the car-body consists of non-conductive materials, more stringent measures are necessary to achieve EMC.

Cables are exposed to electromagnetic interference and they can also act as an interference source.

The requirements of EN 50121-3-1 and EN 50121-3-2 (concerning test methods and limit values) shall be fulfilled.

In order to fulfil EN 50121-3-1 and EN 50121-3-2, the following cabling requirements should be fulfilled to the greatest possible extent.

Regarding magnetic fields which may have impact on human beings bearing active implantable medical devices, care should be taken when planning high power cable lying (e.g. DC power conductors should have their feed and return cables laid as close together as practicable.).

5.2 Cable categories

For cable lying, all cables should be classified employing at least three EMC cable categories as given in Table 5.

Table 5 – Cable categories with respect to EMC

EMC cable category	Task of cable
A	Power supply 1: Pantograph/current collector cables supplying traction, heating, auxiliary power supply converters. Power supply 2: Motor cables, braking resistor cables, cables to line filters (on inverter side), auxiliary equipment supply cables, combustion motor starter cables, etc.
B	Battery cables, binary control cables, etc.
C	Cables for signal transmitters, antenna cables, loudspeaker cables, databus cables, etc.

NOTE 1 The category names A, B, C are not mandatory.

NOTE 2 More categories and/or sub-categories are allowed.

NOTE 3 Splitting of category A into 2 groups is for safety reasons only, see 4.11.

5.3 Separation of cables

Cables of different categories should be laid separately wherever possible. The required distance between cables or cable bundles is in theory dependent on power, frequency components, length of parallel lying and immunity against emission. For practical purposes, the minimum distances in air between the cables in different cable categories shall be chosen according to Table 6.

When crossing of cables of different categories is necessary, this shall be done perpendicular wherever possible.

Table 6 – Minimum distances between cables of different EMC categories

EMC cable categories	Separation distance m
A and B	0,1
A and C	0,2
B and C	0,1

Separate lying of the cables belonging to each of the various cable categories and separation by the minimum distances according to Table 6 should be maintained wherever possible.

The minimum distances specified by Table 6 may not be applied in the case of the intersection of cables belonging to different EMC categories, which are perpendicular to each other.

In cases where the minimum distances between cables in different categories cannot be obtained (in particular with respect to the distances between categories A and C), cables should be separated by metallic sheathings, metallic overall screenings, metallic coverings or metallic enclosures, which are electrically connected to car-body structure (grounding).

5.4 Return conductor

The feed and the return cables of a circuit should be laid as close together as practicable, in particular in the case of power cables emitting disturbances, and sensitive signal cables. Twisted cables or cores should be used for this purpose, where available and practicable.

NOTE This measure can reduce not only EMC problems but also noise problems.

5.5 Use of conductive structure

Cables shall be installed as close as possible to conductive vehicle structures (metallic car-body plates, metallic cable ducts, metallic tubes, etc., connected to the car-body by means of a conductive connection) to make maximum use of the reduction effect resulting from the cancellation of the field from the cable by the opposite field reflected from the metal surface.

5.6 Shielding and earthing

Cables of category A may be shielded, in order to reduce emissions. If not otherwise recommended by sub system manufacturer, cables of category C shall be shielded, in order to increase immunity. In cases where high levels of electromagnetic disturbance are expected, cables of all categories should be shielded.

NOTE Shielding may be performed by a screen around a single core or by a screen around the cable or by a metallic enclosure.

Where screens are connected to car-body, this should be done over an area as wide as possible (i.e. a low inductive connection). Connections where the screen is brought down to a single conductor (“pigtail”) and extended through a connector pin or to an earth point should not be used in a frequency range above 100 kHz or where other practical solutions are possible.

At frequencies below 100 kHz where pigtails cannot be avoided, the length of the pigtail should be as short as possible and should not exceed 5 cm.

In general, the screen of a cable should be connected to car-body structure (grounding) as often as possible, and at least at both ends. (Refer to Annex I). Exceptions from this requirement can be necessary when the current flowing through the screen could be too high, or if unwanted signals could be generated (e.g. at axle mounted speed sensor signals, or at audible signals like loud-speaker signals).

An earthing concept (or earthing plan) should be drawn up to ensure that higher compensating or return currents due to voltage differences between the screen earthing points, do not flow through the screens.

In trolley buses, the EMC purpose screens shall be connected to the car-body. The protective earth screens – if any - shall be connected to an intermediate potential without any electrical connection to car-body.

5.7 Supply connection from battery

Separate cables from the battery should be employed for the battery side supply of components with pulse-shaped or pulse controlled load, where this is necessary. The branch off from the other supply cables should then be situated as close as possible to the battery.

5.8 Databus lines

Databus lines should always be routed through dedicated plug connectors. Exceptions should only be made where there is no other physical solution (e.g. in vehicle couplers).

Different databus lines may be routed through a common plug connector. The databus cores shall then be assigned to the plug connector pins in such a manner that the greatest possible separation is achieved between the different databus lines.

NOTE This has also space advantages in the plug housing.

Interruption of databus screening, if necessary, shall be according to the databus specification or standard.

6 Marking for identification

6.1 General

This clause specifies marking additional to type marking on cables or equipment, in order to identify a particular piece of cable or equipment as being responsible for a certain function.

The marking for identification of cables, cores and connectors etc. should be changeable. The marking itself shall be permanent and easily legible for the expected lifetime of the cabling. The information contained in the marking shall be in accordance with the documentation (circuit diagrams, wiring lists etc., as appropriate).

6.2 Marking for identification of cables and busbars

Cables and/or the individual cores installed in the vehicle - including spares - shall be marked for identification at all terminals and other detachable points in a practical way.

Individual cores in a multi-core cable may be un-marked if the cable is marked in accordance with the documentation (circuit diagrams, wiring lists etc., as appropriate) and if the individual cores are identifiable by insulation colours or numbers etc. on the core insulation, or by configuration (see Figure 11).

NOTE For cables, there are several marking systems existing, e.g.

– unique numbers: each cable part has a certain number which identifies it. This system will give the same marking at both ends of the cable,

– equipment numbers: each end of each core part has a marking, identifying the connection point of equipment where the core will end. This system will give different marking at the ends.

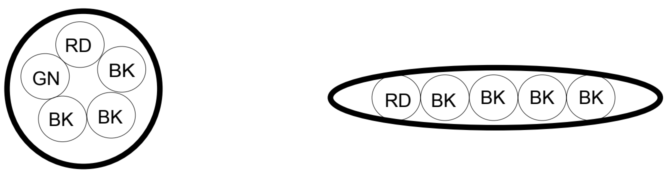


Figure 11 – Examples of cable or plug constructions where identification is done by configuration

For abbreviations of colours see IEC 60757.

If the space available is too small to provide a full marking for identification of the individual cores, it may be omitted if the identification is unambiguously present or replaced by an individual core number coding system.

If marking for identification by printing directly on the cables is used, the printing method shall be submitted to the same contrast tests as other marking for identification systems and it should only be used for minimum cross section ≥ 1 mm² to improve legibility. The printing direction may be mirrored to respect the reading direction towards both termination ends.

