Sizing conductors and selecting protection devices

04

POWER GUIDE 2009 / **BOOK 04**

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INTRO

Careful selection of the sizes of the conductors in wiring systems and the characteristics of protection devices will ensure basic protection of the installation:
- Protection against overloads
- Limitation of voltage drops
- Protection against short-circuits
- Checking of the thermal stresses
- Protection against indirect contact

The complete calculation of installations has been found to be so long, complex, and even daunting as to justify the ongoing development of practical aids: calculation charts, note-boards, etc. and now software, such as XL PRO² Calculation. We must not however let the absolute accuracy, reliability and ease of use of these tools make us lose sight of the calculation principles on which they are based. The purpose of this book is to cover the main rules that are used for sizing conductors, wiring systems and their electrical protection (against overloads, voltage drops, short-circuits and indirect contact) according to the parameters of the installation: physical (type of conductor, installation conditions, temperature, length of lines, etc.) and electrical (power, prospective short-circuit, operating currents, etc.). Examples of how they are determined are given for each parameter.

The complete process for estimating the short-circuit currents at all levels in the installation is illustrated on page 54.

The rules for selecting and mounting wiring systems are specified in standard IEC 60364-5-52.

CENELEC guide R064-003 gives a rigorous calculation method suitable for calculation software. In practice two approximate methods are used. These are called the conventional method and the composition method.

Overcurrents

Protection against overloads

Checking voltage drops

Protection against short-circuits

Protection against indirect contact

Estimation of short-circuits and calculation example

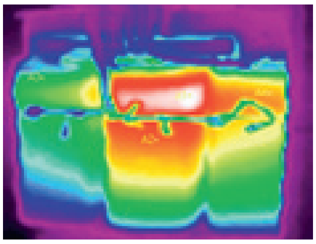
Conductors

Overcurrents

All live conductors in the installation (phase and neutral) must in principle be protected against overloads and short-circuits.

OVERLOADS

An overload is an overcurrent circulating when there is no electrical fault in a circuit. It is caused by under-sizing of the wiring system for the load being supplied, or by the load being too high for the wiring system.
Protection devices must be provided to break any overload current before the overheating of the conductor damages its insulation, its connections and the surrounding equipment. Protection against overloads can be provided by fuses (type gG), circuit breakers with thermal or electronic release or contactors with measurement relays. aM fuses do not provide protection against overloads.
The rules for determining overload protection are described on page 06.



> Infrared thermography can be used to detect overloads, as shown here in a transformer winding

!

The devices for protecting the circuits in the installation are not designed to protect internal circuits in devices or flexible conductors (power supply cables of mobile devices) connected to the power sockets. It may be necessary to design appropriate separate protection devices if this is called for by the risk of overcurrents (for example, overload on motors).

> The concentration of the conductors requires compliance with strict installation rules and the application of correction factors to the current-carrying capacities of the cables

SHORT-CIRCUITS

A short-circuit is an overcurrent produced by a minor impedance fault between conductors with different potentials. It is accidental and can be due to clumsiness (dropping a tool, cutting a cable) or an equipment defect.
Protection devices must be provided to limit and break the short-circuit currents before their thermal (heating of the conductors, electric arcs) and mechanical (electrodynamic forces) effects become harmful and dangerous. Protection against short-circuits can be provided by fuses (type gG or aM), by circuit breakers with magnetic relays or by circuit breakers with electronic relays (overcurrent).
Their breaking capacities and circuit opening times must be suitable for the circuit being protected.
The rules for determining short-circuit protection are described on page 28 et seq.

In principle, all the lines must be protected against short-circuits.
Devices can be combined in order to increase the breaking capacity (see the "Breaking and protection devices" book). Exemption from protection is also possible in certain cases.
The protection of conductors in parallel for the same circuit must be subject to special wiring precautions.

Fault currents

In equipment or installations, fault currents between live parts and exposed conductive parts generally arise as a result of a fault or ageing of the insulation. The circulation of the current may, depending on the value it reaches, create sparks, or even set alight the surrounding equipment. The choice of the neutral earthing system determines the maximum value of the fault currents.
If there is a risk of fire:
- The TN-C system is not allowed, as the currents can reach several kA and may even circulate in the structures of the buildings
- The TN-S system is inadvisable unless residual current devices with sensitivity IΔn ≤300 mA are added
- The TT system is possible (limitation by residual current device)
- The IT system is recommended in intrinsic safety systems as the 1st fault current can be limited to a very low value (a few mA), to avoid the risk of arcing. Caution: the 2nd fault must be protected by a residual current device IΔn ≤ 300 mA. In hazardous situations it is strongly recommended that preventive maintenance is carried out based on monitoring the insulation value of the whole installation: values indicated by the permanent insulation monitor (IT) or regular campaigns to measure the insulation resistance.
The presence of contaminants, humidity or the ageing of the insulation leads to weak points in the insulation. If the test voltage value is significantly increased, a considerable reduction in the resistance value will be observed. The application of increasing measurement voltages, for example: 500 V, 1000 V, 1500 V, 2500 V, 5000 V, will reveal any defects if the insulation value drops by more than 25% at each increasing voltage level. Caution: the test value must remain much lower than the dielectric strength of the installation (min. 2 U + 1000).

Overcurrents (continued)

CALCULATION PRINCIPLE FOR INSTALLATIONS

The conductors must be sized and the protection conditions determined for each circuit in the installation. The procedure is identical for every circuit and involves a number of steps, which are described below.

■ **Calculate the actual operating current (I_B)** of the wiring system. This value is derived by estimation of the total load connected with the receivers on the circuit concerned (see p. 06).

■ **Determine the cross-section of the conductors** to be used according to this actual operating current. The current-carrying capacity (I_Z) of a wiring system is dependent on the temperature it can withstand and its dissipation conditions. The characteristics of the wiring system (type of core, type of insulation, number of conductors) and its circulation conditions (installation method, ambient temperature, group of several circuits) are therefore determining factors (see p. 07 to 22).

■ **Select the overload protection device** with the required rating (In) and if necessary determine its setting (Ir) (see p. 06).

■ **Calculate the voltage drop** in the wiring system according to its length and the actual operating current. If this value exceeds the specified value, the cross-section of the conductors must be increased (see p. 24).

■ **Calculate the maximum short-circuit current** (Ik_{max}, fault at the origin of the circuit) and minimum short-circuit current (Ik_{min}, fault at the end of the circuit). These values are derived from the supply voltage and the impedance of the fault loop (see p. 46).

■ **Determine the characteristics of the short-circuit protection device:** breaking capacity (Icu) and magnetic trip threshold (or setting Im). The breaking capacity must be greater than the maximum short-circuit current. The trip threshold will be determined according to the minimum short-circuit current (see p. 28)

■ **Check the thermal stresses permitted by the conductors,** in particular for the overload and minimum short-circuit currents (see p. 29).

■ **Check the maximum lengths protected against short-circuits.** The lowest short-circuit current (at the end of the wiring system) must effectively trip the protection device (see p. 32).

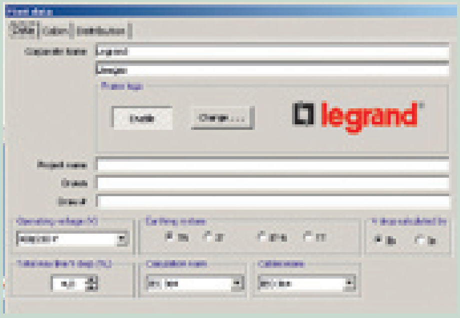
■ **Check the protection conditions against indirect contact.** The breaking time for a fault at the end of a wiring system (minimum fault current) must be compatible with protecting people (see p. 36).

Standards and exemptions

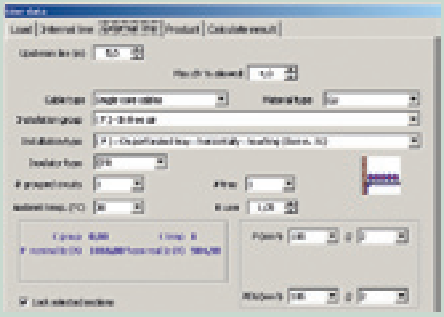
A device providing protection against overloads and short-circuits must be placed where a change of cross-section, type, installation or construction method results in a reduction in the current-carrying capacity (IEC 60364-473).
If it were applied to the letter, this rule would lead to over-sizing of cross-sections for the fault conditions.
The standard therefore allows for there to be no protection device at the origin of the branch line in two cases.
1 - The protection device placed upstream effectively protects the branch line.
2 - The branch line is less than three metres long, is not installed near any combustible materials and every precaution has been taken to limit the risks of short-circuits.

XL PRO² Calculation

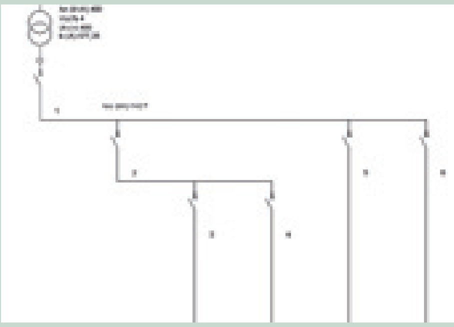
Using the parameters of the installation, XL Pro² Calculation enables you to determine the cross-sections of cables, the protection devices, etc., then create a complete technical folder (diagram of the installation, dedicated calculation sheets, etc.)



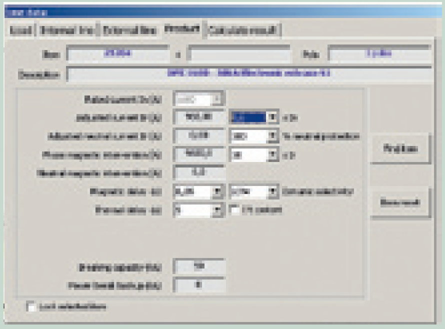
< Selection of the parameters of the installation: type and characteristics of the source, regulatory context, calculation preferences, etc.



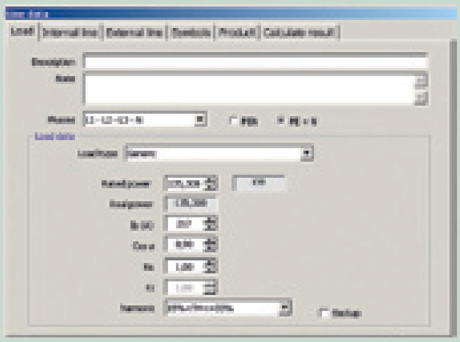
^ Characteristic and circulation conditions of the conductors



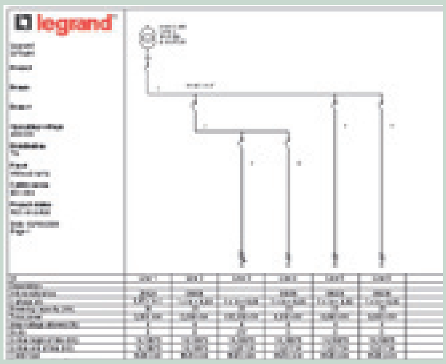
< Diagram of the installation



^ Selection and settings of protection devices



< Determination of the operating current for each circuit



^ Calculation of all the parameters, printing out or exporting the results

Protection against overloads

An electric current flowing in a conductor causes a temperature rise proportional to the square of the current: this is the Joule effect. With this principle as the starting point, the current-carrying capacity Iz of the conductor must be determined according to its cross-section, its type and its installation conditions (installation methods). This is a prerequisite which will then enable suitable overload protection to be chosen.

DETERMINATION OF THE ACTUAL OPERATING CURRENT IB

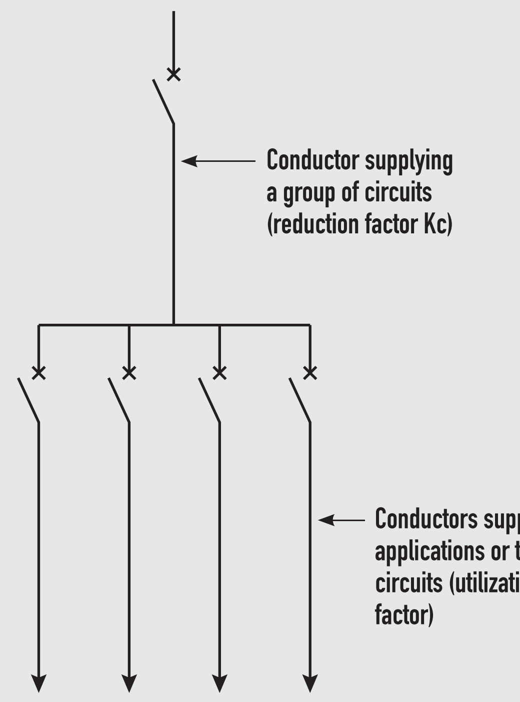
The actual operating current I_B must not exceed the rated current (rating In or setting Ir) of the protection device, which itself must not exceed that of the current-carrying capacity of the wiring system Iz. Value Iz must be reduced by a factor R in the event of fuse protection.
It is therefore advisable to comply with the following:

$$I_B \leqslant In \leqslant R \times Iz$$

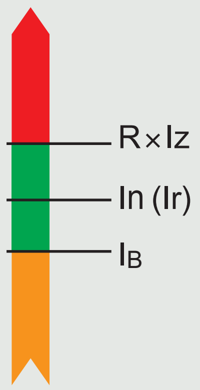
where:
R = 1 for circuit breakers
R = 0.75 for gG fuses < 16 A
R = 0.9 for gG fuses ⩾ 16 A

The values of factor R are the result of design differences between the devices and between the standards used to determine their rated currents.

! **For adjustable circuit breakers, it is advisable for Iz to be higher than the nominal rating In of the device. There will be no adverse consequences if there is an unsuitable thermal setting Ir or a change in the operating current I_B.**



Load areas of a wiring system



Value In (Ir) must be in the green area

In the red area, the wiring system is overloaded

In the orange area, the protection is under-rated with a risk of unwanted tripping

Value Iz represents the maximum current that the wiring system can withstand continuously without adversely affecting its service life.

The determination of the actual operating currents (I_B) in conductors supplying terminal circuits or receivers must incorporate utilization factors connected with the type of load (cos φ, output, inrush current, etc.).
An example for a lighting circuit is given on the next page.

The actual operating currents (I_B) in the conductors supplying groups of circuits can be reduced by a factor kc, known as coincidence, which takes account of the fact that not all the circuits and their respective loads are in use at the same time.

Example

Calculation of the operating current of a 230 V circuit supplying forty 2 × 36 W fluorescent tube strip lights.

Theoretical power: 2 × 36 × 40 = 2880 W

i.e. a theoretical current of $\frac{2880}{230}$ = 12.5 A

which should be increased by the factors connected with the cos φ and the output.

Generic cos φ values are given for various types of receiver (see the "Power analysis and selection of sources" book). The output values will be given in the manufacturer's data.

If a factor of 1.8 is used for the strip lights, the following operating current is obtained
I_B = 12.5 × 1.8 = 22.5 A

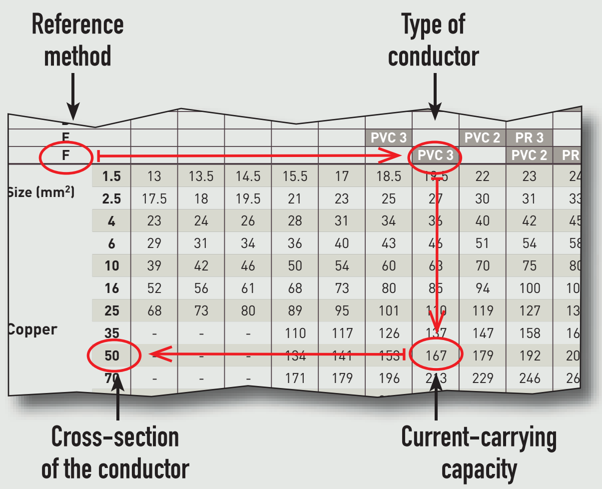
In the informative appendix of standard IEC 60364-1 it is recommended that the coincidence and operating factors are checked.
In France, UTE guide C 15-105 describes a method for determining the maximum operating current, based on knowledge of the power of each load circuit for which various factors are given.
• Reduction factors:
- Coincidence factor connected with the large number of circuits (for example, power sockets)
- Operating factor (or load factor) generally set at between 0.7 and 0.8.
• Increasing factors:
- Factor connected with the output or downgraded cos φ (fluorescent bulbs) and overcurrents (motor starting)
- Factor allowing for extension of the installation.

DETERMINING THE CROSS-SECTIONS OF CONDUCTORS

The determination of the cross-section of the conductors is based on knowledge of the maximum current-carrying capacity of the wiring system, which is itself determined based on the conductors and their operating conditions.
Standard IEC-60364-5-52 determines the current values according to the basic operating principles for installations and safety of people. The main elements are given below.
The table of current-carrying capacities (page 20) can be used to directly determine the cross-section of the conductors according to:
- Type of conductor
- Reference method (installation method)
- The theoretical current-carrying capacity Iz (Iz_{th})
Iz_{th} is calculated by applying all the correction factors f to the operating current value I_B. The factors f are determined according to the installation method, grouping, temperature, etc.

$$I_B = Iz_{th} \times f \quad \text{giving} \quad Iz_{th} = \frac{I_B}{f}$$

Determining the cross-section using the table of current-carrying capacities (page 20)



Protection against overloads
(continued)

1 CHARACTERISTICS OF THE CONDUCTORS

The following information is taken into consideration.
- The type of core: copper or aluminium.
- The type of insulation, which defines the maximum permissible temperature during operation, XLPE or EPR for insulation that can withstand 90°C and PVC for insulation that can withstand 70°C

Maximum operating temperatures according to the type of insulation (IEC 60344-5-52)

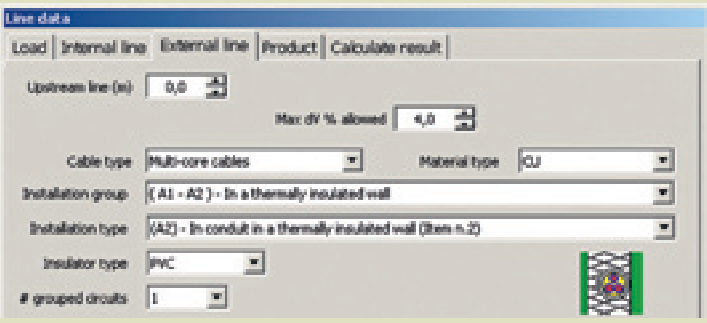
Type of insulation	Maximum temperature[1] °C
Polyvinyl chloride (PVC)	Conductor: 70
Cross-linked polyethylene (XLPE) and ethylene-propylene (EPR)	Conductor: 90[1]
Mineral (with or without PVC sheath, and accessible)	Sheath: 70
Mineral (without sheath, accessible and not in contact with combustible materials)	Sheath: 105[2]

(1) If a conductor operates at a temperature greater than 70°C, it is advisable to check that the equipment connected to this conductor is suitable for the final temperature of the connection.
(2) Higher operating temperatures may be permitted for certain types of insulation, depending on the type of cable, its ends, the environmental conditions and other external influences.

2 WIRING SYSTEMS: INSTALLATION METHODS

The standard defines a number of installation methods which represent the various installation conditions.
In the following tables, they are divided into groups and defined by the letters A to G which determine how to read the table of the current-carrying capacities in conductors (see p. 20).
If several installation methods are used along the length of the wiring system, the methods for which the thermal dissipation conditions are the least favourable must be chosen.