If there is any possibility of confusion, busbars shall be marked for identification.

6.3 Marking for identification of terminal blocks, individual terminals, plugs and sockets

All terminal blocks shall be marked for identification, if there is any possibility of confusion. Marking shall be placed on the block, adjacent to it or on the cover on it.

The individual terminals on the terminal block shall be identified by numbers, letters, symbols etc.

All plug/socket devices should be marked for identification. If there is any possibility of confusion, plug/socket devices shall be marked for identification or coded.

6.4 Marking of insulators

Insulators may not be marked for identification, but shall be identifiable from the available documentation. The marking - if any - shall be placed in the vicinity of the insulators.

6.5 Marking for warning against electrical shock

Live parts of conducting elements to which operation or maintenance staff may have access, shall be indicated by warning labels accordingly.

Refer to EN 50153 and EN 61310-2 for details.

6.6 Marking using heat-shrinkable sleeves

If the marking is by heat-shrinkable sleeves, the tests described in Annex H shall be used for demonstrating the quality of the marking.

NOTE Black printing on yellow or white heat-shrinkable sleeves is preferable for contrast reasons.

7 Testing

7.1 General concerning testing

After installation, the completed cabling shall be tested by routine tests. Any component tests - cable type tests included - should be completed before this testing starts.

Concerning testing of cabling on rolling stock, EN 50215:2009 specifies the following items:

– cable lengths (refer to 8.2.2.3 in EN 50215:2009, concerning appropriate length for car-to-car and car-to-bogie connections);

– electric insulation tests (8.7 in EN 50215:2009). The concerned routine tests shall show that the cabling has been installed and finished correctly, being free from damage to insulation materials. It is not intended to test the installed equipment or the cable material, since this is expected to have been tested before, during their manufacturing (see below);

– earthing circuits (8.8 in EN 50215:2009);

– train control circuits (8.15 in EN 50215:2009);

– traction system (8.17 in EN 50215:2009);

– safety related systems (8.20 in EN 50215:2009);

– EMC (9.15 in EN 50215:2009);

– etc.

7.2 Electrical insulation tests

7.2.1 General

The objective is to test the insulation integrity of the vehicle electrical circuits.

In a series of cabled vehicles or components, these tests shall be performed on all cabled vehicles or components.

All connection devices which are part of the cabling installations on board railway rolling stock, e.g. connectors, terminals, etc shall be designed to pass all cabling tests described in 7.2.2 and 7.2.3.

The voltage withstand tests according to 7.2.2 may be carried out not on the completed vehicle, but upon completion of the cabling, after mounting and before connection of items of electrical equipment already tested individually for dielectric strength e.g. according to their equipment standard. In this case the insulation impedance test according to 7.2.3 shall be carried out once the vehicle has been entirely completed.

Equipment which has previously passed insulation tests to an agreed standard (EN or IEC) may also be disconnected before the vehicle insulation test.

In cases where double insulation of the electrical equipment from the car-body is specified, e.g. trolley bus systems, then it shall be verified that such insulation exists and that each part of the insulation system can withstand the requirements of the insulation tests in this clause.

Any functional tests shall be performed after the electrical insulation tests.

The insulation integrity shall be demonstrated by applying both voltage withstand test and insulation impedance test as described under 7.2.2 and 7.2.3.

If an insulation impedance test is carried out both before and after the voltage withstand test, the test conditions shall be the same during both insulation impedance tests, and the impedance value measured by the test following the voltage withstand test shall be within 10 % of those measured in the initial test.

NOTE In many cases, it is useful to perform the insulation impedance test (DC 500 V) before the voltage withstand test, in order to find elementary insulation faults without applying higher test voltage.

The test procedure used and the test results shall be recorded. This information shall be made available for the purchaser on request.

7.2.2 Voltage withstand test

7.2.2.1 Preparing for the test

Frequently, the equipment is composed of several groups of circuits with different voltage levels; each group shall be separately tested to earth, all other groups in principle being earthed.

As necessary, contactors and other switchgear should be closed or short circuited to ensure that all parts of the circuit are connected. All precautions shall be taken in order to avoid abnormal voltages due to capacitive or inductive effects.

Equipment likely to suffer during the tests, e.g. electronic components, shall be disconnected or short circuited. Such equipment shall have previously passed an insulation test to a relevant equipment standard.

The withstand test voltages are given in Table 7 and Table 8 below. They shall be applied between the various circuits and earth.

Each core or circuit may be tested separately to earth. In this case, the other conductors or circuits may not be earthed.

NOTE It is allowed to test each circuit separately, because this is according to practice, i.e. when testing with automatic machines.

7.2.2.2 Test voltages

Unless otherwise agreed in the contract, the test voltages shall be selected as follows.

a) Testing by alternating current (AC 50 Hz)

The test voltages shall be selected according to Table 7 and Table 8. Test voltages shall however not be higher than 85 % of the test voltages for associated components including the cable type test voltages.

Testing should preferably be performed with AC 50 Hz rms. If the circuits to be tested contain diodes or capacitors, the appropriate DC voltage value shall be used. (DC value = AC value x $\sqrt{2}$).

The test voltage shall be increased progressively from zero and shall be reached within 5 s and be maintained for a minimum of 10 s and then be decreased progressively to zero. If a flashover occurs during this test, the test should be stopped by switching off the voltage immediately.

NOTE 1 Other standards may require that the test voltage be maintained for 1 min or more. The cable material used is assumed to have passed a product test before installation. As the test described in this document is intended to discover installation problems, a test duration shorter than 1 min may be used.

This test has been passed when no flashover has occurred and no voltage breakdown has been detected during the test.

b) Testing by impulse voltage

This procedure may be preferred when using automatic testing machines. If no voltage values are agreed in the contract, these voltages shall be selected according to Table 7 and Table 8. The voltages shall be applied according to EN 61180-1 and the test has been passed when no flashover and no voltage breakdown have occurred.

Table 7 – Test voltages according to on-board voltages

Nominal on-board voltage (DC or AC rms, conductor to earth) U_n	Test voltage AC 50 Hz U_p	Impulse test voltage (1,2/50 µs according to EN 61180-1) U_{imp}
up to 36 V	500 V	1000 V
up to 72 V	750 V	1500 V
up to 120 V	1000 V	2000 V
up to 240 V	1500 V	3000 V
up to 360 V	2000 V	4000 V
Over 360 V	(2,5 x U_n + 2000) x 0,85 V	U_p x 2 V

Table 8 – Test voltages according to supply line voltages

Nominal supply line voltage U_n	Test voltage AC 50 Hz U_p	Impulse test voltage (1,2/50 µs according to EN 61180-1) U_{imp}
DC 750 V	3300 V	6500 V
DC 1500 V	4900 V	10000 V
DC 3000 V	8100 V	20000 V
AC 15000 V 16,7 Hz	34000 V	65000 V
AC 25000 V 50 Hz	55000 V	110000 V

If voltage withstand tests are repeated, the test voltage should be reduced by 20 % of original test voltage for each new test, in order not to destroy insulation. A maximum reduction to 60 % of the original test voltage should be applied.

7.2.3 Insulation impedance test

7.2.3.1 Preparing for the test:

All preparation steps should be the same as described under 7.2.2.

7.2.3.2 Test limits

Unless other values are agreed in the contract, the test voltages shall be DC 500 V and the minimum insulation impedance values measured shall not be less than those given below for new vehicles:

– 5 MΩ for circuits having a rated voltage equal to or greater than DC 300 V or AC 100 V ;

– 1 MΩ for circuits having a rated voltage less than DC 300 V or AC 100 V.

In the case of extraordinary test conditions, as high relative humidity or high ambient temperature, use of special cables, etc, values of less than 1 MΩ may be accepted.

Such conditions shall be recorded.

When testing vehicles which have been in service, reduced test insulation impedance values should be accepted.

Annex A
(normative)

Cable sizing – Calculation under short time current conditions

If operation assures the cooling down of the cable, due to that the load is not continuous or not sustained cyclic. Not continuous or not sustained cyclic is the case when the “off time” is longer than 5 times the thermal time constant.

I_{load} is the maximum load within t_2 .

t_2 is the duration of a typical „on-time” during service, in minutes (min)

T is the thermal time constant of the cable in minutes (the thermal time constant or an equivalent formula shall be that provided by the cable manufacturer)

The k_4 correction factor according to Table A.1 shall be used when calculating I_{corr} in 4.2.3 b). Linear interpolation between two lines in Table A.1 is allowed.

Table A.1 – Modification factor k_4

Coefficient of use t_2 / T	**Modification factor k_4**
3	1,02
2,7	1,03
2,4	1,04
2,1	1,06
1,8	1,09
1,5	1,13
1,2	1,19
0,9	1,30
0,75	1,38
0,6 and lower	1,49

For cables according to EN 50264 series with cross-sectional areas (A) above 50 mm², the following empirical formula may be applied to determine the thermal time constant T:

$$\mathrm{T} = 1{,}8 \times (\sqrt{\mathrm{A}} - 5)$$

where A is the cross-sectional area of the conductor in square millimetres (mm²) and T is the thermal time constant of the cable in minutes (min).

Annex B
(informative)

Cable sizing – Examples of current ratings

The values presented below concern single-core cables in free air with copper conductors, which in practice are valid when a clearance between the cable surface and any adjacent surface of at least 1,0 times the outer diameter of the cable exists.

The values are based on DC or AC 50 Hz at an ambient temperature of T_{ref} = 45 °C with a maximum conductor operating temperature of $T_{c(max)}$ = 90 °C. The values are taken from EN 50355 and they are intended for use with railway cables defined in EN 50264 series, EN 50382 series and EN 50306 series.

I_{cable} for other maximum conductor temperatures than $T_{c(max)}$ = 90 °C , refer to Annex C.

The same I_{cable} value for screened and unscreened cables may be used, when no significant current is flowing through the screen.

Table B.1 – Examples of current ratings for standard wall cables, with 90 °C maximum conductor operating temperature

Nominal conductor cross sectional area **(Examples: for information only)** mm²	**Current carrying capacity (effective value; one cable in air)** T_{ref} **= 45 °C;** $T_{c(max)}$ **= 90 °C** **DC or AC 50 Hz** I_{cable} **(A)**
1	20
1,5	25
2,5	33
4	46
6	60
10	85
16	110
25	150
35	190
50	240
70	300
95	360
120	425
150	490
185	560
240	675
300	775
400	950

When significant current is flowing through the screen, the screen should be considered as an additional current carrying conductor. The current load on a screen shall not exceed the value specified by the cable manufacturer.

At higher frequencies, cables have reduced current carrying capacity. In such cases, current carrying capacity should be defined by the cable manufacturer.

Annex C
(normative)

Cable sizing – Calculating current ratings for temperature classes other than 90 °C

For temperature classes other than 90 °C, the values in Table B.1 shall be used after multiplying the values in Table B.1, column I_{cable} by a factor k^* according to Table C.1 or according to the formula below.

Table C.1 – Factor k^*, used when comparing current ratings for 90 °C maximum conductor operating temperature with other temperature classes

$T_{\text{c(max)}}$ °C	**Factor k^* (comparing with 90 °C class values)**
90	1,0
105	1,14
120	1,26
140	1,40
150	1,46

The values in Table C.1 may be calculated by the formula

$$\mathrm{k}^* = \sqrt{\frac{(T^*_{\text{c(max)}} - T^{45°}_{\text{ref}}) \times (1 + 0{,}004 \times T^{90°}_{\text{c(max)}})}{(T^{90°}_{\text{c(max)}} - T^{45°}_{\text{ref}}) \times (1 + 0{,}004 \times T^*_{\text{c(max)}})}}$$

where

$T^*_{c(\max)}$ is the new temperature class to be calculated;

$T^{90°}_{c(\max)}$ is the temperature class of the basic Table B.1 (see Annex B) = 90 °C;

$T^{45°}_{ref}$ is the reference ambient temperature for both temperature classes = 45 °C.

Observe that for use in the above formula only temperature values in Kelvin (K) shall be used.

Annex D
(normative)

Cable sizing – Correction factor k_1 for expected ambient temperature

In Table D.1 are listed some values of modification factor k_1 for current capacity, depending on T = ambient temperature of the selected cable type, and on a maximum conductor operating temperature of $T_{c(max)}$ of selected cable type. Reference ambient temperature T_{ref} = 45 °C.

The values are calculated with the formula in 4.2.3 b). Other values - if necessary - can also be obtained with that formula.

Table D.1 – Modification factor k_1

	Expected ambient temperature T °C											
Cable type	35	45	55	65	75	85	95	105	115	125	135	145
k_1 for $T_{c(max)}$ = 90 °C	1,11	1	0,88	0,75	0,58	0,33	-	-	-	-	-	-
k_1 for $T_{c(max)}$ = 105 °C	1,08	1	0,91	0,82	0,71	0,58	0,41	-	-	-	-	-
k_1 for $T_{c(max)}$ = 120 °C	1,06	1	0,93	0,86	0,77	0,68	0,58	0,45	0,26	-	-	-
k_1 for $T_{c(max)}$ = 140 °C	1,05	1	0,95	0,89	0,83	0,76	0,69	0,61	0,51	0,40	0,23	-
k_1 for $T_{c(max)}$ = 150 °C	1,05	1	0,95	0,90	0,85	0,79	0,72	0,65	0,58	0,49	0,38	0,22
Reference ambient temperature T_{ref} = 45 °C.												

Annex E
(normative)

Cable sizing – Prediction of cable lifetime

E.1 General cable lifetime considerations

In 4.2.3 b), the formula for the current carrying capacity of the cable in service, I_{corr}, is given. To allow for a change in predicted cable lifetime by this formula, the correction factor k_3 shall be used.

k_3 values >1,0 indicates that cable lifetime is decreased. k_3 values <1,0 indicates that cable lifetime is increased.

NOTE For many relevant materials there is a relation between temperature and change of characteristics over time; this change is called ageing.