! **There is no explicit provision in the standard on the determination of the cross-section of conductors inside low voltage distribution boards. However standard IEC 60439-1 defines the currents (used for the temperature rise tests) for PVC insulated copper conductors. A "guide" table taking account of work practices is given on p. 66.**



< In the XL Pro^2 Calculation software, the reference installation methods are called "installation groups".

"Installation group" according to the type of cable

Installation group	Cable type		
	Insulated conductors	Single-core cables	Multi-core cables
(A1) In a thermally insulated wall	•	•	
(A1) In conduit in a thermally insulated wall	•	•	
(A1-A2) In a thermally insulated wall			•
(B1-B2) In conduit on a wooden wall	•	•	•
(C) On a wooden wall		•	•
(C) Fixed on a wooden wall		•	•
(D) In ducts in the ground		•	•
(E) In free air			•
(F) In free air		•	
(G) Spaced in free air	•		

(A1) In a thermally insulated wall	Insulated conductors and single-core cables	Multi-core cables
In conduit in a thermally insulated wall		
In conduit in architrave		
In conduit in window frame		

(A1) In conduit in a thermally insulated wall	Insulated conductors and single-core cables	Multi-core cables
Run in mouldings		-

(A2) In a thermally insulated wall	Insulated conductors and single-core cables	Multi-core cables
In conduit in a thermally insulated wall	-	

Protection against overloads
(continued)

(B1-B2) in conduit on wooden wall	Insulated conductors	Single-core cables	Multi-core cables
In conduit on a wooden, or masonry wall	(B1)	(B1)	(B2)
In conduit in masonry	(B1)	(B1)	(B2)
In cable trunking in a wooden wall-run horizontally	(B1)	(B1)	(B2)
In cable trunking in a wooden wall-run vertically	(B1)	(B1)	(B2)
In suspended cable trunking	(B1)	(B1)	(B2)
In skirting trunking	(B1)	(B1)	(B2)
In embedded trunking	(B1)	(B1)	(B2)
In a building void (V ⩾ 20 De)	-	(B1)	(B1)
In cable ducting in a building void (V ⩾ 20 De)	(B1)	(B1)	(B1)
In a celling void (5 De ⩽ V < 50 De)	-	(B1)	(B1)
In a suspended floor (5 De ⩽ V < 50 De)	-	(B1)	(B1)
In cable ducting in a masonry(5 De ⩽ V < 50 De)	(B1)	-	-
In flush cable trunking in the floor	(B1)	(B1)	(B2)
In conduit in an cable unventilated cable channel (V ⩾ 20 De)	(B1)	(B1)	-
In conduit in an open or ventilated cable channel in the floor run horizontally or vertically	(B1)	(B1)	(B1)
In cable ducting in building void (1,5 De ⩽ V < 20 De)	(B2)	(B2)	(B2)
In cable ducting in masonry (1,5 De ⩽ V < 5 De)	(B2)	-	-
In conduit in an cable unventilated cable channel (1,5 De ⩽ V < 20 De)	(B2)	(B2)	-
In building void (1,5 De ⩽ V < 20 De)	-	(B2)	(B2)
In celling void (1,5 De ⩽ V < 5 De)	-	(B2)	(B2)
In a suspended floor (1,5 De ⩽ V < 5 De)	-	(B2)	(B2)

(C) on wooden wall	Insulated conductors	Single-core cables	Multi-core cables
Direct in masonry without added mechanical protection	-		
Direct in masonry with added mechanical protection	-		

(C) Fixed on wooden wall	Insulated conductors	Single-core cables	Multi-core cables
Fixed on wooden wall	-		
Fixed directly under a wooden ceiling	-		

(D) In ducts in the ground	Insulated conductors	Single-core cables	Multi-core cables
In conduit or in cable ducting in the ground	-		
Direct in the ground without added mechanical protection	-		
Direct in the ground with added mechanical protection	-		

(E -F) In free air	Insulated conductors	Single-core cables	Multi-core cables
On unperforated tray	-	[F]	[E]
On perforated tray-Horizontally-Touching	-	[F]	[E]
On perforated tray-Vertically-Touching	-	[F]	[E]
On perforated tray-horizontally-Trefoil	-	[F]	[E]
On perforated tray-vertically-Trefoil	-	[F]	[E]
On brackets or on wire mesh-touching	-	[F]	[E]
On brackets or on wire mesh-trefoil	-	[F]	[E]
Space more than 0,3 times cable diameter from a wall touching	-	[F]	[E]
Space more than 0,3 times cable diameter from a wall trefoil	-	[F]	[E]
On ladder touching	-	[F]	[E]
On ladder trefoil	-	[F]	[E]
Suspended from or incorporating from a support wire	-	[F]	[E]

(G) Spaced in free air	Insulated conductors	Single-core cables	Multi-core cables
On insulators spaced horizontally		-	-

Protection against overloads
(continued)

3 GROUPS OF CIRCUITS

The tables giving the installation methods also refer to specific tables to be used to determine the correction factors connected with the group of circuits and conduits

Reduction factors for groups of more than one circuit or of more than one multi-core cable to be used with current-carrying capacities

Reference method	Arrangement (cables touching)	Number of circuit or multi-core cables											
		1	2	3	4	5	6	7	8	9	12	16	20
A to F	Bunched in air, on a surface, embedded or enclosed	1.00	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.45	0.41	0.38
C	Single layer on wall, floor or unperforated tray	1.00	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	No further reduction factor for more than nine circuits or multi-core cables		
	Single layer fixed directly under a wooden ceiling	0.95	0.81	0.72	0.68	0.66	0.64	0.63	0.62	0.61			
E and F	Single layer on a perforated horizontal or vertical tray	1.00	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72			
	Single layer on ladder support or cleats etc.	1.00	0.87	0.82	0.80	0.80	0.79	0.79	0.78	0.78			

These factors are applicable to uniform groups of cables, equally loaded.

Where horizontal clearances between adjacent cables exceeds twice their overall diameter, no reduction factor need be applied.

The same factors are applied to:
– groups of two or three single-core cables;
– multi-core cables.

If a system consists of both two- and three-core cables, the total number of cables is taken as the number of circuits, and the corresponding factor is applied to the tables for two loaded conductors for the two-core cables, and to the tables for three loaded conductors for the three-core cables.

If a group consists of n single-core cables it may either be considered as n/2 circuits of two loaded conductors or n/3 circuits of three loaded conductors.

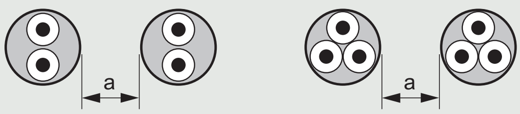
The values given have been averaged over the range of conductor sizes and types of installation included in tables, the overall accuracy of tabulated values is within 5%.

For some installations and for other methods not provided for in the above table, it may be appropriate to use factors calculated for specific cases.

Reduction factors for groups of more than one circuit, cables laid directly in the ground
Installation method D - Single-core or multi-core cables

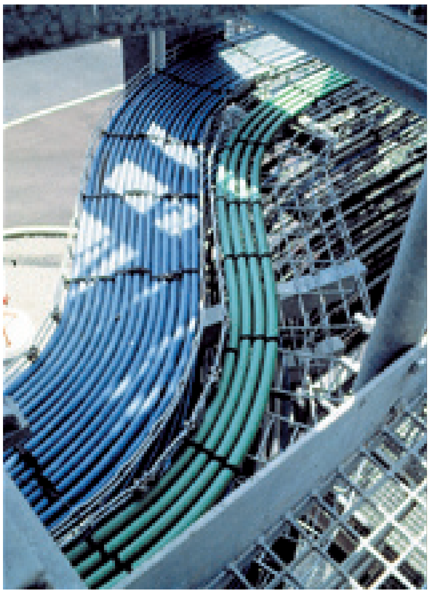
Number of cables	Duct to duct clearance (a)				
	Nil (ducts touching)	One cable diameter	0.125 m	0.25 m	0.5 m
2	0.75	0.80	0.85	0.90	0.90
3	0.65	0.70	0.75	0.80	0.85
4	0.60	0.60	0.70	0.75	0.80
5	0.55	0.55	0.65	0.70	0.80
6	0.50	0.55	0.60	0.70	0.80

Multi-core cables



Single-core cables

Values given apply to an installation depth of 0,7 m and a soil thermal resistivity of 2,5 K.m/W. They are average values for the range of cable sizes and types quoted for tables. The process of averaging, together with rounding off, can result in some cases in errors up to ±10%. (Where more precise values are required they may be calculated by methods given in IEC 60287-2-1).

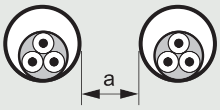


< Grouping circuits together results in a reduction of the current-carrying capacity (application of a correction factor)

Protection against overloads
(continued)

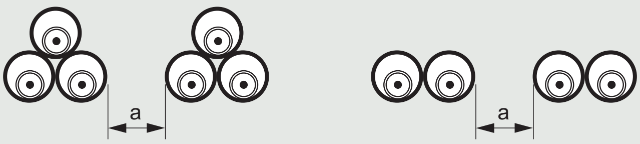
Reduction factors for groups of more than one circuit, cables laid in ducts in the ground
Installation method D

Multi-core cables in single-way ducts

Number of cables	Cable to cable clearance (a)			
	Nil (ducts touching)	0.25 m	0.5 m	1.0 m
2	0.85	0.90	0.95	0.95
3	0.75	0.85	0.90	0.95
4	0.70	0.80	0.85	0.90
5	0.65	0.80	0.85	0.90
6	0.60	0.80	0.80	0.90
Multi-core cables				

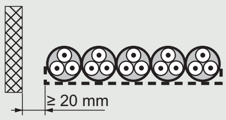
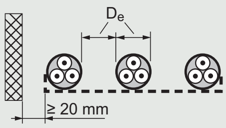
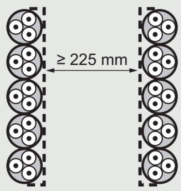
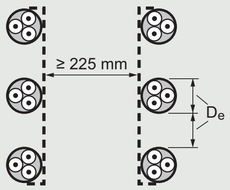
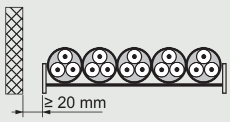
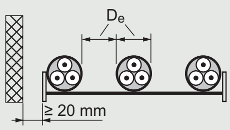
Values given apply to an installation depth of 0,7 m and a soil thermal resistivity of 2,5 K·m/W. They are average values for the range of cable sizes and types quoted for tables. The process of averaging, together with rounding off, can result in some cases in errors up to ±10 %. Where more precise values are required they may be calculated by methods given in IEC 60287.

Single-core cables in single-way ducts

Number of single-core circuits of two or three cables	Duct to duct clearance (a)			
	Nil (ducts touching)	0.25 m	0.5 m	1.0 m
2	0.80	0.90	0.90	0.95
3	0.70	0.80	0.85	0.90
4	0.65	0.75	0.80	0.90
5	0.60	0.70	0.80	0.90
6	0.60	0.70	0.80	0.90
Single-core cables				

Values given apply to an installation depth of 0,7 m and a soil thermal resistivity of 2,5 K·m/W. They are average values for the range of cable sizes and types considered in tables. The process of averaging, together with rounding off, can result in some cases in errors up to ±10%. Where more precise values are required they may be calculated by methods given in IEC 60287

Reduction factors for groups of more than one multi-core cable to be applied to reference ratings for multi-core cables in free air - Method of installation E

Method of installation in table		Number of trays	Number of cables					
			1	2	3	4	6	9
Perforated trays[1]		1 2 3	1.00 1.00 1.00	0.88 0.87 0.86	0.82 0.80 0.79	0.79 0.77 0.76	0.76 0.73 0.71	0.73 0.68 0.66
		1 2 3	1.00 1.00 1.00	1.00 0.99 0.98	0.98 0.96 0.95	0.95 0.92 0.91	0.91 0.87 0.85	- - -
vertical perforated trays[2]		1 2	1.00 1.00	0.88 0.88	0.82 0.81	0.78 0.76	0.73 0.71	0.72 0.70
		1 2	1.00 1.00	0.91 0.91	0.89 0.88	0.88 0.87	0.87 0.85	- -
Ladder supports, cleats, etc.[1]		1 2 3	1.00 1.00 1.00	0.87 0.86 0.85	0.82 0.80 0.79	0.80 0.78 0.76	0.79 0.76 0.73	0.78 0.73 0.70
		1 2 3	1.00 1.00 1.00	1.00 0.99 0.98	1.00 0.98 0.97	1.00 0.97 0.96	1.00 0.96 0.93	- - -

Values given are averages for the cable types and range of conductor sizes considered in tables. The spread of values is generally less than 5%.

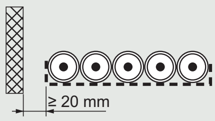
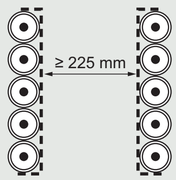
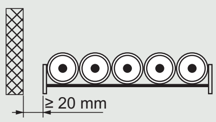
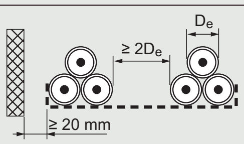
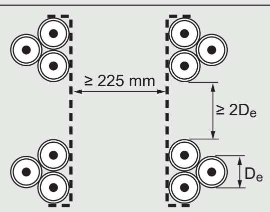
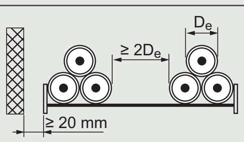
Factors apply to single layer groups of cables as shown above and do not apply when cables are installed in more than one layer touching each other. Values for such installations may be significantly lower and must be determined by an appropriate method

(1) Values are given for vertical spacings between trays of 300 mm and at least 20 mm between trays and wall. For closer spacing the factors should be reduced.

(2) Values are given for horizontal spacing between trays of 225 mm with trays mounted back to back. For closer spacing the factors should be reduced

Protection against overloads
(continued)

Reduction factors for groups of more than one circuit of single-core cables[1] to be applied to reference rating for one circuit of single-core cables in free air – Method of installation F

Method of installation		Number of trays	Number of three-phase circuits[4]			Use as a multiplier to rating for
			1	2	3	
Perforated trays[2]		1 2 3	0.98 0.96 0.95	0.91 0.87 0.85	0.87 0.81 0.78	Three cables in horizontal formation
Vertical perforated trays[3]		1 2	0.96 0.95	0.86 0.84	- -	Three cables in vertical formation
Ladder support, cleats, etc.[2]		1 2 3	1.00 0.98 0.97	0.97 0.93 0.90	0.96 0.89 0.86	Three cables in trefoil horizontal
Perforated trays[2]		1 2 3	1.00 0.97 0.96	0.98 0.93 0.92	0.96 0.89 0.86	
Vertical perforated trays[3]		1 2	1.00 1.00	0.91 0.90	0.89 0.86	Three cables in trefoil arrangement
Ladder support, cleats, etc.[2]		1 2 3	1.00 0.97 0.96	1.00 0.95 0.94	1.00 0.93 0.94	

Values given are averages for the cable types and range of conductor sizes considered in tables. The spread of values is generally less than 5%.

(1) Factors are given for single layers of cables (or trefoil groups) as shown in the table and do not apply when cables are installed in more than one layer touching each other. Values for such installations may be significantly lower and must be determined by an appropriate method.

(2) Values are given for vertical spacings between trays of 300 mm. For closer spacing the factors should be reduced.

(4) Values are given for horizontal spacing between trays of 225 mm with trays mounted back to back and at least 20 mm between the tray and any wall. For closer spacing the factors should be reduced.

(5) For circuits having more than one cable in parallel per phase, each three phase set of conductors should be considered as a circuit for the purpose of this table.

4 AMBIENT TEMPERATURE

The ambient temperature has a direct influence on the sizing of the conductors.
The temperature to be taken into account is that of the air around the cables (open air installation), and that of the ground for buried cables.
The following tables, taken from standard IEC 60364-5-52, can be used to determine the correction factor to be applied for temperatures ranging from 10 to 80°C.
The basic temperature in air is given at 30°C and that of the ground at 20°C for all these tables.

The ambient temperature around cables must not be confused with that taken into account for the protection devices, which is the internal temperature of the distribution board in which these protection devices are installed.

Correction factors for ambient air temperatures other than 30°C to be applied to the current-carrying capacities for cables in the air

Ambient temperature[1] (°C)	Insulation			
	PVC	XLPE and EPR	Mineral	
			PVC covered or bare and exposed to touch 70°C	bare not exposed to touch 105°C
10	1.22	1.15	1.26	1.14
15	1.17	1.12	1.20	1.11
20	1.12	1.08	1.14	1.07
25	1.06	1.04	1.07	1.04
35	0.94	0.96	0.93	0.96
40	0.87	0.91	0.85	0.92
45	0.79	0.87	0.87	0.88
50	0.71	0.82	0.67	0.84
55	0.61	0.76	0.57	0.80
60	0.50	0.71	0.45	0.75
65	-	0.65	-	0.70
70	-	0.58	-	0.65
75	-	0.50	-	0.60
80	-	0.41	-	0.54
85	-	-	-	0.47
90	-	-	-	0.40
95	-	-	-	0.32

(1) For higher ambient temperatures, consult manufacturer

Protection against overloads
(continued)

Correction factors for ambient ground temperatures other than 20°C to be applied to the current-carrying capacities for cables in ducts in the ground		
Ground temperature °C	Insulation	
	PVC	XLPE and EPR
10	1.10	1.07
15	1.05	1.04
25	0.95	0.96
30	0.89	0.93
35	0.84	0.89
40	0.77	0.85
45	0.71	0.80
50	0.63	0.76
55	0.55	0.71
60	0.45	0.65
65	-	0.60
70	-	0.53
75	-	0.46
80	-	0.38

Correction factor for cables in buried ducts for soil thermal resistivities other than 2,5 K.m/W to be applied to the current-carrying capacities for reference method D

Thermal resistivity (K.m/W)	1	1.5	2	2.5	3
Correction factor	1.18	1.1	1.05	1	0.96

The correction factors given have been averaged over the range of conductor sizes and types of installation considered in tables.
The overall accuracy of correction factors is within ±5%.

The correction factors are applicable to cables drawn into burried ducts; for cables laid direct in the ground the correction factors for thermal resistivities less than 2,5 K.m/W will be higher. Where more precise values are required they may be calculated by methods given in IEC 60287.

The correction factors are applicable to ducts buried at depths of up to 0,8 m.

5 RISKS OF EXPLOSION

In installations where there is a risk of explosion (presence, processing or storage of materials which are explosive or have a low flash point, including the presence of explosive dust), wiring systems must include appropriate mechanical protection and the current-carrying capacity will be subject to a reduction factor. The description and installation rules are given in standard IEC 60079.

6 PARALLEL CONDUCTORS

As long as the arrangement of the conductors complies with the grouping rules, the current-carrying capacity of the wiring system can be considered as being equal to the sum of the current-carrying capacities of each conductor to which the correction factors connected with the group of conductors are applied.