The insulation and sheath materials etc, of a cable are mostly made of different components where some components are more prone to ageing than others. Normally one must analyze that component which is ageing at the highest speed. Ageing effects for insulation materials may be described by Arrhenius plots according to EN 60216-1.

A thumb rule for this called „Montsinger’s rule“ allows - for a limited temperature interval - the assumption that an 8 K increase of temperature will reduce the lifetime by a factor of 2.

(Example: If a train cabling is made for 20 years of service, the cabling lifetime would according to the above rule be reduced to 5 years by increasing its current load so that the temperature rises 16 K.)

Railway rolling stock manufacturers are facing the fact that their trains are expected to be used for 30 years or more.

Expecting from a train that it will be in service 18 h per day, 350 days per year would give 6300 h service per year. 15 years respectively 40 years would then mean approx. 100.000 h respectively 250.000 h service time.

If the cabling cannot be designed for the lifetime of the train, then it should be replaced after the designated lifetime of the cabling.

The following text including the following table is copied from EN 50355:2013, 6.3 e):

The continuous maximum conductor temperature for the cable types defined in the various parts of EN 50264, EN 50306 and EN 50382 are given in Table E.1. This is based either on proven experience and reliability over many years or, in the case of newer, less well defined insulations, upon an acceptance test, using long-term thermal endurance ageing to EN 60216-1 to demonstrate an expected lifetime of at least 20 000 h at the temperatures given in Table E.1 (i.e. 20 °C above the continuous rating). Data from this thermal testing can, with care, be extrapolated to the conductor temperature to provide a predicted continuous lifetime of the cable.

This estimated lifetime may be used in conjunction with the known duty cycle of the vehicle, and its predicted time out of service, to estimate the ability of cable to function reliably for the expected service life of the whole vehicle.

Table E.1 - Temperature for expected lifetime according to reference standard

Standard reference	Continuous maximum conductor temperature °C	Temperature for 20 000 h expected lifetime °C
EN 50264	90	110
EN 50306	90	110
	105	125
EN 50382	120	140
	150	170

E.2 Reducing cable lifetime

When decreasing lifetime, k_3 shall be calculated according to the following formula

$$k_3(\Delta T) = \sqrt{\frac{(T_{c(max)} + \Delta T - T_{ref}) \times (1 + 0{,}004 \times T_{c(max)})}{(T_{c(max)} - T_{ref}) \times (1 + 0{,}004 \times (T_{c(max)} + \Delta T))}}$$

where

$T_{c(max)}$ and T_{ref} are as defined under 4.2.3 b). Observe that for use in the above formula only temperature values in Kelvin (K) shall be used;

ΔT is the deviation of $T_{c(max)}$ for decrease in predicted cable lifetime, in Kelvin (K). Unless otherwise specified by the cable manufacturer, the maximum possible ΔT shall be 24 K and the minimum ΔT shall be 0 K.

NOTE 1 The above formula only takes into account temperature changes as the CSA of the cable changes while keeping the current constant. Ageing as a chemical process is not considered.

NOTE 2 For some cable types, it is not allowed to increase temperature over the value of $T_{c(max)}$ for sustained periods. Overload values need to be agreed with the cable manufacturer.

The parameter 0,004 is valid only for copper.

Examples of $k_3(\Delta T)$ for $T_{c(max)}$ = 363 K (equal to 90 °C) and T_{ref} = 318 K (equal to 45 °C) as calculated by this formula are given in Table E.2.

Table E.2 – Examples of values of correction factor k3 to allow for decrease in predicted cable lifetime for a 90 °C cable

ΔT	$k_3(\Delta T)$	**Influence on predicted cable lifetime**
0 K	1,00	Unchanged predicted lifetime
8 K	1,08	Lifetime divided by 2
16 K	1,15	Lifetime divided by 4
20 K	1,18	Lifetime divided by 5
24 K	1,21	Lifetime divided by 8

E.3 Increasing cable lifetime

When increasing lifetime, in theory the same formula as under E.2 above may be used.

Each used cable mostly consists of several components which each can have a different speed of ageing. Further, ageing is not linear over a wider range. For these reasons, amongst others, it is important that in each case an agreement with the cable manufacturer is achieved when sizing the cables.

Annex F
(informative)

Cable sizing – Calculation examples

In this annex, some calculation examples concerning the items considered in 4.2.3 and Annex A, Annex B, Annex D and Annex E are given.

EXAMPLE 1:

concerning use of formulae and factors considered in 4.2.3 and in Annex B, Annex D, and Annex E. (I.e. the load is supplied cyclically for a longer time).

A cable is to be dimensioned for a typical operation carrying DC 475 A, being cyclically switched 'on' for 8 min and 'off' for 40 s.

Expected ambient temperature with T = 55 °C.

4 cables in closed tube.

So total cycle time is 520 s and on-time is 480 s.

We choose a cable type with $T_{c(max)}$ = 90 °C and a given current carrying capacity at T_{ref} = 45 °C (according Annex B, Table B.1).

Cable rating according to the procedure in 4.2.3 is then:

$$I_{\text{load}} = \sqrt{\frac{1}{t_1}\int i^2 \, \text{dt}} = \sqrt{\frac{(475\text{ A})^2 \text{ x } 480\text{ s}}{520 s}} \approx 456{,}4 \text{ A}$$

Now we use the formula under 4.2.3 c), finding

k_1 = 0,88 (according to Annex D, Table D. 1, modification factor k_1 for ambient temperature 55 °C with $T_{c(max)}$ = 90 °C)
k_2 = 0,65 (according to 4.2.3 c), Table 2, in a closed tube [Type f)], 4 cables fully loaded)
k_3 = 1,0 for lifetime 100 000 h
k_4 = 1,0 (current load is applied in continuous operation)
k_5 = 1,0 (single core cable used, according to 4.2.3 b, Table 1).

$$I_{\text{cable}} \geq \frac{I_{\text{load}}}{k_1 \times k_2 \times k_3 \times k_4 \times k_5} = \frac{456{,}4\ A}{0{,}88 \times 0{,}65 \times 1{,}0 \times 1{,}0 \times 1{,}0} \approx 798 A$$

So a 300 mm² size conductor in a cable of this type having an I_{cable} = 775 A is in theory too small.

As it is planned to replace this cable after 50 000 h of service, we choose k_3 = 1,08 according to Annex E:

$$I_{\text{cable}} \geq \frac{I_{\text{load}}}{k_1 \times k_2 \times k_3 \times k_4 \times k_5} = \frac{456{,}4\ A}{0{,}88 \times 0{,}65 \times 1{,}08 \times 1{,}0 \times 1{,}0} \approx 739\ A$$

Now, a 300 mm² size conductor in a cable of this type is correctly sized.

<u>EXAMPLE 2:</u>

concerning use of formulae and factors explained in 4.2.6, for a cable or bare conductor carrying a high current for a very short time (i.e. short-circuit calculation).

A short-circuit is assumed to be applied with 15 kV and 40 kA during 100 ms.

In this case, the relevant formula is given by HD 60364-5-54:2011, 543.1.2:

$$S = \frac{\sqrt{I^2 t}}{k}$$

where

S is the cross-sectional area, in mm² ;

I is the value (rms) in A of prospective fault current for a fault of negligible impedance, which can flow through the protective device (see EN 60909-0);

t is the operating time of the protective device for automatic disconnection in s;

k is a factor dependent on the material of the protective conductor, the insulation and other parts and the initial and the final temperatures (for calculation of k, see HD 60364-5-54:2011, Annex A).

If application of the formula produces non-standard sizes, conductors of a higher standard CSA will be used.

Because we have a bare conductor, the k factor is taken from HD 60364-5-54:2011, Table A.54.6. We prefer a copper cable and assume “normal conditions” according to the Table, an initial temperature of 30 °C and a maximum cable temperature of 200 °C, which gives k = 159.

$$S = \frac{\sqrt{40000^2 \times 0{,}1}}{159} mm^2 = 79{,}55 mm^2$$

As this is a non-standard size, we chose the next higher standard cross-sectional area which is **95 mm²** .

EXAMPLE 3:

concerning use of formulae and factors explained in 4.2.7, for an insulated cable carrying a current load for a time shorter than 5 s.

A supply cable for a thermal engine starter motor must be sized.

The starter motor will operate at 2200 A and is assumed to be switched on for 4 s.

To be able to chose the correct k factor from Annex A of HD 60364-5-54:2011, we assume the ambient temperature to be 45 °C and an maximum end temperature of 130 °C to avoid damage of e.g. fixations. A copper cable is preferred.

Using the general formula for k in the beginning of Annex A of HD 60364-5-54:2011, we get

$$k = 226\sqrt{\ln(1 + \tfrac{130-45}{234{,}5+45})} = 116.$$

Here, the 226 value is taken for copper material in Table A.54.1, and the square root term is calculated using the formula before Table A.54.1.

The formula for S is the same as used in above example 2:

$$S = \frac{\sqrt{2200^2 \times 4}}{116} mm^2 = 38 mm^2$$

As 38 mm² is a non-standard size, we chose the next higher standard cross-sectional area which is **50 mm².**

Annex G
(informative)

Terminations

G.1 Methods of terminating cables

Table G.1 – Methods of terminating cables – Conductor side

Type	Mechanical aspects	Electric aspects
Crimping	- Predictable mechanical behaviour - Permanent pressure applied on core from crimping barrel around - Many materials can be used - Wide spectrum of cross-sectional areas can be used - Correct stripping length	- Permanent good electrical connection
Soldering	- Small mechanical forces only - Danger of breaking - Only certain materials can be used	- Good electrical connection
Welding	- Only certain materials can be used	- Good electrical connection
Untreated core ends (insulation stripped or displaced)	- Permanent pressure applied on core with spring-clamp technology - Unpredictable mechanical behaviour when re-terminating without precautions	- Permanent good electrical connection with spring-clamp technology - Unpredictable electrical behaviour when re-terminating without precautions
In general, soldering should be used only for internal connections of e.g. electronic devices or certain components if there is no risk of fatigue failure or if precautions have been taken to avoid this risk. Soldering is forbidden for rolling stock cabling between components in certain countries.		

Table G.2 – Methods of terminating cables – Terminal side – Crimp connections (1 of 2)

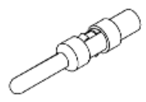
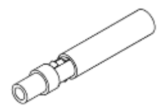
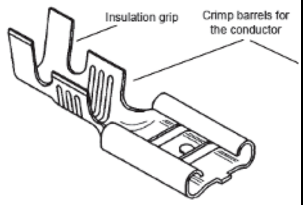
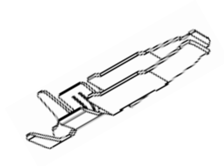
Type	Standards	Examples	General aspects	Mechanical aspects	Electric aspects
Crimp connection Closed barrel crimp contact CSA ≤ 10 mm² CSA > 10 mm²	EN 60352-2 EN 50467	 	- Closed barrel crimp contact (machine turned) - EN 60352-2 for CSA ≤ 10 mm² - Crimping rules for tubular lug are applicable for CSA > 10 mm²	- Vibration proof - Pull out force according to EN 60352-2:2006, Table 1 - Pull out force according to Table G.7	- Permanent good electrical connection - Contact resistance according to EN 60352-2:2006, Figure 6 curve A
Crimp connection Open barrel crimp contact	EN 60352-2 EN 50467	 With insulation grip 	- Open barrel crimp contact (stamped and formed) - EN 60352-2 for CSA ≤ 10 mm²	- Insulation grip to improve strain relief and vibration resistance - Pull out force according to EN 60352-2:2006, Table 1	- Good electrical connection - Contact resistance according to EN 60352-2:2006, Figure 6 curve A

Table G.2 – Methods of terminating cables – Terminal side – Crimp connections (2 of 2)

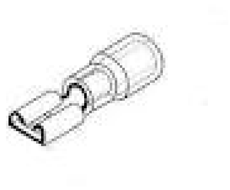
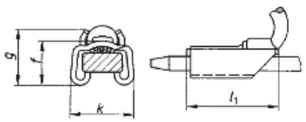
Type	Standards	Examples	General aspects	Mechanical aspects	Electric aspects
Crimp connection Insulated clip (Faston, female connection)	EN 61210		- Insulation material on the clip according to EN 45545 series - Clip material to retain the elasticity i.e. phosphor bronze - CSA ≤ 6 mm²	- Insulation support - Reinforced body to absorb vibrations - Pull out force according to EN 61210:2010, Table 9 - Retention force according to EN 61210:2010, Table 6	- Permanent good electrical connection - Recommended max. current load per tab size [mm]: 6,3 x 0,8 : 16 A 5,0 x 0,8 : 10 A 2,8 x 0,5 : 5 A
Crimp connection Insulated lug (Ring terminal)	EN 60352-2		- Insulation material on the clip according to EN 45545 series - CSA ≤ 6 mm²	- Insulation support - Reinforced body to absorb vibrations - Pull out force according to EN 60352-2:2006, Table 1	- Permanent good electrical connection
Crimp connection Tubular lug	DIN 46235 NF F 00-363		- Inspection hole - Chamfered cable entry - Tin plated annealed copper - Wide range of cross-sectional areas can be used	- Pull out force according to Table G.3 - Reliable repeated crimp method with calibrated tooling	- Permanent good electrical connection
Termi-point (Pin or post crimping)	DIN 41611-4		- Connection method not to be used without prior agreement of the customer - Electronic devices only	- Only for small forces - Cable insulation support	- Good electrical connection

Table G.3 – Methods of terminating cables – Terminal side – Screwed and bolted connection