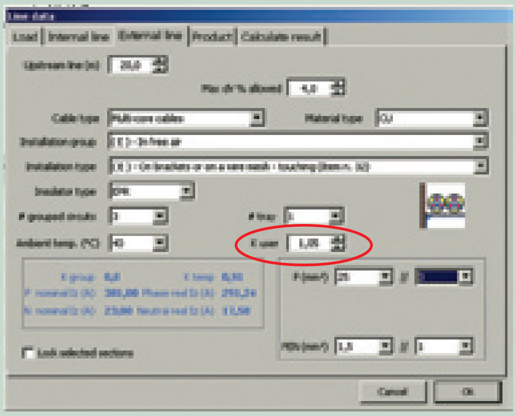
7 GLOBAL CORRECTION FACTOR

When all the specific correction factors are known, it is possible to determine the global correction factor f, which is equal to the product of all the specific factors. The procedure then consists of calculating the theoretical current-carrying capacity Iz_{th} of the wiring system:

$$Iz_{th} = \frac{I_B}{f}$$

Knowing Iz_{th} then enables reference to be made to the tables for the current-carrying capacities (see p. 20) for determining the necessary cross-section.
Read from the column corresponding to the type of conductor and the reference method.
Then simply choose in the table the current-carrying capacity value immediately above the Iz_{th} value to find the cross-section.

A tolerance of 5% on the value of Iz is generally permitted. For example, an operating current I_B of 140 A would lead to the selection of a 35 mm² cross-section with a current-carrying capacity of 169 A. Applying this tolerance enables a smaller cross-section of 25 mm² to be chosen, which can then withstand a current of 145 A (138 + 0.5% = 145 A).



In the XL Pro² Calculation software, this tolerance is taken into account by "K user"

Protection against overloads
(continued)

Current-carrying capacities in amperes

Reference methods		Number of loaded conductors and type of insulation(1)															
A1			PVC 3	PVC 2		PR 3	PR 2										
A2		PVC 3	PVC 2		PR 3	PR 2											
B1					PVC 3	PVC 2		PR 3		PR 2							
B2				PVC 3	PVC 2		PR 3	PR 2									
C						PVC 3		PVC 2	PR 3		PR 2						
D														PVC 2	PVC 3	PR 2	PR 3
E							PVC 3		PVC 2	PR 3		PR 2					
F								PVC 3		PVC 2	PR 3		PR 2				
Size (mm²)	1.5	13	13.5	14.5	15.5	17	18.5	19.5	22	23	24	26	-	22	18	26	22
	2.5	17.5	18	19.5	21	23	25	27	30	31	33	36	-	29	24	34	29
	4	23	24	26	28	31	34	36	40	42	45	49	-	38	31	44	37
	6	29	31	34	36	40	43	46	51	54	58	63	-	47	39	56	46
	10	39	42	46	50	54	60	63	70	75	80	86	-	63	52	73	61
	16	52	56	61	68	73	80	85	94	100	107	115	-	81	67	95	79
	25	68	73	80	89	95	101	110	119	127	135	149	161	104	86	121	101
Copper	35	-	-	-	110	117	126	137	147	158	169	185	200	125	103	146	122
	50	-	-	-	134	141	153	167	179	192	207	225	242	148	122	173	144
	70	-	-	-	171	179	196	213	229	246	268	289	310	183	151	213	178
	95	-	-	-	207	216	238	258	278	298	328	352	377	216	179	252	211
	120	-	-	-	239	249	276	299	322	346	382	410	437	246	203	287	240
	150	-	-	-	-	285	318	344	371	395	441	473	504	278	230	324	271
	185	-	-	-	-	324	362	392	424	450	506	542	575	312	258	363	304
	240	-	-	-	-	380	424	461	500	538	599	641	679	361	297	419	351
	300	-	-	-	-	-	-	-	-	-	-	-	-	408	336	474	396
Size (mm²)	2.5	13.5	14	15	16.5	18.5	19.5	21	23	24	26	28	-	22	18.5	26	22
	4	17.5	18.5	20	22	25	26	28	31	32	35	38	-	29	24	34	29
	6	23	24	26	28	32	33	36	39	42	45	49	-	36	30	42	36
	10	31	32	36	39	44	46	49	54	58	62	67	-	48	40	56	47
	16	41	43	48	53	58	61	66	73	77	84	91	-	62	52	73	61
	25	53	57	63	70	73	78	83	90	97	101	108	121	80	66	93	78
	35	-	-	-	86	90	96	103	112	120	126	135	150	96	80	112	94
Aluminium	50	-	-	-	104	110	117	125	136	146	154	164	184	113	94	132	112
	70	-	-	-	133	140	150	160	174	187	198	211	237	140	117	163	138
	95	-	-	-	161	170	183	195	211	227	241	257	289	166	138	193	164
	120	-	-	-	186	197	212	226	245	263	280	300	337	189	157	220	186
	150	-	-	-	-	226	245	261	283	304	324	346	389	213	178	249	210
	185	-	-	-	-	256	280	298	323	347	371	397	447	240	200	279	236
	240	-	-	-	-	300	330	352	382	409	439	470	530	277	230	322	308
	300	-	-	-	-	-	-	-	-	-	-	-	-	313	260	364	308

(1) **PVC 2**: PVC insulation, 2 loaded conductors - **PVC 3**: PVC insulation, 3 loaded conductors - **PR 2**: XLPE or EPR insulation, 2 loaded conductors - **PR 3**: XLPE or EPR insulation, 3 loaded conductors.

Use PVC 2 or PR 2 for single phase or two-phase circuits and PVC 3 or PR 3 for three-phase circuits.

Example of determining a three-phase circuit constituting the link between a main distribution board and a secondary distribution board

Hypotheses

- The estimation of the loads has enabled the operating current of the conductors to be calculated: I_B = 600 A
- The wiring system consists of single-core copper cables with PR insulation
- The conductors are installed touching one another in perforated cable ducting
- Preference is given to install the cables in parallel to limit the unit cross-section to 150 mm^2

Solution

Installing single-core cables in a perforated cable tray corresponds to reference method F

(E -F) In free air	Insulated conductors	Single-core cables	Multi-core cables
On unperforated tray	-	(F)	(E)
On perforated tray-Horizontally-Touching	-	(F)	(E)
On perforated tray-Vertically-Touching	-	(F)	(E)
On perf... ...lly-Trefoil	-		

< Extract from the installation methods table (see p. 11)

If a single conductor per phase is sufficient, no correction need be applied.
If two conductors per phase are necessary, a reduction factor of 0.88 must be applied.

Reference method	Arrangement (cables touching)	Number of circuit or multi-core cables											
		1	2	3	4	5	6	7	8	9	12	16	20
A to F	Bunched in air, on a surface, embedded or enclosed	1.00	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.45	0.41	0.38
C	Single layer on wall, floor or unperforated tray	1.00	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	No further reduction factor for more than nine circuits or multi-...les		
	Single layer fixed directly under a wooden ceiling	0.95	0.81	0.72	0.68	0.66	0.64	0.63	0.62	0.61			
E and F	Single layer on a perforated horizontal or vertical tray	1.00	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72			
	...on ladder...		0.87	0.82									

< Extract from the table giving the correction factors for groups (see p. 12)

The theoretical value Iz will therefore be determined by: $Iz_{th} = \frac{I_B}{f} = \frac{600}{0,88} = 682\ A$ i.e. 341 A per conductor.

Reading from the table of current-carrying capacities (opposite page)

For a PR 3 conductor in reference method F and a current-carrying capacity of 382 A (value immediately above 341 A) the table gives a cross-section of 120 mm^2.

D														PVC 2	PVC 3	PR 2	PR
E							PVC 3		PVC 2	PR 3		PR 2					
F								PVC 3		PVC 2	PR 3		PR 2				
Size (mm^2)	1.5	13	13.5	14.5	15.5	17	18.5	19.5	22	23	24	26	-	22	18	26	22
	2.5	17.5	18	19.5	21	23	25	27	30	31	33	36	-	29	24	34	29
	4	23	24	26	28	31	34	36	40	42	45	49	-	38	31	44	37
	6	29	31	34	36	40	43	46	51	54	58	63	-	47	39	56	46
	10	39	42	46	50	54	60	63	70	75	80	86	-	63	52	73	61
	16	52	56	61	68	73	80	85	94	100	107	115	-	81	67	95	79
	25	68	73	80	89	95	101	110	119	127	135	149	161	104	86	121	10
Copper	35	-	-	-	110	117	126	137	147	158	169	185	200	125	103	146	12
	50	-	-	-	134	141	153	167	179	192	207	225	242	148	122	173	14
	70	-	-	-	171	179	196	213	229	246	268	289	310	183	151	213	17
	95	-	-	-	207	216	238	258	278	298	328	352	377	216	179	252	21
	120				239	249	276	299	322	346	382	410	437	246	203	287	24
	150	-	-	-	-	285	318	344	371	395	441	473	504	278	230	324	27

Protection against overloads (continued)

8 CROSS-SECTION OF THE NEUTRAL CONDUCTOR

In principle, the neutral must be the same cross-section as the phase conductor in all single phase circuits. In three-phase circuits with a cross-section greater than 16 mm² (25 mm² alumin.), the cross-section of the neutral can be reduced to cross-section/2. However this reduction is not permitted if:
- The loads are not in practice balanced
- The third harmonic (row3) content is greater than 15 %. If this content is greater than 33 %, the cross-section of the live conductors of multi-core cables is chosen by increasing current I_B.
Standard IEC 60364-5-52 gives a table showing the correction factors according to the THD, followed by an example of determining the current-carrying capacity of the cable.

The limits for harmonic disturbance produced by devices are defined in standards IEC 61000-3-2 (In ≤ 16 A) and IEC 61000-3-12 (16 < In ≤ 75 A)

Reduction factors for harmonics currents in four-core and five-core cables (IEC 60364-5-52)

Third harmonic content of phase current (%)	Reduction factor	
	Size selection is based on phase current	Size selection is based on neutral current
0 - 15	1.0	-
15 - 33	0.86	-
33 - 45	-	0.86
> 45	-	1.0

Examples of the application of reduction factors for harmonic currents (IEC 60352-5-52)

Consider a three-phase circuit with a design load of 39 A to be installed using four-core PVC insulated cable clipped to a wall, installation method C.

A 6 mm² cable with copper conductors has a current-carrying capacity of 41 A and hence is suitable if harmonics are not present in the circuit.

If 20 % third harmonic is present, then a reduction factor of 0,86 is applied and the design load becomes:

$$\frac{39}{0{,}86} = 45\ \text{A}$$

For this load a 10 mm² cable is necessary.

If 40 % third harmonic is present, the cable size selection is based on the neutral current which is:

39 x 0,4 x 3 = 46,8 A

and a reduction factor of 0,86 is applied, leading to a design load of:

$$\frac{46{,}8}{0{,}86} = 54{,}4\ \text{A}$$

For this load a 10 mm² cable is suitable.

If 50% third harmonic is present, the cable size is again selected on the basis of the neutral current, which is:

39 x 0,5 x 3 = 58,5 A

in this case the rating factor is 1 and a 16 mm² cable is required.

All the above cable selections are based on the current-carrying capacity of the cable; voltage drop and other aspects of design have not been considered.

DEVICES FOR PROTECTION AGAINST OVERLOADS

1 LOCATION AND CHOICE OF PROTECTION DEVICES

In principle, a protection device must be placed at the origin of each wiring system (main line or tap-off), as soon as the current-carrying capacity Iz of the wiring system becomes lower than the current In of the upstream protection device.
The protection device must therefore have a rated current I (rating In, or setting Ir) such that:
$I_B \leqslant I \leqslant R \times I_Z$ (see p. 04)

2 EXEMPTION FROM PROTECTION AGAINST OVERLOADS

It is possible to dispense with protection against overloads in the following cases:
- The wiring system is effectively protected against overloads by a device upstream
- The wiring system is not likely to be subject to overloads and has no tap-offs or sockets (devices with integrated protection that is adapted to the cross-section of the cable, fixed device that does not generate overloads and whose operating current is compatible with the current-carrying capacity of the cable, wiring system supplying several tap-offs that are protected individually and for which the sum of the operating currents is less than the current-carrying capacity of the wiring system, wiring systems whose source cannot supply a current greater than the system's current-carrying capacity, etc.)

Exemptions cannot be applied to IT systems and in installations where there is a risk of fire, or without additional verification.

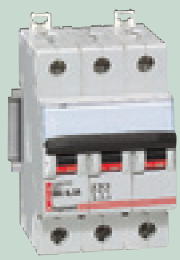
! **Caution, this exemption does not concern short-circuit protection, which must be provided in all cases. The line in question must not have any tap-offs. In principle, a line of power sockets may be subject to overloads and must always be protected.**

It should be noted that it is possible not to protect a tap-off for a length of 3 metres maximum as long as it is created in such a way as to reduce the risk of short-circuits to the minimum and as long as the protection device is placed immediately after this 3 metre distance (see p. 04).
This provision is particularly useful in the wiring of distribution boards.

3 RECOMMENDATION FOR NO PROTECTION AGAINST OVERLOADS

When called for due to continuity of service or safety, or if opening the circuit involves danger (smoke clearance motors, circuits of rotating machines, lifting equipment, etc.) it is not advisable to install any device with overload protection.
In this case, the wiring system must be sized for the overload fault current which may occur: for example, blocked rotor for a motor.

+ **Only Lexic DX-MA magnetic circuit breakers comply with the recommendations for no protection against overloads.**



Checking voltage drops

It is essential to provide the correct voltage to ensure correct use and quality of the electricity service. It is therefore important to check that the cumulative voltage drop from the source up to any point in the installation does not exceed the required values.

If the voltage drop is greater than the permitted limits, it is advisable to increase the cross-section of the conductors until the voltage drop is below the specified values.
When the main wiring systems of the installation are longer than 100 m, the permitted voltage drop limits can be increased by 0.005% per metre above 100 m, but this additional amount must not itself exceed 0.5%.

Calculating voltage drops

$$u = b\left(\rho_1 \frac{L}{S}\cos\varphi + \lambda \times L \times \sin\varphi\right) I_B$$

u: voltage drop in V
b: factor: value 1 for three-phase circuits, and 2 for single phase circuits
ρ_1: resistivity of the conductors in Ωmm²/m (0.023 for copper and 0.037 for aluminium)
L: length of the wiring system in m
S: cross-section of the wiring system in mm²
λ: linear reactance of the conductors in mΩ/m (0.08 for multi-core or single-core cables in trefoil arrangement,
0.09 for single-core cables touching in flat layers and 0.13 for separate single-core cables)
Cos φ: power factor (0.8 in the absence of information)
I_B: operating current of the wiring system in A
The relative voltage drop (as a %) is calculated in the following way:

$$\Delta u = 100 \frac{u}{U_0}$$

u: voltage drop in V
U_0: phase-to-neutral voltage in V

Permitted voltage drop limits

Standard IEC 60364-5-52 recommends a maximum value of 4%.
This value applies to normal operation, and does not take account of devices, such as motors, that can generate high inrush currents and voltage drops.
More restrictive values may be required for the link between the transformer and the main breaking or protection device.

Motor power supplies

If the installation supplies motors, it is advisable to check the voltage drop under starting conditions. To do this, simply replace current IB in the formula opposite with the starting current of the motor and use the power factor on starting. In the absence of more accurate data, the starting current can be taken as being 6 × In. The voltage drop, taking account of all the motors that may start at the same time, must not exceed 15%. Apart from the fact that too high a voltage drop can hinder other users of the installation, it may also prevent the motor starting.

The unit voltage drop v (in volts per ampere and for 100 m), can be determined directly from the tables on the following pages, according to the:
- Cross-section (in mm²) and type of core (copper or aluminium)
- Linear reactance of the conductors, λ (in mΩ/m), connected with their relative arrangement

- Cos φ (1 for heating and lighting, 0.85 for mixed applications, 0.5 when starting motors).

The voltage drop value for the three-phase wiring system with length L (in m) along which the operating current I_B (in A) travels is then,
- Expressed in volts:

$$u = \frac{v}{100} \times I_B \times L$$

- Expressed as a percentage:

$$\Delta u = \frac{v \times I_B \times L}{U_0}$$

U_0 = 230 V in 400 V three-phase supply.

For single phase wiring systems, the u and Δu values must be multiplied by 2 (drop in "the outgoing conductor" and in the "return conductor" with the same current travelling along both).

Example

In the example on page 54, the precise calculation of the voltage drop for the "Outgoing 2" cable gives a result of 4.04 V, i.e. a relative voltage drop of 1.75%.
An identical result is obtained using the tables. Reading from the table opposite for a copper phase cross-section of 70 mm² and a cos φ of 0.85 gives a value of 0.032. This value is given for 100 m of cable and for a current of 1 A. This value must then be multiplied by 250 (IB = 250 A) and by 0.5 (50 m of cable), which gives an absolute voltage drop of 4 V and a relative voltage drop of 1.73%.