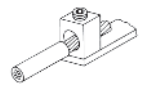
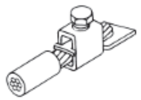
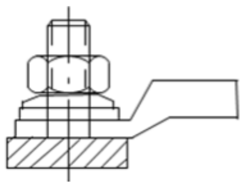
Type	Standards	Examples	General aspects	Mechanical aspects	Electric aspects
Screw terminal (applying directly or indirectly permanent pressure on the conductor end, but not penetrating it)	EN 60999-1 EN 60999-2 EN 60947-1 EN 60947-7-1	 	- Untreated core ends with screw terminals is forbidden	- Contact force could decrease during time (low resistance to vibration) - Contact force could decrease during time due to ductility of the material - Pull out force according to EN 60947-1:2007, Table 5	- Contact resistance (voltage drop) according to EN 60947-7-1
Bolted connection (applying permanent pressure on the conductor end; having a bolt hole in the cable lug or terminal end)	EN 60947-7-1		- Respect the sequence according to 4.22 and respect the maximum allowed number of connections according to 4.17.3 - Wide range of cross-sectional areas can be used	- Tightening torque value shall be specified by manufacturer - Very high contact forces possible - Each bolted connection should be, once tightened and torque controlled, clearly identified for visual inspection (colour marking)	- Permanent good electrical connection - Contact resistance (voltage drop) according to EN 60947-7-1
Axial screw terminal			- Connection method not to be used without prior agreement of the customer	- Sensitive to vibration and bending - Radial stresses to be avoided, adequate strain relief needed	

Table G.4 – Methods of terminating cables – Terminal side – Connection by clamping

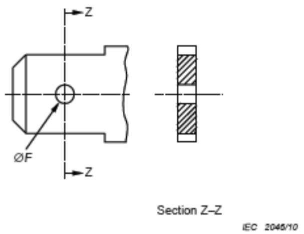
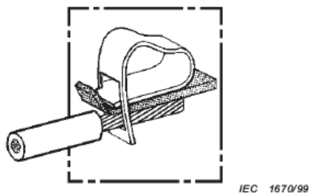
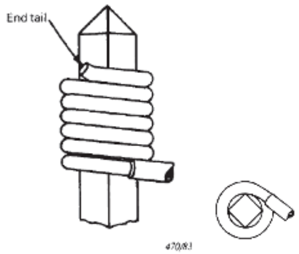
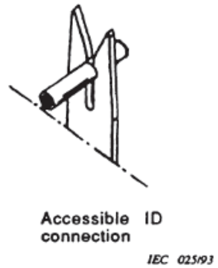
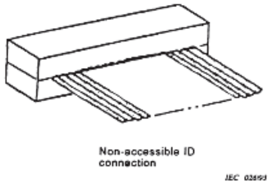
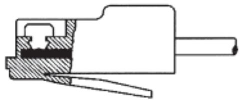
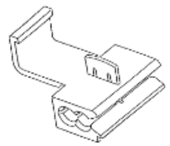
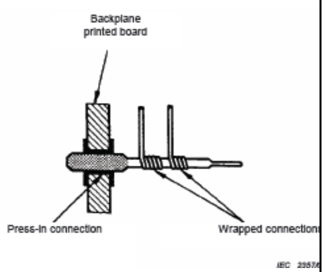
Type	Standards	Examples	General aspects	Mechanical aspects	Electric aspects
Flat quick-connect termination (Male tab connection)	EN 61210 EN 60947-7-1 EN 60947-7-2	 	- CSA ≤ 6 mm²	- Dimple or hole to latch the female clip - Retention force according to EN 61210:2010, Table 6	- Permanent good electrical connection
Spring-clamp connection	EN 60352-7 EN 60947-1 EN 60947-7-1 EN 60947-7-2 EN 60998-2-2 EN 60999-2	 	- Only 1 conductor per clamping point - CSA ≤ 10 mm² - Overlength for at least 3 re-terminations needed	- High reliability (because contact pressure on conductor remains constant over time) - Pull out force according to EN 60947-1:2007, Table 5	- Permanent good electrical connection - Contact resistance (voltage drop) according to EN 60947-7-1
Wire-wrap (Pins or posts wrapping)	EN 60352-1	 	- Minimum wire Ø ≥ 0,5 mm - Minimum 4 turns of stripped wire around the post - Minimum 1 turn of the insulated wire and wrapped at least around 3 corners of the post to ensure mechanical stresses are absorbed - Electronic devices only	- Only small dimensions - Only solid conductors - Only certain materials	- Good electrical connection - Low contact resistance because multiple contact points increase significantly the contact surface - Contact points between post corners and stripped wire are gastight

Table G.5 – Methods of terminating cables – Terminal side – Connection by insulation displacement or penetration

Type	Standards	Examples	General aspects	Mechanical aspects	Electric aspects
Accessible insulation displacement connections	EN 60352-3 EN 60998-2-3		- Maximum 2 conductors of the same CSA - CSA ≤ 4 mm² - Over length for at least 3 re-terminations - Each re- termination implicates a new wire cut-off	- Mechanical locking device to overcome the low transverse extraction force	- Contact resistance according to EN 60352-3:1994, Table 3 - Recommended max. current load: 16 A
Non-accessible insulation displacement connections	EN 60352-4 EN 60998-2-3		- Electronic devices only - Only 1 conductor per slot - CSA ≤ 0,5 mm²	- Adequate strain relief needed to avoid mechanical stresses on the contacts	- Contact resistance according to EN 60352-4:1994, Table 2
Insulation piercing connection	EN 60352-6 EN 60998-2-3		- On board diagnostics - CSA ≤ 0,5 mm²	- Only small dimensions - Pull out force as per EN 60352-6 → ≥ 20 N per wire	- Contact resistance according to EN 60352-6:1997, Table 2
Penetrating the insulation	EN 60947-7-1 EN 60947-7-2 EN 60998-2-3		- Connection method not recommended	- Only small dimensions - Only certain materials	
Press-in connections	EN 60352-5		- Electronic devices only	- Only small dimensions - Only for small forces	

For termination methods, useful national standards are existing as follows (see Table G.6):

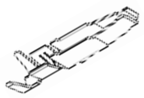
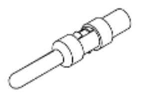
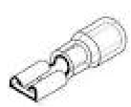
Table G.6 – National standards for termination methods

Method	Existing product standards
Crimping	NF F00-363 from 0,34 mm² to 500 mm² DIN 46235
Termi-point	DIN 41611-4
Soldering	NF F61-014 requires at least 55 % tin and lead
All	NF F61-030 describes in general electrical connectors for railways.
NOTE Termi-point is only used in particular equipment, not in rolling stock cabling.	

G.2 Tensile strength test values

Unless otherwise specified by the manufacturer in the detail specifications, the minimum pull out force for the different crimp methods should comply to the values stated in Table G.7. The values given in Table G.7 are for stranded cables of class 5 or 6 according to EN 60228.

Table G.7 – Pull out force for crimp connections

CSA mm²	**Minimum pull out force** [a] N			
	 Open barrel crimp (stamped and formed) [b]	 Closed barrel crimp (machine turned) [c,d]	 Pre-insulated crimp (Faston and ring-terminal) [e]	 Non-insulated Cu crimp [e]
0,25	32	35	32	
0,50	60	70	56	75
0,75	85	100	84	112
1	108	130	108	150
1,5	150	195	150	225
2,5	230	325	230	375
4	310	520	310	600
6	360	780	360	780
10	380	1 000		1 300
16		1 600		1 600
25		2 000		2 500
35		2 800		3 500
50		3 000		4 500
70		4 200		5 250
95		5 700		5 700
120		7 200		7 200
150		9 000		9 000
185		11 100		11 100
240		14 400		14 400
300				18 000
400				20 000
500				20 000

[a] EN 60512-16-4 Test 16d: Tensile strength, with a steady exerting travelling speed of the jaws of approximately (25-50) mm/min axially to the wire of the specimen until the wire is pulled out or breaks.

[b] EN 60352-2:2006, Table 1.

[c] For CSA ≤ 6 mm² apply 130 N/mm² CSA, for 10 mm² ≤ CSA ≤ 16 mm² apply 100N/mm² CSA, for 25 mm² ≤ CSA ≤ 35 mm² apply 80 N/mm² CSA and for CSA ≥ 50 mm² apply EN 61238-1, Table 3.

[d] EN 61210:2010, Table 9 for faston or EN 60352-2:2006, Table 1 for ring terminal.

[e] For CSA ≤ 4 mm² apply 150 N/mm² CSA, for 6 mm² ≤ CSA ≤ 10 mm² apply 130 N/mm² CSA, for 16 mm² ≤ CSA ≤ 35 mm² apply 100 N/mm² CSA, for 50 mm² apply 90 N/mm² CSA, for 70 mm² apply 75 N/mm² CSA and for CSA ≥ 95 mm² apply EN 61238-1, Table 3.

Annex H
(normative)

Tests on marking when using heat-shrinkable sleeves

H.1 General

If the marking is by heat-shrinkable sleeves, the following tests shall be used for demonstrating the quality of the marking.

H.2 Preparation of specimens

The test marking should be carried out on the sleeves according to supplier's requirements. The markings should be tested as described in H.3 after the specimens have been prepared as described in Table H.1. At least one specimen should be used for each test (i.e. each line in Table H.1).

Table H.1 – Preparation of heat-shrinkable sleeve for test of marking quality

Type of preparation	Expanded state	Unrestricted recovery state
Thermal ageing: The test specimens in the unrestricted recovery state shall be kept in a temperature of (120 ± 2) °C for a duration of (240 ± 2) h.		X
Resistance to mineral oil: The test specimens in the expanded state shall be immersed for (70 ± 1) h in test fluid IRM902 maintained at a temperature of (50 ± 1) °C.	X	
Resistance to liquid fuel: The test specimens in the expanded state shall be submitted to the action of test fluid IRM903 for (168 ± 2) h maintained at a temperature of (70 ± 1) °C.	X	
Immersion for 1 min in a normal hydrochloric acid solution at a temperature of (23 ± 1) °C.	X	
Immersion for 1 min in a normal sodium hydroxide solution at a temperature of (23 ± 1) °C.	X	

NOTE 1 A normal solution is a concentration with one mole of the substance per litre.

NOTE 2 The resistance to liquid fuel is only required when the sleeves may be subject to contamination from diesel fuel.

H.3 Testing of specimens

The specimens in the expanded state and the specimens in the unrestricted recovery state are placed on a flat support and rubbed with a soft pencil eraser.

The rubbing action is performed by applying the eraser firmly over the whole marked length. The maximum manually applicable pressure is used for this test.

The marking is submitted to 10 passes of the eraser at the rate of one pass every 2 s or 3 s.

H.4 Result of test

The marking should remain legible, using normal lighting, after the specimens have been submitted to the tests.

Annex I
(informative)

Effects of the number of earth connections to a cable screen

The effects of shielding, depending on the frequency of the disturbances and depending on the number of connected points between screen and earth, can generally be explained by Table I.1.

Table I.1 – Effects of shielding

Type of field	Range of frequency (approximately)	Effects when one end of the screen is earthed	Effects when at least both ends of the screen are earthed
Electrical field E	f < 1 MHz	Good	Good (see Note 1)
Electrical field E	f > 1 MHz	Almost no shielding effects	Good
Magnetic field H	f < 1 kHz	Almost no shielding effects	Bad (see Note 2)
Magnetic field H	f > 1 kHz	Almost no shielding effects	Good
NOTE 1 Low or no return currents flowing through the screen (caused by potential differences between screen earthing points) are essential and achieved by a good earthing concept.			
NOTE 2 The undesirable effects are avoided when the signal is symmetrical (differential-mode).			

Annex J
(informative)

Differences of electrochemical potentials between some conductive materials

Table J.1 – Differences of electrochemical potentials between some conductive materials (in mV)

Considered metal	Coupled metal																				
	Platinium	Gold/Carbon	Stainless steel	Titanium	Silver — Mercury	Nickel	Copper alloy	Copper	Alu-bronze Brass 30 % ZN	Silicon	Brass 50 % ZN	Bronze	Tin	Lead	Light alloy NSA 3001	Steels	Aluminium A5	Cadmium	Chromium	Zinc	Manganese	Magnesium
Platinium	0	130	250	340	350	430	450	570	600	685	700	770	800	840	940	1 000	1 090	1 100	1 200	1 400	1 470	1 950
Gold/Carbon	130	0	110	210	220	300	320	440	470	535	570	640	670	710	810	870	960	970	1 070	1 270	1 340	1 620
Stainless steel	250	110	0	90	100	160	200	320	350	415	450	520	550	590	690	750	840	850	950	1 150	1 220	1 700
Titanium	340	210	90	0	10	90	110	230	260	325	360	430	460	500	600	680	750	760	860	1 060	1 150	1 610
Silver — Mercury	350	220	100	10	0	80	100	220	250	315	350	420	450	490	590	650	740	750	850	1 050	1 120	1 600
Nickel	430	300	180	90	80	0	20	140	170	235	270	340	370	410	510	570	650	670	770	970	1 040	1 520
Copper alloy	450	320	200	110	100	20	0	120	150	215	250	320	350	390	490	530	640	650	750	950	1 020	1 500
Copper	570	440	320	230	220	140	120	0	30	95	130	200	230	270	370	430	520	530	630	830	900	1 380
Alu-bronze Brass 30 % ZN	600	470	350	260	250	170	150	30	0	65	100	170	200	240	340	400	490	500	600	800	870	1 350
Silicon	665	535	415	325	315	235	215	95	65	0	35	105	135	175	275	335	425	435	353	735	805	1 285
Brass 50 % ZN	700	570	520	360	350	270	250	130	100	35	0	70	100	140	240	300	390	400	500	700	770	1 250
Bronze	770	640	550	430	420	340	320	200	170	105	70	0	30	70	170	230	320	330	435	630	700	1 180
Tin	800	670	590	460	450	370	350	230	200	135	100	30	0	40	140	200	290	300	400	600	670	1 150
Lead	840	710	680	500	490	410	390	270	240	175	140	70	40	0	100	160	250	260	300	560	630	1 110
Light alloy NSA 3001	940	810	690	600	590	510	490	370	340	275	240	170	140	100	0	60	150	160	260	460	530	1 010
Steels	1 000	870	750	660	650	570	550	430	400	335	300	230	200	160	60	0	90	150	200	400	470	950
Aluminium A5	1 090	960	840	750	740	650	640	520	490	425	390	320	290	250	150	90	0	100	110	310	380	860
Cadmium	1 100	970	850	760	750	670	650	530	500	435	400	330	300	260	160	150	100	0	100	300	370	850
Chromium	1 200	1 070	950	860	850	770	750	630	600	535	500	430	400	360	260	200	110	100	0	200	270	750
Zinc	1 400	1 270	1 150	1 050	1 050	970	950	830	800	735	700	630	600	560	460	400	310	300	200	0	70	550
Manganese	1 470	1 340	1 220	1 150	1 120	1 040	1 020	900	870	805	770	700	670	630	530	470	380	370	270	70	0	480
Magnesium	1 950	1 620	1 700	1 610	1 600	1 520	1 500	1 380	1 350	1 285	1 250	1 180	1 150	1 110	1 010	950	860	850	750	550	480	0

Below the line - - - - - - considered metal is attacked

Above the line ——— coupled metal is attacked

Between these 2 thick lines, the contact is practically neutral.