Multi-core or single-core cables in trefoil arrangement (λ = 0.08 mΩ/m) Voltage drop per unit (in V) for 100 m of cable

Cross-section mm²	Three-phase Cu 100 m			Three-phase Al 100 m		
	cos φ			cos φ		
	1	0.85	0.35	1	0.85	0.35
1.5	1.533	1.308	0.544	2.467	2.101	0.871
2.5	0.920	0.786	0.329	1.480	1.262	0.525
4	0.575	0.493	0.209	0.925	0.790	0.331
6	0.383	0.330	0.142	0.617	0.528	0.223
10	0.230	0.200	0.088	0.370	0.319	0.137
16	0.144	0.126	0.058	0.231	0.201	0.088
25	0.092	0.082	0.040	0.148	0.130	0.059
35	0.066	0.060	0.030	0.106	0.094	0.044
50	0.046	0.043	0.024	0.074	0.067	0.033
70	0.033	0.032	0.019	0.053	0.049	0.026
95	0.024	0.025	0.016	0.039	0.037	0.021
120	0.019	0.021	0.014	0.031	0.030	0.018
150	0.015	0.017	0.013	0.025	0.025	0.016
185	0.012	0.015	0.012	0.020	0.021	0.014
240	0.010	0.012	0.011	0.015	0.017	0.013
300	0.008	0.011	0.010	0.012	0.015	0.012
400	0.006	0.009	0.010	0.009	0.012	0.011
500	0.005	0.008	0.009	0.007	0.011	0.010
630	0.004	0.007	0.009	0.006	0.009	0.010
2 x 120	0.010	0.010	0.007	0.015	0.015	0.009
2 x 150	0.008	0.009	0.006	0.012	0.013	0.008
2 x 185	0.006	0.007	0.006	0.010	0.011	0.007
2 x 140	0.005	0.006	0.005	0.008	0.009	0.006
3 x 120	0.006	0.007	0.005	0.010	0.010	0.006
3 x 150	0.005	0.006	0.004	0.008	0.008	0.005
3 x 185	0.004	0.005	0.004	0.007	0.007	0.005
3 x 240	0.003	0.004	0.004	0.005	0.006	0.004
4 x 185	0.003	0.004	0.003	0.005	0.005	0.004
4 x 240	0.002	0.003	0.003	0.004	0.004	0.003

Checking voltage drops (continued)

Single-core cables touching in flat layers (λ = 0.09 mΩ/m) Voltage drop per unit (in V) for 100 m of cable						
Cross-section mm^2	Three-phase Cu 100 m			Three-phase Al 100 m		
	cos φ			cos φ		
	1	0.85	0.35	1	0.85	0.35
1.5	1.533	1.308	0.544	2.467	2.101	0.872
2.5	0.920	0.787	0.330	1.480	1.263	0.526
4	0.575	0.493	0.210	0.925	0.791	0.332
6	0.383	0.331	0.143	0.617	0.529	0.224
10	0.230	0.200	0.089	0.370	0.319	0.138
16	0.144	0.127	0.059	0.231	0.201	0.089
25	0.092	0.083	0.041	0.148	0.131	0.060
35	0.066	0.061	0.031	0.106	0.095	0.045
50	0.046	0.044	0.025	0.074	0.068	0.034
70	0.033	0.033	0.020	0.053	0.050	0.027
95	0.024	0.025	0.017	0.039	0.038	0.022
120	0.019	0.021	0.015	0.031	0.031	0.019
150	0.015	0.018	0.014	0.025	0.026	0.017
185	0.012	0.015	0.013	0.020	0.022	0.015
240	0.010	0.013	0.012	0.015	0.018	0.014
300	0.008	0.011	0.011	0.012	0.015	0.013
400	0.006	0.010	0.010	0.009	0.013	0.012
500	0.005	0.009	0.010	0.007	0.011	0.011
630	0.004	0.008	0.010	0.006	0.010	0.010
2 x 120	0.010	0.011	0.008	0.015	0.015	0.010
2 x 150	0.008	0.009	0.007	0.012	0.013	0.009
2 x 185	0.006	0.008	0.006	0.010	0.011	0.008
2 x 240	0.005	0.006	0.006	0.008	0.009	0.007
3 x 120	0.006	0.007	0.005	0.010	0.010	0.006
3 x 150	0.005	0.006	0.005	0.008	0.009	0.006
3 x 185	0.004	0.005	0.004	0.007	0.007	0.005
3 x 240	0.003	0.004	0.004	0.005	0.006	0.005
4 x 185	0.003	0.004	0.003	0.005	0.005	0.004
4 x 240	0.002	0.003	0.003	0.004	0.004	0.003

Separate single-core cables (λ = 0.13 mΩ/m)
Voltage drop per unit (in V) for 100 m of cable

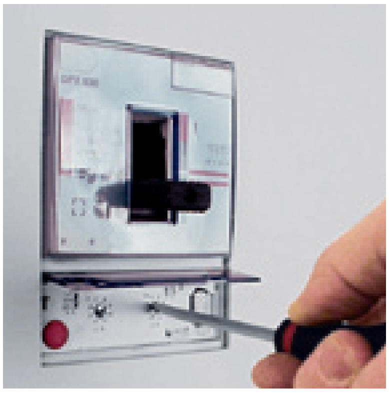
Cross-section mm²	Three-phase Cu 100 m			Three-phase Al 100 m		
	cos φ			cos φ		
	1	0.85	0.35	1	0.85	0.35
1.5	1.533	1.310	0.549	2.467	2.104	0.876
2.5	0.920	0.789	0.334	1.480	1.265	0.530
4	0.575	0.496	0.213	0.925	0.793	0.336
6	0.383	0.333	0.146	0.617	0.531	0.228
10	0.230	0.202	0.093	0.370	0.321	0.142
16	0.144	0.129	0.062	0.231	0.203	0.093
25	0.092	0.085	0.044	0.148	0.133	0.064
35	0.066	0.063	0.035	0.106	0.097	0.049
50	0.046	0.046	0.028	0.074	0.070	0.038
70	0.033	0.035	0.024	0.053	0.052	0.031
95	0.024	0.027	0.021	0.039	0.034	0.026
120	0.019	0.023	0.019	0.031	0.033	0.023
150	0.015	0.020	0.018	0.025	0.028	0.021
185	0.012	0.017	0.017	0.020	0.024	0.019
240	0.010	0.015	0.016	0.015	0.020	0.018
300	0.008	0.013	0.015	0.012	0.017	0.016
400	0.006	0.012	0.014	0.009	0.015	0.015
500	0.005	0.011	0.014	0.007	0.013	0.015
630	0.004	0.010	0.013	0.006	0.012	0.014
2 x 120	0.010	0.012	0.009	0.015	0.017	0.011
2 x 150	0.008	0.010	0.009	0.012	0.014	0.010
2 x 185	0.006	0.009	0.008	0.010	0.012	0.010
2 x 240	0.005	0.007	0.008	0.008	0.010	0.009
3 x 120	0.006	0.008	0.006	0.010	0.011	0.008
3 x 150	0.005	0.007	0.006	0.008	0.009	0.007
3 x 185	0.004	0.006	0.006	0.007	0.008	0.006
3 x 240	0.003	0.005	0.005	0.005	0.007	0.006
4 x 185	0.003	0.004	0.004	0.005	0.006	0.005
4 x 240	0.002	0.004	0.004	0.004	0.005	0.004

Protection against short-circuits

To guard against the risks of short-circuit currents, all short-circuit protection devices must comply with the following two rules:
- The breaking capacity of the device must be at least equal to the maximum prospective short-circuit current at its installation point
- The breaking time, for a short-circuit occurring at any point in the installation, must not be greater than the time taken for the temperature of the conductors to reach the maximum permissible value.

When applying these rules, it is necessary to determine the maximum short-circuit current for each circuit at its origin and the minimum short-circuit current at its end.
The maximum short-circuit current at the origin of the circuit is used to:
- Determine the necessary breaking capacity of the protection devices
- Check the protection of the conductors against thermal stresses
The minimum short-circuit current at the end of the circuit is used to:
- Check the breaking conditions for the magnetic setting of the circuit breakers
- Check the protection of the conductors against thermal stresses in particular in the event of protection using fuses or time-delayed circuit breakers.

As a general rule the short-circuit protection must be placed at the supply end of each circuit.
For the standards and exceptions, see p. 04.



< Adjusting the magnetic threshold of a DPX circuit breaker

BREAKING CAPACITY

The breaking capacity of a protection device must be at least equal to the maximum prospective short-circuit current which may occur at the point at which this device is installed.

Breaking capacity ⩽ Ik_{max}

The maximum prospective short-circuit current to be taken into account is:
- The symetrical three-phase short-circuit current Ik3, for three-phase circuits (3 phases or 3 phases + neutral)
- The two-phase short-circuit current Ik2, for two-phase circuits (phase/phase)
- The single phase short-circuit current Ik1 for single phase circuits (phase/neutral)
For details of how to estimate Ik values, see p. 46.

! **Back up or coordination of protection devices**

The breaking capacity of the protection device can, by special dispensation, be lower than the maximum prospective short-circuit provided that:
- The device is combined with a device upstream that has the necessary breaking capacity
- The downstream device and the protected wiring systems can withstand the power limited by the combination of the devices.
For the characteristics of DX and DPX devices used in combination see the "Breaking and protection devices" book.

Special case of the IT system in France

Article 533.3 of standard NF C 15-100 indicates that when an IT system is used for an installation, the breaking capacity rule must be applied for the three-phase short-circuit and also for the prospective double fault current. By convention, the protection device must be able to break the double fault current at the phase-to-phase voltage and on a single pole. The double fault current is taken as being:
- 0.15 times the three-phase short-circuit current at the installation point if it is less than or equal to 10 kA
- 0.25 times the three-phase short-circuit current at the installation point if it is greater than 10 kA
Example: in a 230/400 V installation, for a 20 kA three-phase short-circuit current, the protection devices must be able to break 0.25 x 20 = 5 kA, at 400 V and on a single pole.
For the characteristics of Legrand circuit breakers in IT systems, see the "Breaking and protection devices" book.

CHECKING THE THERMAL STRESSES PERMITTED BY CONDUCTORS

Following a short-circuit that takes place at any point on a circuit, the breaking time of a circuit breaker must not be longer than the time taken for the temperature of the conductors to reach the permissible limit θ° max. in the table below. In practice, it is advisable to check that the energy which the circuit breaker allows to pass is not greater than that which the cable can actually withstand.

The maximum thermal stress (for times of less than 5 s) that a wiring system can withstand is calculated using the following formula:

$$I^2t = K^2 \times S^2$$

Value of K for live and protective conductors

Insulation material		PVC	XLPE/EPR	Rubber 60°C	Rubber 85°C	Silicone rubber	No insulation
θ°max (°C)		160/140(2)	250	200	220	350	200/150(1)
Protective conductor not incorporated in a cable or conductors not grouped together	Copper	143/133(2)	176	159	166	201	159/138(1)
	Aluminium	95/88(2)	116	105	110	133	105/91(1)
	Steel	52/49(2)	64	58	60	73	58/50(1)
Live or protective conductor as part of a multi-core cable or conductors grouped together	Copper	115/103(2)	143	141	134	132	138
	Aluminium	76/68(2)	94	93	89	87	91
	Steel						50

(1) If there is a particular fire risk

(2) Cross-section greater than 300 mm² or conductors grouped together

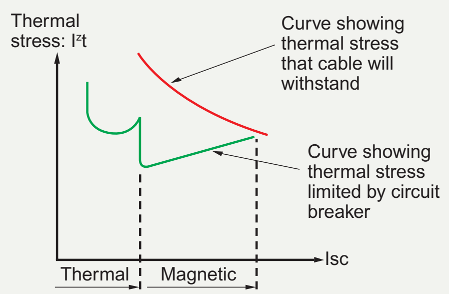
Protection against short-circuits (continued)

1 LIVE CONDUCTORS

1.1 Protection using circuit breaker

In the case of protection using a circuit breaker, it is advisable to check that the energy which the device allows to pass remains below the maximum stress permitted by the wiring systems.
The current to be taken into account is the maximum short-circuit current at the origin of the circuit in question:
- Ik3 for three-phase circuits (3 phases or 3 phases + neutral)
- Ik2 for two-phase circuits
- Ik1 for single phase circuits (phase + neutral).

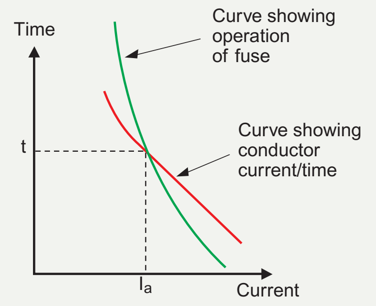
It is possible to check that the limit value is actually below that which the conductors can withstand for the prospective fault conditions by directly reading from the thermal stress limitation curves for circuit breakers.



In the case of circuit breakers on which the magnetic release is delayed, the thermal stresses must be systematically checked.
It is not generally necessary to do this for live conductors (phase and neutral) if:
- The protection device, at the origin of the wiring system, has an overload protection function
- The cross-section of the neutral conductor is not smaller than that of the phase conductors.

1.2 Fuse protection

In the case of fuse protection, it is necessary to check that the smallest short-circuit value at the end of the installation will cause the fuse to "blow" within a time that is compatible with the thermal stress of the cable.
Caution: the short-circuit currents to be taken into account are those at the end of the wiring system:
- Ik1 for circuits with distributed neutral
- Ik2 for circuits without distributed neutral



The minimum short-circuit current value must be greater than value I_a

Maximum thermal stress values in cables (in A^2s) according to their type and cross-section

S (mm²)	Cu/PVC	Cu/PR	Al/PVC	Al/PR
1.5	$2.98 \cdot 10^{4}$	$4.6 \cdot 10^{4}$		
2.5	$8.27 \cdot 10^{4}$	$1.28 \cdot 10^{5}$		
4	$2.12 \cdot 10^{5}$	$3.27 \cdot 10^{5}$		
6	$4.76 \cdot 10^{5}$	$7.36 \cdot 10^{5}$		
10	$1.32 \cdot 10^{6}$	$2.04 \cdot 10^{6}$	$5.78 \cdot 10^{5}$	$8.84 \cdot 10^{5}$
16	$3.39 \cdot 10^{6}$	$5.23 \cdot 10^{6}$	$1.48 \cdot 10^{6}$	$2.26 \cdot 10^{6}$
25	$8.27 \cdot 10^{6}$	$1.28 \cdot 10^{7}$	$3.61 \cdot 10^{5}$	$5.52 \cdot 10^{5}$
35	$1.62 \cdot 10^{7}$	$2.51 \cdot 10^{7}$	$7.08 \cdot 10^{6}$	$1.08 \cdot 10^{7}$
50	$3.31 \cdot 10^{7}$	$5.11 \cdot 10^{7}$	$1.44 \cdot 10^{7}$	$2.21 \cdot 10^{7}$
95	$1.19 \cdot 10^{8}$	$1.85 \cdot 10^{8}$	$5.21 \cdot 10^{7}$	$7.97 \cdot 10^{7}$
120	$1.9 \cdot 10^{8}$	$2.94 \cdot 10^{8}$	$8.32 \cdot 10^{7}$	$1.27 \cdot 10^{8}$
150	$2.98 \cdot 10^{8}$	$4.60 \cdot 10^{8}$	$1.3 \cdot 10^{8}$	$1.99 \cdot 10^{8}$
185	$4.53 \cdot 10^{8}$	$7 \cdot 10^{8}$	$1.98 \cdot 10^{8}$	$3.02 \cdot 10^{8}$
240	$7.62 \cdot 10^{8}$	$1.18 \cdot 10^{9}$	$3.33 \cdot 10^{8}$	$5.09 \cdot 10^{8}$
300	$1.19 \cdot 10^{9}$	$1.84 \cdot 10^{9}$	$5.2 \cdot 10^{8}$	$7.95 \cdot 10^{8}$
400	$2.12 \cdot 10^{9}$	$3.27 \cdot 10^{9}$	$9.24 \cdot 10^{8}$	$1.41 \cdot 10^{9}$
500	$3.31 \cdot 10^{9}$	$5.11 \cdot 10^{9}$	$1.44 \cdot 10^{9}$	$2.21 \cdot 10^{9}$

2 PROTECTIVE CONDUCTORS

It is not necessary to check the thermal stresses if the cross-section of the protective conductor has been selected in accordance with the table below.
In TN-C systems, the cross-section of the PEN conductor must not be less than 10 mm^2 for copper and 16 mm^2 for aluminium.
If the cross-section of protective conductors is determined by the calculation, the short-circuit current to be taken into account for checking the thermal stress is the minimum fault current (I_f). In this case it is determined between a live conductor and the protective conductor, at the end of the circuit in question, irrespective of the type of protection.
The cross-section is calculated for breaking times of less than 5 s using the following formula:

$$S_{PE} = \frac{\sqrt{I^2 t}}{K}$$

S_{PE}: cross-section of the protective conductor in mm^2
I: rms value of the fault current in A
t: operating time of the breaking device
K: factor depending on the permissible temperatures, the metal of which it is made and the insulation material (see actual value in the table on p. 29).

cross-section of the protective conductor (S_{PE}) according to the cross-section of the phase conductors (Sph)

Cross-section of phase conductors Sph	Cross-section of protective conductors S_{PE}
Sph < 16 mm^2	Sph
16 mm^2 < Sph ⩽ 35 mm^2	16 mm^2
Sph > 35 mm^2	½ Sph

For equipment with high permanent leakage currents (>10 mA), the cross-section S_{PE} of the protective conductor must be at least 10 mm^2 for copper or 16 mm^2 for aluminium, or even twice the"normal" cross-section by the provision of a second conductor parallel to the first installed up to the point in the installation where a cross-section of 10 mm^2 (copper) or 16 mm^2 (aluminium) is reached.
Use of the TN system is recommended when there are high leakage currents.

Calculating If

The conventional approximate method can be applied, in view of the distance of the power supply. The phase/earth fault current I_f can be taken (ignoring the reactances) as being:

$$I_f = 0,8 \times \frac{U_0}{R_{Ph} + R_{PE}}$$

U_0: simple phase/neutral voltage
R_{Ph}: resistance of the phase conductor
R_{PE}: resistance of the protective conductor
The value 0.8 is based on the hypothesis that the voltage at the origin of the circuit is 80% of the nominal voltage or that the impedance of the part of the fault loop upstream of the protection devices represents 20% of the total impedance of the loop.

Calculation of the K factor

K expressed as As$^{0.5}$/mm^2 is calculated using the formula:

$$K = \frac{\sqrt{C_V(B_0 + 20)}}{\rho_{20}} \times 10^{-12} \times \ln\left(1 + \frac{\theta_f - \theta_1}{B_0 + \theta_1}\right)$$

where:
C_V: thermal capacity per unit volume in J/°C·m^3
$C_V = C_M \times M_V$
C_M: specific heat of the conductor in J/°C·kg
M_V: density in kg/m^3
B_0: inverse of the resistance factor at 0°C
ρ_{20}: resistance the material at 20°C in Ωm
θ_1: initial temperature of the conductor in °C
θ_f: final temperature of the conductor in °C

Protection against short-circuits (continued)

CHECKING THE MAXIMUM PROTECTED LENGTHS

A check must be carried out to ensure that the smallest short-circuit current will correctly activate the protection device. Do do this, all that is necessary is to check that this current at the end of the wiring system to be protected is higher than the magnetic trip threshold of the circuit breaker. The most unfavourable trip value must be taken into account. If there is no manufacturer's data, the upper limits of the standard tripping curves must be used:
- 5 × In for curve B circuit breakers
- 10 × In for curve C circuit breakers
- 20 × In for curve D circuit breakers

For adjustable magnetic devices, the threshold is increased by a tolerance of 20%.
A simple calculation method (known as the conventional method) can be used to estimate the maximum protected lengths according to the magnetic setting of the circuit breakers. It is valid for circuits located some distance from the source and not supplied by an alternator.
This method assumes that if there is a short-circuit, the voltage at the origin of the faulty circuit is equal to 80% of the nominal voltage of the power supply. This means that the impedance of the faulty circuit represents 80% of the total impedance of the fault loop.
This can be expressed by the formula below:

$$0,8 \times U = Z_d \times Ik_{min}$$

U: voltage during normal service at the location where the protection device is installed
Z_d: impedance of the fault loop for the part concerning the faulty circuit. Twice the length of the circuit must be taken into consideration (outgoing and return current)
Ik_{min}: minimum short-circuit current
This formula can also be written in the following form:

$$L_{max} = \frac{0,8 \times U_0 \times S}{2 \times \rho \times I_a}$$

L_{max}: maximum protected length, in m
U_0: nominal phase-to-neutral voltage of the installation, in V. If the neutral is not distributed, use the phase-to-phase voltage
S: cross-section of the conductors, in mm^2
ρ: resistivity of the metal constituting the core of the conductor, in Ω mm^2/m
I_a: tripping current of the circuit breaker, in A
It is however necessary, for large cross-section cables (≥ 150 mm^2), to make a correction in order to take account of the effect of their reactance. This is already incorporated in the tables on the following pages.

Correction factors to be applied to the conductor lengths given in the tables

• Conductor core
The values are given for copper conductors. For aluminium conductors, these values must be multiplied by 0.62 for protection using circuit breakers and by 0.41 for protection using fuses.

• Type of circuit
The tables are given for 230 V single phase and 400 V three-phase circuits with neutral. The table below gives the values of the multiplication factors to be applied in other cases.

400 V three-phase or two-phase circuit	Multiplication correction factor
Without neutral	1.72
With full neutral	1
With half neutral	0.67

! **The tables on the following pages can be used to determine the maximum lengths of protected cable, but under no circumstances the current-carrying capacities I_Z (see p. 20).**

Maximum theoretical lengths (in m) of conductors protected against minimum short-circuits according to the cross-section of the conductor and the protection device(1)

Circuit breaker	S (mm²)	Circuit breaker rating In (in A)													
		2	4	6	10	16	20	25	32	40	50	63	80	100	125
LR, DX, DX-E curve C	1.5	300	150	100	60	38	30	24	19						
	2.5	500	250	167	100	63	50	40	31	25					
	4	800	400	267	160	100	80	64	50	40	32				
	6		600	400	240	150	120	96	75	60	48	38			
	10			667	400	250	200	160	125	100	80	63	50		
	16			1067	640	400	320	256	200	160	128	102	80	64	
	25				1000	625	500	400	313	250	200	159	125	100	80
	35					875	700	560	438	350	280	222	175	140	112
	50							800	625	500	400	317	250	200	160
LR, DX, DX-E curve B	1.5	600	300	200	120	75	60	48	38						
	2.5	1000	500	333	200	125	100	80	63	50					
	4	1600	800	533	320	200	160	128	100	80	64				
	6		1200	800	480	300	240	192	150	120	96	76			
	10			1333	800	500	400	320	250	200	160	127	100		
	16			2133	1280	800	640	512	400	320	256	203	160	128	
	25				2000	1250	1000	800	625	500	400	317	250	200	160
	35					1750	1400	1120	875	700	560	444	350	280	224
	50							1600	1250	1000	800	635	500	400	320
DX curve D	1.5	150	75	50	30	19	15	12	9						
	2.5	250	125	83	50	31	25	20	16	13					
	4	400	200	133	80	50	40	32	25	20	16				
	6		300	200	120	75	60	48	38	30	24	19			
	10			333	200	125	100	80	63	50	40	32	25		
	16			233	320	200	160	128	100	80	64	51	40	32	
	25				500	313	250	200	156	125	100	79	63	50	40
	35					438	350	280	219	175	140	111	88	70	56
	50							400	313	250	200	159	125	100	80

(1) **Caution**: These values are given for copper conductors in 230 V single phase or 400 V three-phase supply networks with neutral ($S_{neutral} = S_{phase}$). For any other type of conductor or circuit, apply a correction factor (see p. 32)

Protection against short-circuits (continued)

Maximum theoretical lengths (in m) of conductors protected against minimum short-circuits by a DPX according to the cross-section of the conductor and the setting of the DPX [1]

Magnetic setting of the DPX (Im in A)		90	100	125	160	200	250	320	400	500	700	800	875	1000
Cross-section of conductor (S in mm²)	**1.5**	56	50	40	31	25	20	16	13	10	7	6	6	5
	2.5	93	83	67	52	42	33	26	21	17	12	10	10	8
	4	148	133	107	83	67	53	42	33	27	19	17	15	13
	6	222	200	160	125	100	80	63	50	40	29	25	23	20
	10	370	333	267	208	167	133	104	83	67	48	42	38	33
	16	593	533	427	333	267	213	167	133	107	76	67	61	53
	25			667	521	417	333	260	208	167	119	104	95	83
	35					583	467	365	292	233	167	146	133	117
	50						667	521	417	333	238	208	190	167
	70							729	583	467	333	292	267	233
	95										452	396	362	317
	120											500	457	400
	150												497	435
	185													514

Magnetic setting of the DPX (Im in A)		1120	1250	1600	2000	2500	3200	4000	5000	6300	8000	12,500	16,000
Cross-section of conductor (S in mm²)	1.5	4	4	5									
	2.5	7	7	5	4	3	3						
	4	12	11	8	7	5	4	3	3				
	6	18	16	13	10	8	6	5	4	3			
	10	30	27	21	17	13	10	8	7	5	4		
	16	48	43	33	27	21	17	13	11	8	7	4	3
	25	74	67	52	42	33	26	21	17	13	10	7	5
	35	104	93	73	58	47	36	29	23	19	15	9	7
	50	149	133	104	83	67	52	42	33	26	21	13	10
	70	208	187	146	117	93	73	58	47	37	29	19	15
	95	283	253	198	158	127	99	79	63	50	40	25	20
	120	357	320	250	200	160	125	100	80	63	50	32	25
	150	388	348	272	217	174	136	109	87	69	54	35	27
	185	459	411	321	257	206	161	128	103	82	64	41	32
	240	571	512	400	320	256	200	160	128	102	80	51	40
	300			500	400	320	250	200	160	127	100	64	50

(1) **Caution**: These values are given for copper conductors in 230 V single phase or 400 V three-phase supply networks with neutral ($S_{neutral} = S_{phase}$). For any other type of conductor or circuit, apply a correction factor (see p. 32)

Maximum theoretical lengths (in m) of conductors protected against minimum short-circuits by fuses according to the cross-section of the conductor and the type of fuse [1]

S (mm²)	Rated current of PVC/XLPE aM fuses (in A)																			
	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
1.5	28/33	19/23	13/15	8/10	6/7															
2.5	67	47/54	32/38	20/24	14/16	9/11	6/7													
4	108	86	69	47/54	32/38	22/25	14/17	9/11	6/7											
6	161	129	104	81	65/66	45/52	29/34	19/23	13/15	9/10	6/7									
10				135	108	88	68	47/54	32/38	21/25	14/16	9/11	6/7							
16						140	109	86	69	49/55	32/38	21/25	14/17	9/11	6/7					
25								135	108	86	67	47/64	32/38	21/25	14/16	9/11				
35									151	121	94	75	58/60	38/45	25/30	17/20	11/13	7/9		
50											128	102	82	65	43/51	29/36	19/24	13/15	8/10	
70												151	121	96	75	56/60	38/45	26/30	17/20	11/13
95												205	164	130	102	82	65	43/51	29/34	19/23
120														164	129	104	82	65	44/52	29/35
150															138	110	88	69	55	37/44
185																128	102	80	64	61
240																	123	97	78	62

S (mm²)	Rated current of PVC/XLPE gG fuses (in A)																			
	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
1.5	82	59/61	38/47	18/22	13/16	6/7														
2.5		102	82	49/56	35/43	16/20	12/15	5/7												
4			131	89	76	42/52	31/39	14/17	8/10	4/5										
6				134	113	78	67/74	31/39	18/23	10/12	7/9									
10					189	129	112	74	51/57	27/34	19/24	19/12	7/9	3/4						
16							179	119	91	67	49/56	24/30	18/23	9/11	5/7	3/4				
25								186	143	104	88	59/61	45/53	22/27	13/16	7/9	4/5			
35									200	146	123	86	75	43/52	25/36	14/18	8/11	4/5		
50										198	167	117	101	71	45/54	26/33	16/22	8/11	5/7	
70											246	172	150	104	80	57/60	34/42	17/22	11/14	
95												233	203	141	109	82	62	32/40	20/25	9/11
120													256	179	137	103	80	51/57	32/40	14/18
150													272	190	145	110	85	61	42/48	20/24
185														220	169	127	98	70	56	27/34
240															205	155	119	85	68	43/46

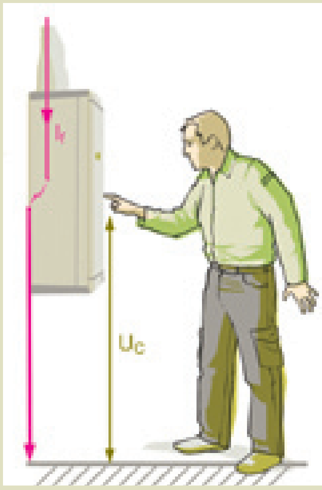
(1) **Caution**: These values are given for copper conductors in 230 V single phase or 400 V three-phase supply networks with neutral ($S_{neutral} = S_{phase}$). For any other type of conductor or circuit, apply a correction factor (see p. 32)

Protection against indirect contact

All electrical installations must be protected against indirect contact. Various methods described in the book "Electrical danger and the protection of people" can be used to provide this protection. This section defines the protection conditions involving automatic disconnection of the power supply.

The standard specifies that the fault current I_f must be eliminated within a time that is compatible with the safety of people.
This time is determined by reading the curves (see the book "Electrical danger and the protection of people") defined according to the prospective touch voltage Uc. These curves have been presented in the form of tables giving the maximum breaking time according to the selected earthing system, the nominal voltage of the installation and the limit voltage.
More often than not in TT systems, the presence of residual current devices enables this verification to be dispensed with. The residual current device must be sized according to the value of the earth connection and the type of use.
In principle, it is necessary to calculate the fault current values and comply with the maximum breaking times.

! Limit voltage



The limit voltage represents the value of the threshold below which there is no risk of electrocution. As a general rule, the nominal voltage of installations is higher than the limit voltage (50 V). To ensure there is no danger, the prospective touch voltage U_C must remain below the limit voltage.

TT SYSTEM

In this neutral earthing system, protection is more often than not based on the use of residual current devices. The impedance of the fault loop is high (two earthing resistances) and the intensity of the fault current is too low to activate the overcurrent protection devices.
The maximum sensitivity of the residual current devices must be selected so that the touch voltage does not exceed the limit voltage U_L (50 V in the formula below).

$$I\Delta n \leq \frac{50}{R_A}$$

$I\Delta n$: sensitivity of the residual current device
R_A: resistance of the earth connection of the exposed conductive parts in use.

Maximum breaking time in TT systems

Nominal voltage of the power supply U_0 (V)	Breaking time t_0 (s) U_L: 50 V	
	AC	DC
$50 < U_0 \leq 120$	0.3	(1)
$120 < U_0 \leq 230$	0.2	0.4
$230 < U_0 \leq 400$	0.07	0.2
$U_0 < 400$	0.04	0.1

(1) A breaking time may be specified for reasons other than protection against electric shocks

TN SYSTEM

In the TN system, protection against indirect contact is provided by overcurrent protection devices.
It is essential to check that the fault current is high enough to activate these devices and that this occurs within a short enough time.

1 BREAKING TIME

A conventional breaking time of no more than 5 s is permitted for distribution circuits and for terminal circuits with a rated current greater than 32 A.
For terminal circuits with a rated current In ⩽ 32 A, the breaking times of the protection devices must not exceed the values in the table below:

Maximum breaking time in TN systems

Nominal voltage of the power supply U_0 (V)	Breaking time t_0 (s) U_L: 50 V	
	AC	DC
$50 < U_0 \leqslant 120$	0.8	(1)
$120 < U_0 \leqslant 230$	0.4	5
$230 < U_0 \leqslant 400$	0.2	0.4
$U_0 < 400$	0.1	0.1

(1) A breaking time may be specified for reasons other than protection against electric shocks

In Belgium, above 400 V, the safety curves are given in the national requirements.
In the Netherlands, the maximum breaking time given in the table applies to all circuits supplying power socket outlets and for other terminal circuits up to 32 A.
In China, the maximum breaking time given in the table applies to terminal circuits supplying portable or mobile equipment.

In practice, when the circuit is protected by a circuit breaker, it is not necessary to check the breaking time rule. However, if a time-delayed circuit breaker is used, a check must be carried out to ensure that the total breaking time of the device (time delay + opening of the contacts) remains compatible with the specified times.

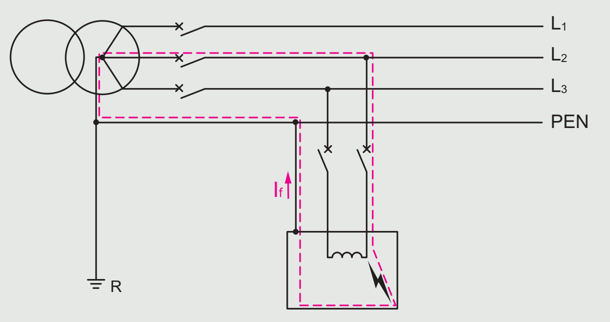
2 FAULT CURRENT

The principle of protection is based on the fact that an insulation fault in a TN system is converted to a phase/neutral short-circuit. If the fault current is high enough, the protection is then provided by the overcurrent protection devices.
This is expressed by the following rule:

$$I_f = \frac{U_0}{Z_S} \geq I_a$$

U_0 = nominal phase-to-neutral voltage of the installation
Z_S = total impedance of the fault loop
I_a = current ensuring operation of the protection device within the required time.

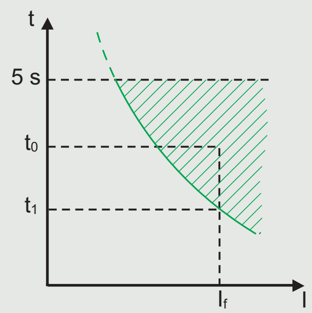
Fault loop in TN systems



Protection against indirect contact (continued)

Protection using fuses

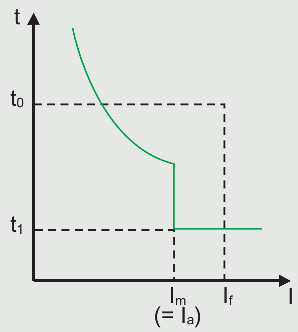
A check must be carried out to ensure that the fault current correctly blows the fuse within the required time. This condition is verified if t_1, the blowing time of the fuse for the calculated fault current I_f, is shorter than time t_0, the breaking time specified by the standard.



If $t_1 < t_0$ then protection is ensured

Protection using circuit breakers

When using circuit breakers for protection, a check must be carried out to ensure that the fault current is higher than the magnetic trip threshold of the circuit breaker.
The most unfavourable trip value must be taken into account. With DPX, this is the setting value of the magnetic relay plus the operating tolerance (20% for thermal-magnetic devices and 10% for electronic devices). In the case of DX modular circuit breakers, it is the maximum value of the tripping range:
4 × In for curve B
9 × In for curve C
14 × In for curve D



I_m: magnetic tripping current
I_f: fault current
t_1: circuit breaker operating time
t_0: maximum breaking time (see table)
If $I_f > I_m + 20\%$ and $t_1 < t_0$ then protection is ensured

3 MAXIMUM PROTECTED LENGTHS

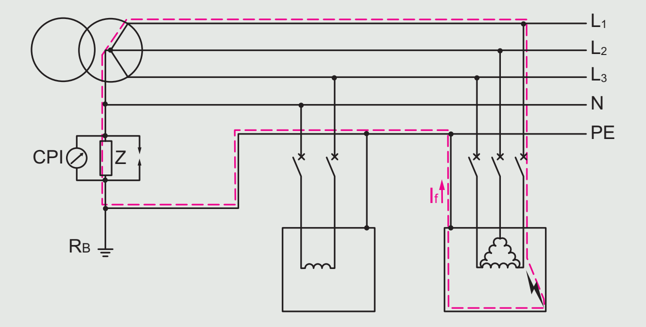
In practice, it is not necessary to know the fault current I_f in order to determine the maximum length of protected wiring system. This length is estimated according to the magnetic tripping current I_m (or I_a) of the protection devices (see p. 32).

IT SYSTEM

1 ON THE FIRST FAULT

The advantage of the IT system is that it does not trip on the first fault. Due to the high loop impedance in the event of a first fault, the fault current which circulates in the installation is low and the touch voltage remains considerably below the limit voltage. There is therefore no risk for users. The presence of this fault must be indicated by the permanent insulation monitoring (PIM).

First fault in IT systems



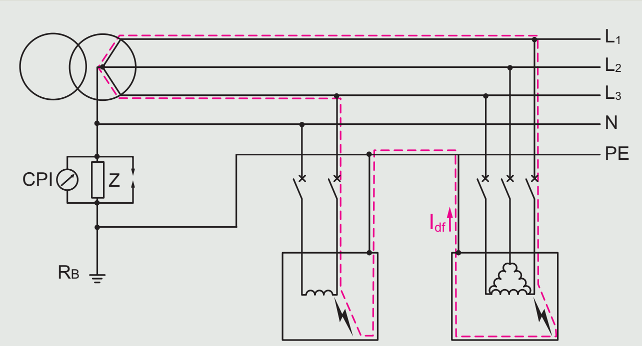
2 ON THE SECOND FAULT

When a second fault occurs, the power supply must be disconnected. There are two possibilities, depending on the way the exposed conductive parts are connected.

1 - The exposed conductive parts of the receivers are all interconnected via the PE conductor (recommended configuration): the conditions to be applied are those of the TN system.

2 - The exposed conductive parts are not interconnected and are connected to separate earth connections: the conditions to be applied are those of the TT system.

Second fault, interconnected exposed conductive parts



If the exposed conductive parts are interconnected, the double fault current is similar to a short-circuit and is no longer limited by the earth connections. As in a TN system, a check must be carried out to ensure that the double fault current is high enough to activate the overcurrent protection devices. The TN system protection rules can then be applied, taking account of the phase or phase-to-phase voltage (distributed or non-distributed neutral) and a loop impedance incorporating the path of the double fault current.

This can be expressed by the following rule:

$$I_{df} = \frac{U'}{2Z_S} \geq I_a$$

I_{df}: double fault current

U': phase-to-phase voltage if the neutral is not distributed; phase-to-neutral voltage if the neutral is distributed

Z_S: total impedance of the fault loop

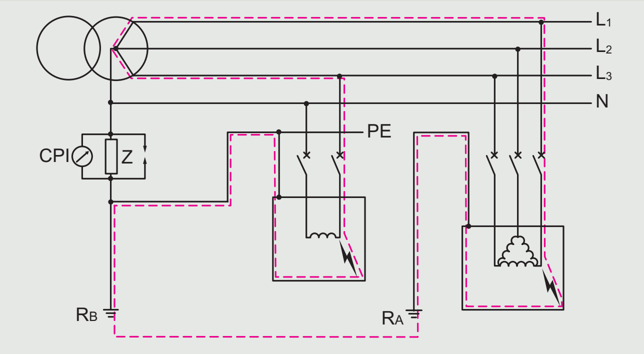
I_a: current ensuring operation of the protection device within the required time.

Protection against indirect contact (continued)

Maximum breaking time according to the supply voltage		
Nominal voltage U_0/U_n (V)	Breaking time t_0 (s) for U_L: 50 V	
	Non-distributed neutral	Distributed neutral
120/240, 127/230	0.8	5
220/380, 230/400	0.4	0.8
400/690	0.2	0.4

If the exposed conductive parts are not interconnected and two faults occur on circuits connected to separate earth connections, the double fault current loops via earth and is limited by two earth connections.
The value of the fault current may be too low to activate the overcurrent protection devices but may nevertheless generate a dangerous touch voltage.
The standard then requires residual current devices to be installed on each group of exposed conductive parts. They are selected in the same way as for TT systems.

Second fault, separate exposed conductive parts



When the exposed conductive parts on the low voltage side of the transformer station are not connected to the other exposed conductive parts in the installation, a residual current device must be installed at the origin of the installation. The same applies when the earth connection of the voltage surge limiter is not connected to all the interconnected exposed conductive parts.

CHECKING THE MAXIMUM PROTECTED LENGTHS

All that is necessary is to verify that the fault current is higher than the magnetic trip threshold of the circuit breaker and to take the most unfavourable trip value into account:
- Upper limit of tripping curves B (4 x In), C (9 x In) or D (14 x In) for DX circuit breakers
- Magnetic setting value plus the operating tolerance of 20% for DPX thermal-magnetic circuit breakers and 10 % for electronic DPX devices.

As when estimating the maximum lengths protected against minimum short-circuits, a simple calculation method (known as the conventional method) can be used to verify the maximum lengths for circuits that are some distance from the source (secondary and terminal circuits) and not supplied by an alternator.

This method assumes that if there is a short-circuit, the voltage at the origin of the faulty circuit is equal to 80% of the nominal voltage of the installation. This means that the impedance of the faulty outgoing line represents 80% of the total impedance of the fault loop.
This can be expressed by the general formula:

$$0{,}8 \times U_0 = (R_a + R_{PE}) \times I_f$$

U_0: phase-to-neutral voltage (in V)
R_{PE}: resistance of the protective conductor of the faulty circuit
R_a: resistance of a live conductor of the faulty circuit
I_f: fault current between phase and exposed conductive part.