Electrolyte: water with 2 % NaCl salt.

Source: EN 3197:2010.

NOTE 1 Dissimilar metals and alloys have different electrochemical potentials and when two or more come into contact a galvanic couple is set up. The potential difference between the dissimilar metals is the driving force for the accelerated attack on the anode member of the galvanic couple.

NOTE 2 The galvanic effect is influenced by the surface ratio of the two metals. The galvanic corrosion effect on the anode is increasing when the size of the anode is becoming smaller than the size of the cathode.

[a] In ambient as sea water or salt solutions, the chromium is depassivated more or less with the time and its potential for dissolution decreases (to 250 mV only in relation to platinum which tends to reduce the effect of corrosion on the metals which are coupled to it)

Annex K
(informative)

Locations on board rolling stock to be distinguished

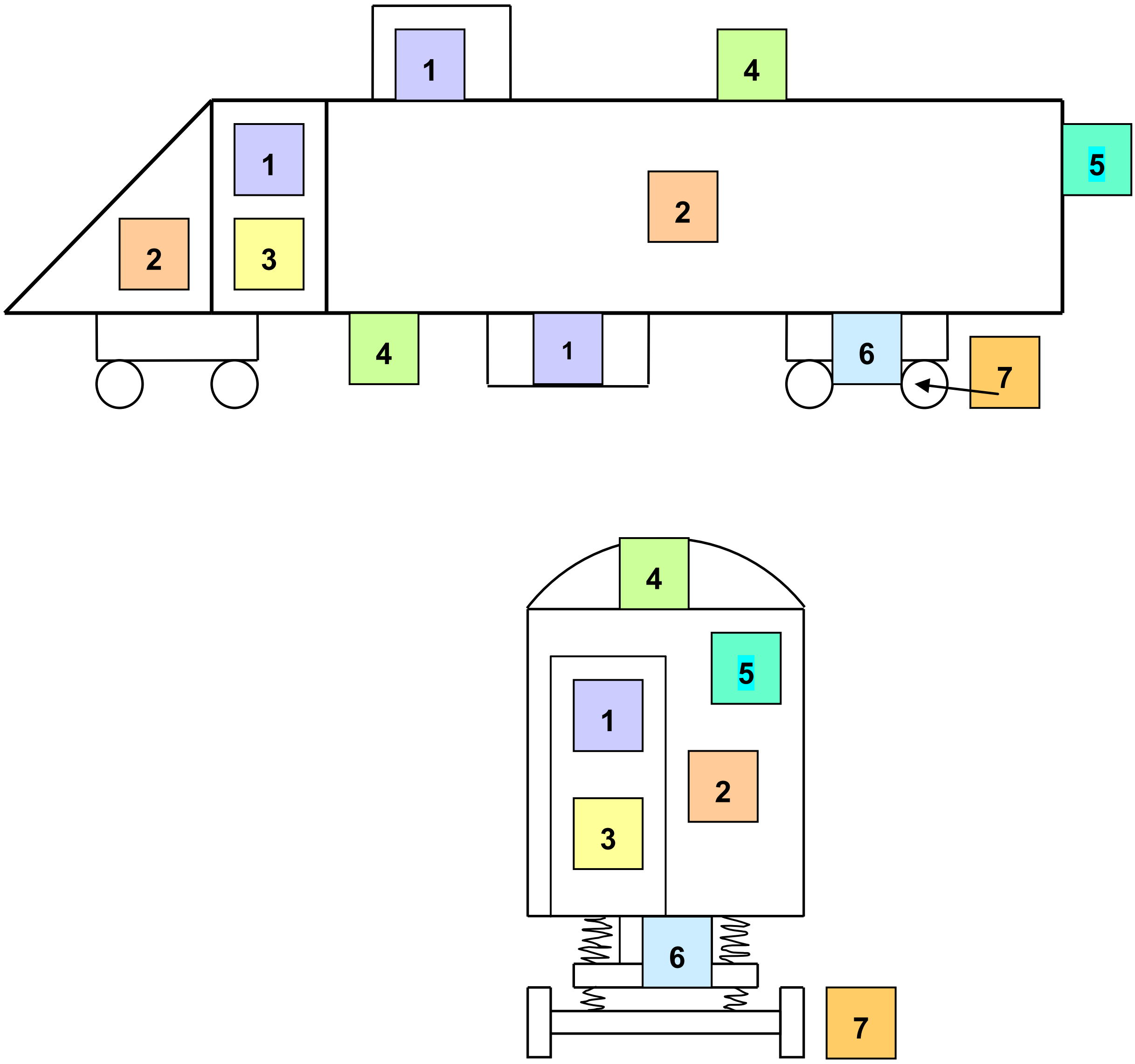


Figure K.1 – Distinguishing locations on board rolling stock

Location according to Figure K.1	Definition	Examples	Examples of consequences on requirements
1	closed electrical operating area	indoor vehicle cubicle (weather-protected) outdoor vehicle cubicle (weather-protected) either under-frame or upper-roof	different vibration and shock levels depending on the installation on bogie or car-body Resistance to ozone for exposed elastomeric is required for areas with power switching
2	Cabin and interiors	passenger vehicle compartment and driver cabin	low IP degree required (air with low dust and chemical contamination)
3	closed electrical operating area; forced filtered ventilation with outside air	machinery compartment	higher temperature resistance if diesel engine, then resistance to fuels and fluids
4	outdoor static applications	under car-body, roof (non weather-protected locations)	non weather-protected location higher IP degree resistance to light (UV) resistance to ozone for rubber and plastic parts
5	outdoor dynamic applications	Car-to-car	non weather-protected location higher IP degree resistance to light (UV) resistance to ozone for rubber and plastic parts higher mechanical resistance
6	outdoor highly dynamic applications	bogie	non weather-protected location higher IP degree resistance to light (UV) resistance to ozone for rubber and plastic parts higher mechanical resistance
7	outdoor highly dynamic applications	axles	non weather-protected location higher IP degree resistance to light (UV) resistance to ozone for rubber and plastic parts higher mechanical resistance Very high vibration and shock constraints resistance to fuels and fluids

Figure K.2 – Distinguishing locations on board rolling stock

NOTE Source of above information is EN 50467

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