This formula can also be written in the following form (TN system):

$$L_{max}=\frac{0,8\times U_0\times S_{ph}}{\rho\times(1+m)\times I_a}$$

L_{max}: maximum protected length (in m)
U_0: phase-to-neutral voltage (in V)
S_{ph}: cross-section of a phase conductor in the faulty circuit, in mm^2
m: Sph/SPE, ratio of the cross-section of the phase conductor over that of the protective conductor
ρ: resistivity of the metal constituting the core of the conductor (in Ω mm^2/m), 0.0225 for copper and 0.035 for aluminium
I_a: tripping current of the circuit breaker

The tables on the following pages can be used to determine the maximum protected lengths according to the type of protection and the type of conductor core. These values are given for circuits in which the cross-section of the PE is equal to the cross-section of the phases. If the PE is smaller, the values must be multiplied by the factors in the table opposite.
The corrections connected with the effect of the reactance of large cross-section conductors (≥ 150 mm^2) are incorporated directly in the tables.

IT system

In the case of IT systems with interconnected exposed conductive parts, the fault current is in fact a double fault current. Since it is impossible to define which circuit will be the second faulty circuit, it is assumed that it will have the same characteristics as the circuit being studied. The formula opposite becomes:

$$L_{max}=\frac{1}{2}\times\frac{0,8\times U'\times S_{ph}}{\rho\times(1+m)\times I_a}$$

L_{max}: maximum protected length (in m)

U': phase-to-phase voltage if the neutral is not distributed; phase-to-neutral voltage if the neutral is distributed (in V)

S_a: cross-section of a live conductor in the faulty circuit (in mm^2), phase conductor if the neutral is not distributed and neutral conductor if the neutral is distributed

m: S_a/S_{PE}, ratio of the cross-section of the live conductor over that of the protective conductor

ρ: resistivity of the metal constituting the core of the conductor (in Ω mm^2/m)

Ia: tripping current of the circuit breaker

If the neutral is distributed and its cross-section is smaller than those of the phase conductors, the tables must be read referring to the actual (smaller) cross-section of the neutral conductor.

Correction factors to be applied to the maximum protected theoretical lengths according to the neutral earthing system and the cross-section of the protective conductor

	Copper conductors					Aluminium conductors				
$m = S_{PE}/S_{ph}$	**1**	**0.5**	**0.33**	**0.25**	**0.2**	**1**	**0.5**	**0.33**	**0.25**	**0.2**
TN 230/400 V	1	0.67	0.5	0.4	0.33	0.62	0.41	0.31	0.25	0.20
IT 400 V non-distributed neutral	0.86	0.58	0.43	0.34	0.28	0.53	0.34	0.26	0.21	0.17
IT 230/400 V distributed neutral	0.5	0.33	0.25	0.2	0.16	0.31	0.20	0.15	0.12	0.1

Protection against indirect contact (continued)

The following tables can be used to determine the maximum lengths of protected cable, but under no circumstances the current-carrying capacities I_Z (see p. 06). The values are given for copper conductors in 230 V single phase or 400 V three-phase supply networks with neutral ($S_{neutral} = S_{phase}$). For any other type of conductor or circuit, apply a correction factor (see p. 41).

Example

A wiring system protected by a DPX 250 ER with:
- Length of busbar: 75 m
- Cross-section of the phase conductors: 70 mm^2
- Cross-section of the PE conductor: 35 mm^2
- Magnetic setting of the circuit breaker: Im = 2500 A

Reading from the table for DPX circuit breakers on the next page gives a maximum protected length of 93 m.
As ratio m (S_{PE}/S_{ph}) is 0.5, in TN systems a correction factor of 0.67 must be applied (see table on p. 41). The length that is actually protected is therefore 62 m (93 x 0.67), and is not compatible with the actual length of the cable, which is 75 m.

Maximum theoretical lengths (in m) of conductors protected against indirect contact by modular circuit breaker according to the cross-section of the conductor and the protection device

Circuit breaker	S (mm^2)	Circuit breaker rating In (in A)													
		2	4	6	10	16	20	25	32	40	50	63	80	100	125
LR, DX-E, DX curve B	1.5	600	300	200	120	75	60	48	35						
	2.5	1000	500	333	200	125	100	80	63	50					
	4	1600	800	533	320	200	160	128	100	80	64				
	6		1200	800	480	300	240	192	150	120	96	76			
	10			1333	800	500	400	320	250	200	160	127	100		
	16			2133	1280	800	640	512	400	320	256	203	160	128	
	25				200	1250	1000	800	625	500	400	317	250	100	160
	35					1750	1400	1120	875	700	560	444	350	280	224
	50							1660	1250	1000	800	635	500	400	320
LR, DX-E, DX curve C	1.5	300	150	100	60	38	30	24	19						
	2.5	500	250	167	100	63	50	40	31	25					
	4	800	400	267	160	100	80	64	50	40	32				
	6		600	400	240	150	120	96	75	60	48	38			
	10			667	400	250	200	160	125	100	80	63	50		
	16			1067	640	400	320	256	200	160	128	102	80	64	
	25				1000	625	500	400	313	250	200	159	125	100	80
	35					875	700	560	438	350	280	222	175	140	112
	50							800	625	500	400	317	250	200	160
DX curve D	1.5	150	75	50	30	19	15	12	9						
	2.5	250	125	83	50	31	25	20	16	13					
	4	400	200	133	80	50	40	32	25	20	16				
	6		300	200	120	75	60	48	38	30	24	19			
	10			333	200	125	100	80	63	50	40	32	25		
	16			233	320	200	160	128	100	80	64	51	40	32	
	25				500	313	250	200	156	125	100	79	63	50	40
	35					438	350	280	219	175	140	111	88	70	56
	50							400	313	250	200	159	125	100	80

Maximum theoretical lengths (in m) of conductors protected against indirect contact by DPX circuit breaker according to the cross-section of the conductor and the setting of the DPX

Magnetic setting of the DPX (Im in A)		90	100	125	160	200	250	320	400	500	700	800	875	1000
Cross-section of conductor (S in mm²)	1.5	56	50	40	31	25	20	16	13	10	7	6	6	5
	2.5	93	83	67	52	42	33	26	21	17	12	10	10	8
	4	148	133	107	83	67	53	42	33	27	19	17	15	13
	6	222	200	160	125	100	80	63	50	40	29	25	23	20
	10	370	333	267	208	167	133	104	83	67	48	42	38	33
	16	593	533	427	333	267	213	167	133	107	76	67	61	53
	25			667	521	417	333	260	208	167	119	104	95	83
	35					583	467	365	292	233	167	146	133	117
	50						667	521	417	333	238	208	190	167
	70							729	583	467	333	292	267	233
	95										452	396	362	317
	120											500	457	400
	150												497	435
	185													514

Magnetic setting of the DPX (Im in A)		1120	1250	1600	2000	2500	3200	4000	5000	6300	8000	12500	16000
Cross-section of conductor (S in mm²)	1.5	4	4	5									
	2.5	7	7	5	4	3	3						
	4	12	11	8	7	5	4	3	3				
	6	18	16	13	10	8	6	5	4	3			
	10	30	27	21	17	13	10	8	7	5	4		
	16	48	43	33	27	21	17	13	11	8	7	4	3
	25	74	67	52	42	33	26	21	17	13	10	7	5
	35	104	93	73	58	47	36	29	23	19	15	9	7
	50	149	133	104	83	67	52	42	33	26	21	13	10
	70	208	187	146	117	93	73	58	47	37	29	19	15
	95	283	253	198	158	127	99	79	63	50	40	25	20
	120	357	320	250	200	160	125	100	80	63	50	32	25
	150	388	348	272	217	174	136	109	87	69	54	35	27
	185	459	411	321	257	206	161	128	103	82	64	41	32
	240	571	512	400	320	256	200	160	128	102	80	51	40
	300			500	400	320	250	200	160	127	100	64	50

Protection against indirect contact (continued)

Maximum theoretical lengths (in m) of conductors protected against indirect contact by fuse cartridge according to the cross-section of the conductor and the type of fuse

	S (mm²)	Rated current of the fuses (in A)																			
		16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
aM	1.5	28	23	18	14	11	9	7	6	5	4										
aM	2.5	47	38	30	24	19	15	12	9	8	6	5									
aM	4	75	60	48	36	30	24	19	15	12	10	8	6	5	4						
aM	6	113	90	72	57	45	36	29	23	18	14	11	9	7	6	5	4				
aM	10	188	151	121	94	75	60	48	36	30	24	19	15	12	10	8	6	5	4		
aM	16	301	241	193	151	121	96	77	60	48	39	30	24	19	15	12	10	6	6	5	4
aM	25	470	377	302	236	188	151	120	94	75	60	47	38	30	24	19	15	12	9	8	6
aM	35	658	627	422	330	264	211	167	132	105	84	66	53	42	33	26	21	17	13	11	8
aM	50	891	714	572	447	357	286	227	179	144	115	90	72	57	46	36	29	23	18	14	11
aM	70			845	660	527	422	335	264	211	169	132	105	84	67	53	42	33	26	21	17
aM	95				895	716	572	454	358	286	229	179	143	115	91	72	67	45	36	29	23
aM	120					904	723	574	452	362	289	226	181	145	115	90	72	57	45	36	29
aM	150						794	630	496	397	317	248	198	159	126	99	79	63	50	40	32
aM	185							744	586	469	375	293	234	188	149	117	94	74	59	47	38
aM	240								730	584	467	365	292	234	185	146	117	93	73	58	47
aM	300									702	582	439	351	281	223	175	140	111	88	70	66

	S (mm²)	Rated current of the fuses (in A)																			
		16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
gG	1.5	53	40	32	22	18	13	11	7	6	4	3									
gG	2.5	88	66	53	36	31	21	18	12	9	7	6	4								
gG	4	141	106	85	58	33	29	19	15	11	9	8	6	4							
gG	6	212	159	127	87	73	60	43	29	22	16	14	10	8	6	4					
gG	10	353	265	212	145	122	84	72	48	37	27	23	16	14	10	7	6	4			
gG	16	566	424	339	231	196	134	116	77	69	43	36	25	22	15	12	9	7	6	4	
gG	25	884	663	530	381	306	209	181	120	92	67	57	40	35	24	18	14	11	8	6	4
gG	35		928	742	606	428	293	263	169	129	94	80	56	48	34	26	20	15	11	9	6
gG	50				667	581	398	343	229	176	128	108	76	66	46	35	27	20	15	12	8
gG	70					856	586	506	337	259	189	159	111	97	67	52	39	30	22	17	11
gG	95						795	887	458	351	256	151	131	92	70	63	29	41	29	23	16
gG	120							868	578	444	323	273	191	166	116	89	67	52	37	29	20
gG	150								615	472	343	290	203	178	123	94	71	54	39	31	21
gG	185								714	547	399	336	235	205	142	110	82	64	46	36	24
gG	240									666	485	409	286	249	173	133	100	77	55	44	29
gG	300										566	477	334	290	202	155	117	90	65	51	34

NB: For cross-sections greater than 300 mm², the reactance value of the cables must be taken into account.

SOLUTIONS WHEN THE TRIPPING CONDITIONS ARE NOT MET

In TN and IT systems, when it is not possible to comply with or verify the protection conditions, several other solutions may be considered:

1 USE OF RESIDUAL CURRENT DEVICES

The fault current remains high enough to allow the use of low sensitivity residual current devices (300 mA to 1 A). As in TT systems, it is therefore no longer necessary to verify the fault current value.

2 USE OF “LOW MAGNETIC” CIRCUIT BREAKERS OR CURVE B CIRCUIT BREAKERS

As the magnetic protection level of these devices is lower, longer length cables are protected.
The possible disadvantage could be false tripping on current peaks when the circuit supplies specific receivers (for example: activation of LV/LV transformers, motor starting, etc.).

3 INCREASING THE CROSS-SECTION

Increasing the cross-section of the conductors raises the fault current to a value that is sufficient to ensure that the overcurrent protection devices trip.

4 CREATING ADDITIONAL EQUIPOTENTIAL LINKS

These links must include all the conductive elements that are simultaneously accessible, such as the exposed conductive parts of devices, metal beams, reinforcements in concrete. The protective conductors of all the equipment and those of the power sockets must also be connected to these links. The effectiveness of this solution must be verified by measuring the actual resistance between the exposed conductive parts that are simultaneously accessible.

< On-site measurement of the end of line short-circuit value provides practical validation of the choice of protection

Estimating short-circuits and calculation example

**It is essential to determine the short-circuit values at all points in an installation in order to select the equipment.
This starts with estimating this value at the origin of the installation, then at any point using a number of methods which are selected according to the size of the installation, the available data, the type of verification to be carried out, etc.**

SHORT-CIRCUIT VALUE AT THE ORIGIN OF THE INSTALLATION

Several calculation methods can be used to estimate short-circuit currents: a rigorous method called the "impedance method" and two approximate methods called the "conventional method" and the "composition method" respectively.

- **The impedance method consists of adding together the resistances and reactances of the fault loops from the source up to the point in question and calculating the equivalent impedance. The various short-circuit and fault currents are then worked out by applying Ohm's Law. This method can be used when all the characteristics of the constituent elements of the fault loops are known.**
- **The conventional method is based on the hypothesis that during a fault the voltage at the origin of the circuit is equal to 80% of the nominal voltage of the installation. It is used when the short-circuit at the origin of the circuit and the upstream characteristics of the installation are not known. It enables the minimum short-circuits to be determined and the tables of the maximum protected lengths to be established (see p. 32 and 40). It is valid for circuits some distance from the source and is not applicable for installations supplied by alternators.**
- **The composition method is used when the short-circuit at the origin of the circuit is known, but the upstream characteristics of the installation are not. It enables the maximum short-circuits at any point in the installation to be determined.**

1 SUPPLY VIA HVA/LV TRANSFORMER

In the case of supply via an HVA/LV transformer, it is advisable to take the impedance of the transformer and also that of the HV supply upstream into account.

1.1 Impedance of the HV supply

The impedance of the HV supply, seen from the LV side, can be obtained from the energy distribution company, measured or calculated using the following formulae:

$$Z_Q = \frac{(m \times U_n)^2}{S_{kQ}} \text{ (in m}\Omega\text{)}$$

m: no-load factor taken as being 1.05
U_n: nominal phase-to-phase voltage of the installation, in V
S_{kQ}: short-circuit power of the HV supply, in kVA
In the absence of precise information from the energy distribution company, standard IEC 60909 recommends calculating the resistances and reactances as follows:

$R_Q = 0.1 \times X_Q$ and $X_Q = 0.995 \times Z_Q$ (values in mΩ).
By default, use S_{kQ} = 500 MVA

1.2 Impedance of the transformer

$$Z_S = \frac{(m \times U_n)^2}{S_{Tr}} \times \frac{U_{CC}}{100} \quad \text{(in m}\Omega\text{)}$$

m: no-load factor, taken as being 1.05
U_n: nominal phase-to-phase voltage of the installation, in V
S_{Tr}: rated operating power of the transformer, in kVA
U_{SC}: short-circuit voltage of the transformer, as a %

The resistance and reactance values are sometimes given by the manufacturer. If not, they must be calculated using the formulae below:
$R_S = 0.31 \times Z_S$ and $X_S = 0.95 \times Z_S$ (values in mΩ)
The following tables give the maximum three-phase resistance, reactance and short-circuit values (zero HV impedance) for immersed and dry-type transformers. These values have been calculated according to the information provided in CENELEC guide R064-003.

Three-phase transformers immersed in a liquid dielectric
Values calculated for a no-load voltage of 420 V(1)

S (kVA)	50	100	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500
In (A)	69	137	220	275	344	433	550	687	866	1100	1375	1718	2200	2749	3437
Usc (%)	4	4	4	4	4	4	4	4	4	6	6	6	6	6	6
Ik3 (kA)	1.81	3.61	5.78	7.22	9.03	11.37	14.44	18.05	22.75	19.26	24.07	30.09	38.52	48.15	60.18
RTR (mΩ)	43.75	21.9	13.7	10.9	8.75	6.94	5.47	4.38	3.47	4.10	3.28	2.63	2.05	1.64	1.31
XTR (mΩ)	134.1	67	41.9	33.5	26.8	21.28	16.76	13.41	10.64	12.57	10.05	8.04	6.28	5.03	4.02

Three-phase dry-type transformers
Values calculated for a no-load voltage of 420 V(1)

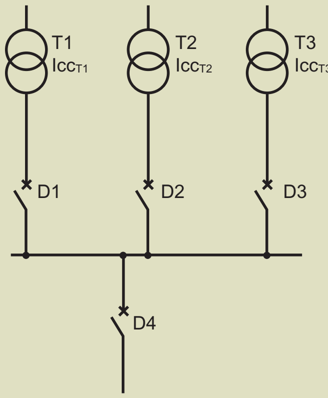
S (kVA)	100	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500
In (A)	137	220	344	344	433	550	687	866	1100	1375	1718	2199	2479	3437
Usc (%)	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Ik3 (kA)	2.41	3.85	4.81	6.02	7.58	9.63	12.04	15.17	19.26	24.07	30.09	38.52	48.15	60.18
R_{TR} (mΩ)	32.8	20.5	16.4	13.1	10.42	8.2	6.52	5.21	4.10	3.28	2.63	2.05	1.64	1.31
X_{TR} (mΩ)	100	62.8	50.3	40.2	31.9	25.1	20.11	15.96	12.57	10.05	8.04	6.28	5.03	4.02

(1) According to IEC 60076 (international standard) or HD 398 (harmonised European standard)
The short-circuit values given in manufacturers' catalogues may be slightly lower as they are generally calculated for a voltage of 410 V

Estimating short-circuits and calculation example (continued)

Transformers in parallel

To ensure correct operation of transformers in parallel (seethe "Power analysis and selection of sources" book), the following conditions must be verified:
- Same transformation ratio on all connectors
- Same time index
- Same short-circuit voltage (tolerance 10%)
- Rated power ratio between 0.5 and 2
Determination of the breaking capacities of the devices



■ Breaking capacity of a supply circuit breaker (e.g. : circuit breaker D1)
This must be at least equal to whichever is higher: the maximum short-circuit (Ik_{T1}) generated by transformer T1 (for a short-circuit downstream from D1) or the sum of all the short-circuits ($Ik_{T2} + Ik_{T3}$) generated by the other connected transformers (for a short-circuit upstream from circuit breaker D1).

■ Breaking capacity of an outgoing line circuit breaker (e.g. : circuit breaker D4)
This must be at least equal to the sum of all the maximum short-circuits generated by all the connected transformers ($Ik_{T1} + Ik_{T2} + Ik_{T3}$).

2 SUPPLY VIA THE MAINS

The short-circuit current values to be taken into account depend on the local supply conditions. The energy distribution company will be able to provide these values.

3 SUPPLY VIA AN ALTERNATOR

The short-circuit values can be calculated as follows (CENELEC R064-003):

$$Ik_3 = \frac{c \times m \times U_0}{X'd}$$

$$Ik_2 = \frac{\sqrt{3}}{2} \times Ik_3$$

$$Ik_1 = \frac{3 \times c \times m \times U_0}{2 \times X'd + X_0}$$

$$X'd = \frac{U_n^2}{S_G} \times \frac{x'_d}{100}$$

(transient reactance, in mΩ) and

$$X_0 = \frac{U_n^2}{S_G} \times \frac{x_0}{100}$$

(zero phase-sequence reactance, in mΩ)

m: no-load factor, taken as being 1.05
c: voltage factor, taken as being 1.05 for the maximum values and 0.95 for the minimum values
U_n: nominal phase-to-phase voltage, in V
U_0: phase-to-neutral voltage, in V
S_G: alternator power rating, in kVA
x'_d: transient reactance, as a %, taken as being 30% in the absence of more precise information
x_0: zero phase-sequence reactance, as a %, taken as being 6% in the absence of more precise information.

Maximum three-phase short-circuit values for an alternator according to its power rating (Un = 400 V and x'_d = 30%)											
P (kVA)	100	160	200	250	315	400	500	630	800	1000	1250
$Ik3_{max}$ (kA)	0.53	0.85	1.06	1.33	1.67	2.12	2.65	3.34	4.24	5.30	6.63

Due to their high internal impedance, alternators generate short-circuit currents that are much lower than those generated by transformers of equivalent power.
The breaking capacities of the protection devices will be lower, but protection against minimum short-circuits and indirect contact will be more difficult to achieve.
The development of a short-circuit which appears at the terminals of an alternator can be broken down into three periods:
- Subtransient period: 10 to 20 ms, during which the short-circuit level is at its highest (> 5 In)
- Transient period: up to 200 to 300 ms, during which the short-circuit is in the region of 3 to 5 In
- The short-circuit level then stabilises at a level of 0.3 to 5 In according to the type of excitation of the alternator.

For alternators, the two-phase short-circuit value may be lower than that of a single phase short-circuit. In this case, the two-phase short-circuit value (Ik2) must be taken into account in calculations that require a minimum short-circuit value (line lengths, protection against indirect contact, etc.).

When an installation is supplied by several different types of source, for example one or more transformers as normal source and a generator as a replacement (or backup), the protection devices must be suitable for the characteristics of the various types of source.
The maximum short-circuits must be calculated by comparing the maximum short-circuit level that may be generated by all the sources that can operate simultaneously and selecting the maximum value.
This generally involves transformers in parallel. The minimum short-circuits must be calculated by comparing the minimum short-circuit level generated by each of the sources and selecting the minimum value.

Estimation of short-circuits and calculation example (continued)

SHORT-CIRCUIT VALUE AT ANY POINT

1 IMPEDANCE METHOD

Using this method, it is possible to determine the value of a short-circuit at any point in the installation by adding together the resistances and reactances of the fault loop from the source up to the point in question and calculating the equivalent impedance. The short-circuit values are then calculated by applying Ohm's Law (general formula):

$$Ik = \frac{c \times m \times U_0}{Z_{CC}} = \frac{c \times m \times U_0}{\sqrt{\sum R^2 + \sum X^2}}$$

c: voltage factor taken as being 0.95 for minimum short-circuits and 1.05 for maximum short-circuits
m: load factor taken as being 1.05
U_0: phase-to-neutral voltage of the installation, in V
Z_{SC}: total impedance of the fault loop at the point in question This is the vectorial sum of the resistances and reactances that make up the loop.
The impedances of the cables are estimated using the following formulae:

$$R = \rho \times 10^3 \frac{L}{n_c \times S_c} \quad \text{(in m}\Omega\text{)}$$

ρ: resistivity of the conductor, in $\Omega mm^2/m$ (see table opposite)
S_c: cross-section of the conductor, in mm^2
n_c: number of conductors in parallel
L: length of the conductor, in m

$$X = \lambda \frac{L}{n_c} \quad \text{(in m}\Omega\text{)}$$

λ: linear reactance of the conductor, in mΩ/m (see table opposite)
S_c: cross-section of the conductor, in mm^2
n_c: number of conductors in parallel
L: length of the conductor, in m

Linear reactance of the conductors to be used according to the type of cable and its installation method

Cables and installation methods	Linear reactance λ (mΩ/m)
Multi-core or single-core cables in trefoil arrangement	0.08
Single-core cables touching in flat layers	0.09
Single-core cables more than one diameter's width apart	0.13

Resistivity of the conductors to be used according to the type of short-circuit calculated (ρ_0: resistivity of the conductors at 20°C)

Fault	Resistivity	Cu (Ω mm^2/m)	Al (Ω mm^2/m)
Isc maximum	ρ_0	0.01851	0.0294
Isc minimum	Circ. breaker $\rho_1 = 1.25\ \rho_0$	0.02314	0.0368
	Fuse $\rho_1 = 1.5\ \rho_0$	0.02777	0.0441
If	$\rho_1 = 1.25\ \rho_0$	0.02314	0.0368
Thermal stresses	$\rho_1 = 1.25\ \rho_0$	0.02314	0.0368

Calculation of the various types of maximum and minimum short-circuits using the general formula

- **Three-phase short-circuit current:**

$$Ik3_{max} = \frac{c_{max} \times m \times U_0}{\sqrt{\left(R_Q + R_S + R_{Pha} + \rho_0 \frac{L}{S_{Ph} \times n_{Ph}}\right)^2 + \left(X_Q + X_S + X_{Pha} + \lambda \frac{L}{n_{Ph}}\right)^2}}$$

- **Two-phase short-circuit current:**

$$Ik2_{max} = \frac{\sqrt{3}}{2} \times Ik3_{max}$$

To calculate the minimum two-phase short-circuit, replace:
- ρ_0 with ρ_1 for protection using circuit breakers or with ρ_2 for fuse protection
- c_{max} with c_{min}.

- **Phase-neutral single phase short-circuit current:**

$$Ik1_{max} = \frac{c_{max} \times m \times U_0}{\sqrt{\left(R_Q + R_S + R_{Pha} + R_{Na} + \rho_0 \times L\left(\frac{1}{S_{Ph} \times n_{Ph}} + \frac{1}{S_N \times n_N}\right)\right)^2 + \left(X_Q + X_S + X_{Pha} + X_{Na} + \lambda \times L\left(\frac{1}{n_{Ph}} + \frac{1}{n_N}\right)\right)^2}}$$

To calculate the minimum single phase short-circuit current, replace:
- ρ_0 with ρ_1 for protection using circuit breakers or with ρ_2 for fuse protection
- c_{max} with c_{min}.

- **Fault current:**

$$I_f = \frac{c_{min} \times m \times \alpha \times U_0}{\sqrt{\left(R_Q + R_S + R_{Pha} + R_{PEa} + \rho_1 \times L\left(\frac{1}{S_{Ph} \times n_{Ph}} + \frac{1}{S_{PE} \times n_{PE}}\right)\right)^2 + \left(X_Q + X_S + X_{Pha} + X_{PEa} + \lambda \times L\left(\frac{1}{n_{Ph}} + \frac{1}{n_{PE}}\right)\right)^2}}$$

c_{max}, c_{min}: voltage factor taken as being 0.95 (c_{min}) for minimum short-circuits and 1.05 (c_{max}) for maximum short-circuits
m: load factor taken as being 1.05
α: 1 in TN system, 0.86 in IT system without neutral and 0.5 in IT system with neutral
U_0: phase-to-neutral voltage of the installation, in V
R_Q, X_Q: equivalent resistance and reactance of the HV supply
R_S, X_S: equivalent resistance and reactance of the source
R_{Pha}, X_{Pha}: resistance and reactance of the phase conductors from the source up to the origin of the circuit in question. It is the sum of the resistances R and the reactances X of the upstream cables.
R_{Na}, X_{Na}: resistance and reactance of a neutral conductor from the source up to the origin of the circuit in question. It is the sum of the resistances R and the reactances X of the upstream cables.
R_{PEa}, X_{PEa}: resistance and reactance of a protective conductor from the source up to the origin of the circuit in question. It is the sum of the resistances R and the reactances X of the upstream cables.
ρ_0, ρ_1, ρ_2: resistivity of the conductors (see table on previous page)
λ: linear reactance of the conductors (see table on previous page)
L: length of the circuit in question, in m
S_{Ph}, n_{Ph}: cross-section and number of conductors in parallel per phase of the circuit in question
S_N, n_N: cross-section and number of conductors in parallel for the neutral of the circuit in question
S_{PE}, n_{PE}: cross-section and number of conductors in parallel for the PE of the circuit in question

Estimating short-circuits and calculation example (continued)

2 COMPOSITION METHOD

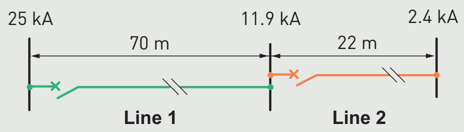
This method is a simplified approach. With a knowledge of the three-phase short-circuit current at the origin of the installation (see previous section), this approach enables the prospective short-circuit current Ik3 at the end of a wiring system of given length and cross-section to be estimated.

This method applies to installations whose power does not exceed 800 kVA. The maximum short-circuit current at any point in the installation is determined using the following tables, based on the:
- Prospective short-circuit current at the supply end of the installation
- Length of the line
- Type and cross-section of the conductors

Aluminium conductors – 240/400 V

Ik3 upstream (kA)	Short-circuit current at the level in question (Ik3 downstream in kA)																					
100	93.5	91.1	87.9	83.7	78.4	71.9	64.4	56.1	47.5	39.0	31.2	24.2	18.5	13.8	10.2	7.4	5.4	3.8	2.8	2.0	1.4	1.0
90	82.7	82.7	80.1	76.5	72.1	66.6	60.1	52.8	45.1	37.4	30.1	23.6	18.1	13.6	10.1	7.3	5.3	3.8	2.7	2.0	1.4	1.0
80	74.2	74.2	72.0	69.2	65.5	61.0	55.5	49.2	42.5	35.6	28.9	22.9	17.6	13.3	9.9	7.3	5.3	3.8	2.7	2.0	1.4	1.0
70	65.5	65.5	63.8	61.6	58.7	55.0	50.5	45.3	39.5	33.4	27.5	22.0	17.1	13.0	9.7	7.2	5.2	3.8	2.7	1.9	1.4	1.0
60	56.7	56.7	55.4	53.7	51.5	48.6	45.1	40.9	36.1	31.0	25.8	20.9	16.4	12.6	9.5	7.1	5.2	3.8	2.7	1.9	1.4	1.0
50	47.7	47.7	46.8	45.6	43.9	41.8	39.2	36.0	32.2	28.1	23.8	19.5	15.6	12.1	9.2	6.9	5.1	3.7	2.7	1.9	1.4	1.0
40	38.5	38.5	37.9	37.1	36.0	34.6	32.8	30.5	27.7	24.6	21.2	17.8	14.5	11.4	8.8	6.7	5.0	3.6	2.6	1.9	1.4	1.0
35	33.8	33.8	33.4	32.8	31.9	30.8	29.3	27.5	25.2	22.6	19.7	16.7	13.7	11.0	8.5	6.5	4.9	3.6	2.6	1.9	1.4	1.0
30	29.1	29.1	28.8	28.3	27.7	26.9	25.7	24.3	22.5	20.4	18.0	15.5	12.9	10.4	8.2	6.3	4.8	3.5	2.6	1.9	1.4	1.0
25	24.4	24.4	24.2	23.8	23.4	22.8	22.0	20.9	19.6	18.0	16.1	14.0	11.9	9.8	7.8	6.1	4.6	3.4	2.5	1.9	1.3	1.0
20	19.6	19.6	19.5	19.2	19.0	18.6	18.0	17.3	16.4	15.2	13.9	12.3	10.6	8.9	7.2	5.7	4.4	3.3	2.5	1.8	1.3	1.0
15	14.8	14.8	14.7	14.6	14.4	14.2	13.9	13.4	12.9	12.2	11.3	10.2	9.0	7.7	6.4	5.2	4.1	3.2	2.4	1.8	1.3	0.9
10	9.9	9.9	9.9	9.8	9.7	9.6	9.5	9.3	9.0	8.6	8.2	7.6	6.9	6.2	5.3	4.4	3.6	2.9	2.2	1.7	1.2	0.9
7	7.0	7.0	6.9	6.9	6.9	6.8	6.7	6.6	6.5	6.3	6.1	5.7	5.3	4.9	4.3	3.7	3.1	2.5	2.0	1.6	1.2	0.9
5	5.0	5.0	5.0	5.0	4.9	4.9	4.9	4.8	4.7	4.6	4.5	4.3	4.1	3.8	3.5	3.1	2.7	2.2	1.8	1.4	1.1	0.8
4	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9	3.8	3.8	3.7	3.6	3.4	3.2	3.0	2.7	2.3	2.0	1.7	1.3	1.0	0.8
3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9	2.9	2.8	2.7	2.6	2.5	2.4	2.2	2.0	1.7	1.5	1.2	1.0	0.8
2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.0	0.8	0.7
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.5
Phase conductor cross-section (mm^2)	**Length of the wiring system (in metres)**																					
2.5														1.3	1.9	2.7	3.8	5.4	7.6	10.8	15	22
4												1.1	1.5	2.2	3.0	4.3	6.1	8.6	12	17	24	34
6												1.6	1.7	2.5	3.5	4.9	7.0	9.9	14	20	28	40
10											1.5	2.1	2.9	4.1	5.8	8.2	11.6	16	23	33	47	66
16										2.2	3.0	4.3	6.1	8.6	12	17	24	34	49	69	98	138
25								1.7	2.4	3.4	4.8	6.7	9.5	13	19	27	38	54	76	108	152	216
35							1.7	2.4	3.3	4.7	6.7	9.4	13	19	27	38	53	75	107	151	213	302
50						1.6	2.3	3.2	4.5	6.4	9.0	13	18	26	36	51	72	102	145	205	290	410
70						2.4	3.3	4.7	6.7	9.4	13	19	27	38	53	75	107	151	213	302	427	
95					2.3	3.2	4.5	6.4	9.0	13	18	26	36	51	72	102	145	205	290	410		
120					2.9	4.0	5.7	8.1	11.4	16	23	32	46	65	91	129	183	259	366			
150					3.1	4.4	6.2	8.8	12	18	25	35	50	70	99	141	199	281	398			
185				2.6	3.7	5.2	7.3	10.4	15	21	29	42	59	83	117	166	235	332	470			
240		1.6	2.3	3.2	4.6	6.5	9.1	13	18	26	37	52	73	103	146	207	293	414				
300	1.4	1.9	2.7	3.9	5.5	7.8	11	16	22	31	44	62	88	124	176	249	352	497				
2 x 120	1.4	2.0	2.9	4.0	5.7	8.1	11.4	16	23	32	46	65	91	129	183	259	366	517				
2 x 150	1.6	2.2	3.1	4.4	6.2	8.8	12	18	25	35	50	70	99	141	199	281	398					
2 x 185	1.8	2.6	3.7	5.2	7.3	10.4	15	21	29	42	59	83	117	166	235	332	470					
2 x 240	2.3	3.2	4.6	6.5	9.1	12.9	18	26	37	52	73	103	146	207	293	414	583					
3 x 120	2.1	3.0	4.3	6.1	8.6	12.1	17	24	34	48	69	97	137	194	274	388	549					
3 x 150	2.3	3.3	4.7	6.6	9.3	13.2	19	26	37	53	75	105	149	211	298	422	596					
3 x 185	2.8	3.9	5.5	7.8	11.0	15.6	22	31	44	62	88	125	176	249	352	498	705					
2 x 300	2.8	3.8	5.4	7.8	11	16	22	32	44	62	88	124	176	248	352	498						
3 x 240	3.4	4.8	6.9	9.7	13.7	19	27	39	55	78	110	155	219	310	439	621						
4 x 240	4.6	6.4	9.2	13	18	26	36	52	74	104	146	206	292	414	586							
4 x 300	5.6	7.6	10.8	14.6	22	32	44	64	88	124	176	248	352	496	704							

Example



- **Line 1**
- **Ik3 at origin: 25 kA**
- **Copper cable: 120 mm²**
- **Length: 75 m (73 m)**

⇒ Ik3 downstream: 11.9 kA

- **Line 2**
- **Ik3 upstream: 11.9 kA rounded up to 15 kA**
- **Copper cable: 6 mm²**
- **Length: 25 m (22 m)**

⇒ Ik3 downstream: 2.4 kA

Copper conductors – 240/400 V

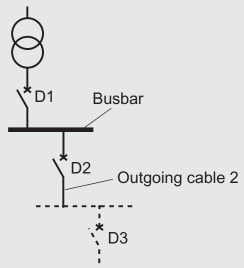
Ik3 upstream (kA)	Short-circuit current at the level in question (Ik3 downstream in kA)																					
100	93.5	91.1	87.9	83.7	78.4	71.9	64.4	56.1	47.5	39.0	31.2	24.2	18.5	13.8	10.2	7.4	5.4	3.8	2.8	2.0	1.4	1.0
90	82.7	82.7	80.1	76.5	72.1	66.6	60.1	52.8	45.1	37.4	30.1	23.6	18.1	13.6	10.1	7.3	5.3	3.8	2.7	2.0	1.4	1.0
80	74.2	74.2	72.0	69.2	65.5	61.0	55.5	49.2	42.5	35.6	28.9	22.9	17.6	13.3	9.9	7.3	5.3	3.8	2.7	2.0	1.4	1.0
70	65.5	65.5	63.8	61.6	58.7	55.0	50.5	45.3	39.5	33.4	27.5	22.0	17.1	13.0	9.7	7.2	5.2	3.8	2.7	1.9	1.4	1.0
60	56.7	56.7	55.4	53.7	51.5	48.6	45.1	40.9	36.1	31.0	25.8	20.9	16.4	12.6	9.5	7.1	5.2	3.8	2.7	1.9	1.4	1.0
50	47.7	47.7	46.8	45.6	43.9	41.8	39.2	36.0	32.2	28.1	23.8	19.5	15.6	12.1	9.2	6.9	5.1	3.7	2.7	1.9	1.4	1.0
40	38.5	38.5	37.9	37.1	36.0	34.6	32.8	30.5	27.7	24.6	21.2	17.8	14.5	11.4	8.8	6.7	5.0	3.6	2.6	1.9	1.4	1.0
35	33.8	33.8	33.4	32.8	31.9	30.8	29.3	27.5	25.2	22.6	19.7	16.7	13.7	11.0	8.5	6.5	4.9	3.6	2.6	1.9	1.4	1.0
30	29.1	29.1	28.8	28.3	27.7	26.9	25.7	24.3	22.5	20.4	18.0	15.5	12.9	10.4	8.2	6.3	4.8	3.5	2.6	1.9	1.4	1.0
25	24.4	24.4	24.2	23.8	23.4	22.8	22.0	20.9	19.6	18.0	16.1	14.0	11.9	9.8	7.8	6.1	4.6	3.4	2.5	1.9	1.3	1.0
20	19.6	19.6	19.5	19.2	19.0	18.6	18.0	17.3	16.4	15.2	13.9	12.3	10.6	8.9	7.2	5.7	4.4	3.3	2.5	1.8	1.3	1.0
15	14.8	14.8	14.7	14.6	14.4	14.2	13.9	13.4	12.9	12.2	11.3	10.2	9.0	7.7	6.4	5.2	4.1	3.2	2.4	1.8	1.3	0.9
10	9.9	9.9	9.9	9.8	9.7	9.6	9.5	9.3	9.0	8.6	8.2	7.6	6.9	6.2	5.3	4.4	3.6	2.9	2.2	1.7	1.2	0.9
7	7.0	7.0	6.9	6.9	6.9	6.8	6.7	6.6	6.5	6.3	6.1	5.7	5.3	4.9	4.3	3.7	3.1	2.5	2.0	1.6	1.2	0.9
5	5.0	5.0	5.0	5.0	4.9	4.9	4.9	4.8	4.7	4.6	4.5	4.3	4.1	3.8	3.5	3.1	2.7	2.2	1.8	1.4	1.1	0.8
4	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9	3.8	3.8	3.7	3.6	3.4	3.2	3.0	2.7	2.3	2.0	1.7	1.3	1.0	0.8
3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9	2.9	2.8	2.7	2.6	2.5	2.4	2.2	2.0	1.7	1.5	1.2	1.0	0.8
2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.0	0.8	0.7
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.5
Phase conductor cross-section (mm²)	**Length of the wiring system (in metres)**																					
1.5														1.3	1.8	2.6	3.6	5.1	7.3	10.3	15	21
2.5												1.1	1.5	2.1	3.0	4.3	6.1	8.6	12	17	24	34
4												1.7	1.9	2.6	3.7	5.3	7.4	10.5	15	21	30	42
6											1.4	2.0	2.8	4.0	5.6	7.9	11.2	16	22	32	45	63
10										2.1	3.0	4.3	6.1	8.6	12.1	17	24	34	48	68	97	137
16								1.7	2.4	3.4	4.8	6.8	9.7	14	19	27	39	55	77	110	155	219
25						1.3	1.9	2.7	3.8	5.4	7.6	10.7	15	21	30	43	61	86	121	171	242	342
35						1.9	2.6	3.7	5.3	7.5	10.6	15	21	30	42	60	85	120	170	240	339	479
50					1.8	2.5	3.6	5.1	7.2	10.2	14	20	29	41	58	81	115	163	230	325	460	
70					2.6	3.7	5.3	7.5	10.6	15	21	30	42	60	85	120	170	240	339			
95				2.5	3.6	5.1	7.2	10.2	14	20	29	41	58	81	115	163	230	325	460			
120		1.6	2.3	3.2	4.5	6.4	9.1	13	18	26	36	51	73	103	145	205	291	411				
150	1.2	1.7	2.5	3.5	4.9	7.0	9.9	14	20	28	39	56	79	112	158	223	316	447				
185	1.5	2.1	2.9	4.1	5.8	8.2	11.7	16	23	33	47	66	93	132	187	264	373	528				
240	1.8	2.6	3.6	5.1	7.3	10.3	15	21	29	41	58	82	116	164	232	329	465	658				
300	2.2	3.1	4.4	6.2	8.7	12.3	17	25	35	49	70	99	140	198	279	395	559					
2 x 120	2.3	3.2	4.5	6.4	9.1	12.8	18	26	36	51	73	103	145	205	291	411	581					
2 x 150	2.5	3.5	4.9	7.0	9.9	14	20	28	39	56	79	112	158	223	316	447	632					
2 x 185	2.9	4.1	5.8	8.2	11.7	16.5	23	33	47	66	93	132	187	264	373	528	747					
3 x 120	3.4	4.8	6.8	9.6	13.6	19	27	39	54	77	109	154	218	308	436	616						
3 x 150	3.7	5.2	7.4	10.5	14.8	21	30	42	59	84	118	168	237	335	474	670						
2 x 240	3.6	5.2	7.2	10.2	14.6	21	30	42	58	82	116	164	232	328	464	658						
3 x 185	4.4	6.2	8.8	12.4	17.5	25	35	49	70	99	140	198	280	396	560							
4 x 185	3.8	8.2	11.6	16.4	23	33	46	66	94	132	186	264	374	528	746							
4 x 240	7.2	10.4	14.4	20	29	41	60	84	116	164	232	328	464	656								

Estimating short-circuits and calculation example (continued)

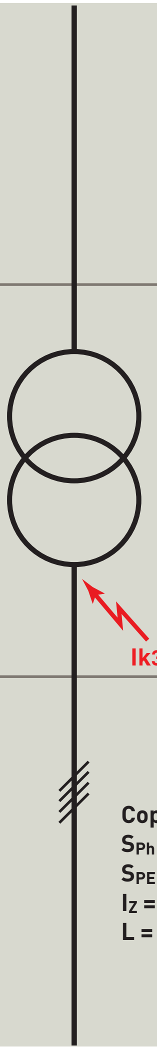
CALCULATION EXAMPLE

This example gives a complete calculation of the installation using the impedance method.
In the context of the protection of people, a complete fault current calculation is also carried out.
As the fault current in this example is always lower than the single phase short-circuit, it will be used as the reference for the setting of the magnetic releases of the circuit breakers.

Basic data for the example below



This is an installation with a 230/400 V TN system supplied via a 630 kVA HVA/LV transformer (Usc: 4%). The short-circuit power of the HV supply is 500 MVA.



S_{kQ} = 500 MVA

HV supply

$$Z_Q = \frac{(m \times U_n)^2}{S_{kQ}} = \frac{(1{,}05 \times 400)^2}{500000} = 0{,}353\ m\Omega$$

X_Q = 0.995 × Z_Q = 0.351 mΩ and R_Q = 0.1 × X_Q = 0.035 mΩ

RQ = 0.035 mΩ	**XQ = 0.351 mΩ**		

S_{Tr} = 630 kVA
U_{SC} = 4%
I_n = 909 A

HVA/LV transformer

■ **Calculation of Ik3**

$$Z_S = \frac{(m \times U_n)^2}{S_{Tr}} \times \frac{U_{CC}}{100} = \frac{(1{,}05 \times 400)^2}{630} \times \frac{4}{100} = 11{,}2\ m\Omega$$

R_S = 0.31 × Z_S = 3.472 mΩ and X_S = 0.95 × Z_S = 10.640 mΩ

R_S = 3.472 mΩ	**X_S = 10.640 mΩ**	**ΣR = 3.507 mΩ**	**ΣX = 10.991 mΩ**

$$\Rightarrow \quad Ik3 = \frac{1{,}05 \times 1{,}05 \times 231}{\sqrt{3{,}507^2 + 10{,}991^2}} = 22{,}07\ kA$$

Ik3 = 22.07 kA

Copper/XLPE
S_{Ph} = 2 × 185 mm²
S_{PEN} = 2 × 185 mm²
I_Z = 984 A
L = 5 m

Incoming cable

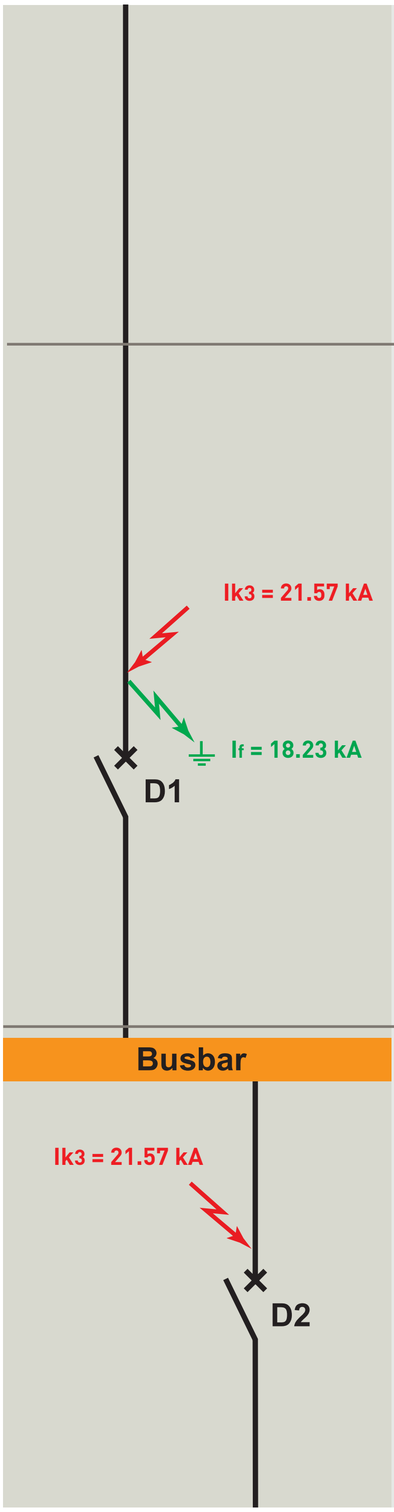
■ **Calculation of Ik3**

$$R_c = \rho_0 \times 10^3 \times \frac{L}{n_{ph} \times S_{ph}} = 0{,}01851 \times 10^3 \times \frac{5}{2 \times 185} = 0{,}250\ m\Omega$$

$$X_c = \lambda \times \frac{L}{n_{ph}} = 0{,}08 \times \frac{5}{2} = 0{,}200\ m\Omega$$

R_C = 0.250 mΩ	**X_C = 0.200 mΩ**	**ΣR = 3.757 mΩ**	**ΣX = 11.216 mΩ**

$$\Rightarrow \quad Ik3 = \frac{1{,}05 \times 1{,}05 \times 231}{\sqrt{3{,}757^2 + 11{,}216^2}} = 21{,}52\ kA$$



■ **Calculation of I_f**

$$R_c = \rho_1 \times 10^3 \times L \left(\frac{1}{n_{ph} \times S_{ph}} + \frac{1}{n_{PEN} \times S_{PEN}} \right) = 0{,}02314 \times 10^3 \times 5 \left(\frac{1}{2 \times 185} + \frac{1}{2 \times 185} \right) = 0{,}625$$

$$X_c = \lambda \times L \left(\frac{1}{n_{ph}} + \frac{1}{n_{PEN}} \right) = 0{,}09 \times 5 \left(\frac{1}{2} + \frac{1}{2} \right) = 0{,}45 \text{ m}\Omega$$

RC = 0.625 mΩ	**X_C = 0.45 mΩ**	**ΣR = 4.382 mΩ**	**ΣX = 11.666 mΩ**

$$\Rightarrow I_f = \frac{0{,}95 \times 1{,}05 \times 231}{\sqrt{4{,}382^2 + 11{,}666^2}} = 18{,}92 \text{ kA}$$

Selection and settings of main circuit breaker D1

■ **Rating (In):**
This must be at least equal to I_B. We will select a 1600 A rated DPX from the options offered, to allow for expansion of the installation.

■ **Breaking capacity:**
Br. capac. ≥ Ik3 ⇒ Br. capac. ≥ 21.57 kA. The breaking capacity of the DPX 1600 is 50 kA.

■ **Number of poles:**
3P

■ **Thermal setting (Ir):**
$I_B \leq Ir \leq I_Z \Rightarrow 909 \leq Ir \leq 984$ A.
The setting must therefore be between $\frac{909}{1600} = 0.57$ and $\frac{984}{1600} = 0.62$.

We will use Ir = 0.6 × In i.e. Ir = 960 A.

■ **Magnetic setting (Im):**

$$Im \leq \frac{If}{1.2}$$

If: smallest fault at end of line (on busbar)
1,2: 20% tolerance taken into account on the tripping curve

$$Im \leq \frac{18230}{1.2} \Rightarrow Im \leq 15191 \text{ A}$$

The maximum possible setting should be used: Im = 10 × Ir = 9600 A.
As a general rule the impedances of the busbars are ignored.

Selection and settings of outgoing line circuit breaker D2

■ **Rating (In):**
This must be at least equal to I_B. We will select a 250 A rated DPX 250 ER.

■ **Breaking capacity:**
Br. capac. ≥ Ik3 ⇒ Br. capac. ≥ 21.52 kA. The breaking capacity of the DPX 250 ER is 50 kA.

■ **Number of poles:** 4P

■ **Thermal setting (Ir):**
$I_B \leq Ir \leq I_Z \Rightarrow 250 \leq Ir \leq 268$ A. The maximum setting should be used:
Ir = 1 × In = 250 A.

■ **Magnetic setting (Im):**

$$Im \leq \frac{If}{1.2} \Rightarrow Im \leq \frac{4390}{1.2} \Rightarrow Im \leq 3658 \text{ A.}$$

The following setting should be used: Im = 10 × In = 2500 A.

Estimating short-circuits and calculation example (continued)

Copper/PR
S_{Ph} = 1 × 70 mm²
S_N = 1 × 35 mm²
S_{PE} = 1 × 35 mm²
I_B = 250 A
I_Z = 268 A
L = 50 m

cos φ = 0.85

Outgoing cable

■ **Calculation of Ik3 (this value will be used to determine the breaking capacity of circuit breaker D3)**

$$R_c = \rho_0 \times 10^3 \times \frac{L}{n_{ph} \times S_{ph}} = 0{,}01851 \times 10^3 \times \frac{50}{1 \times 70} = 13{,}221\ m\Omega$$

$$X_c = \lambda \times \frac{L}{n_{ph}} = 0{,}08 \times \frac{50}{1} = 4\ m\Omega$$

R_C = 13.221 mΩ	X_C = 4 mΩ	ΣR = 17.603 mΩ	ΣX = 15.666 mΩ

$$\Rightarrow \quad Ik3 = \frac{1{,}05 \times 1{,}05 \times 231}{\sqrt{17{,}603^2 + 15{,}666^2}} = 10{,}81\ kA$$

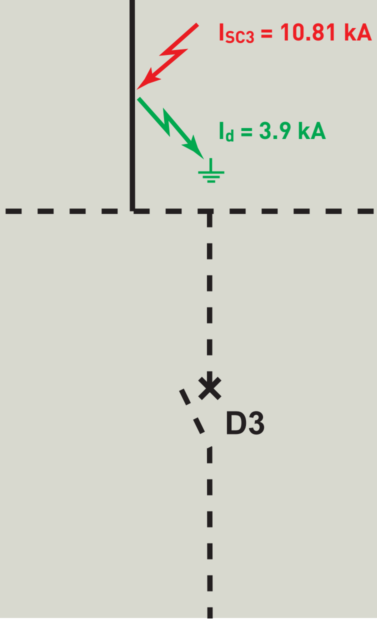
■ **Calculation of I_f**

$$R_c = \rho_1 \times 10^3 \times L \left(\frac{1}{n_{ph} \times S_{ph}} + \frac{1}{n_{PE} \times S_{PE}}\right) = 0{,}02314 \times 10^3 \times 50 \left(\frac{1}{70} + \frac{1}{35}\right) = 49{,}586\ m\Omega$$

$$X_c = \lambda \times L \left(\frac{1}{n_{ph}} + \frac{1}{n_{PE}}\right) = 0{,}08 \times 50 \left(1 + 1\right) = 8\ m\Omega$$

R_C = 13.221 mΩ	X_C = 4 mΩ	ΣR = 17.603 mΩ	∑ΣX = 15.666 mΩ

$$\Rightarrow \quad I_f = \frac{0{,}95 \times 1{,}05 \times 231}{\sqrt{53{,}968^2 + 19{,}666^2}} = 3{,}9\ kA$$



■ **Calculation of the voltage drop**

$$u = b\left(\rho_1 \frac{L}{S} \cos\varphi + \lambda L \sin\varphi\right) I_B$$

b = 1 for three-phase

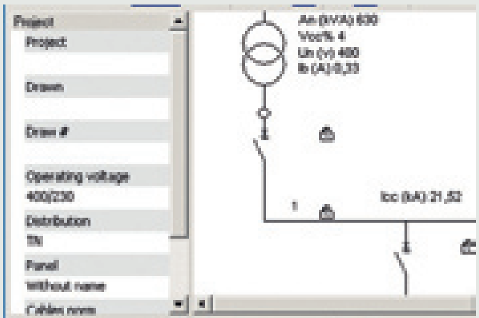
$$u = \left(0.02314 \times \frac{50}{70} \times 0.85 + 0.08 \times 10^{-3} \times 50 \times 0.527\right) \times 250 = 4.04\ V$$

$$\Delta u = \frac{4.04}{231} \times 100 = 1.75\%$$

With the knowledge that the voltage drop upstream is 0.14% (value calculated previously), the total cumulative voltage drop is 1.89%.

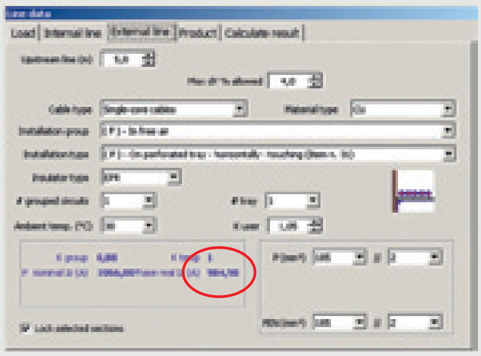
Checking the calculations with XL PRO² Calculation

Using the Legrand calculation software, we can verify the accuracy of the results worked out manually in the previous example.

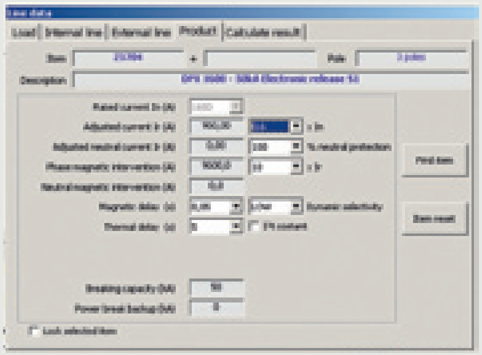


Id	Line 1	Line 2
Description		
Article reference	25704	25216
Ir phase (A)	0,6 x In = 960,00	1 x In = 250,00
Breaking capacity (KA)	50	25
Total power	629,774 KW	173,205 KW
drop voltage allowed (%)	4	4
Ib (A)	250,00	250,00
Ik Max begin of line (KA)	21,52	21,52
Ik Max end of line (KA)	21,52	10,01
Cable type	Single-core cables	Single-core cables
Section phase (mm²)	2 // 185	70
Section neutral (mm²)		35
Section PEN (mm²)	2 // 185	
Section PE (mm²)		35
Downstream external lin...	0,00	50,00
line real drop voltage / t...	0,13 / 0,13	1,88 / 2,01
Ik fault min PEN end of l...	18,93	
Ik fault min PE end of lin...		3,90

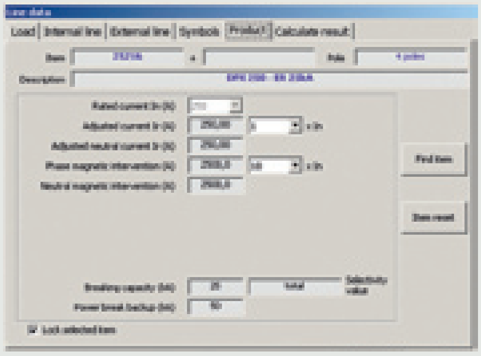
For the line of the D1 circuit breaker used in the example, we find the I_Z of the cable used, i.e. for 2 cables of 185 mm² per phase, an I_Z of 984.98 A

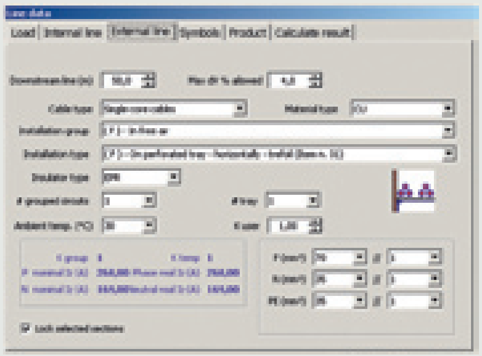


The software automatically gives the setting of the protection devices



Results for the line of circuit breaker D2





Conductors

The diversity of conductors is virtually unlimited. Their choice and their identification results from multiple technical criteria but also from local customs. A normative work of harmonization has been engaged successfully since years, especially in Europe.
Technical characteristics and uses of the most common types of installation conductors are described in this chapter.

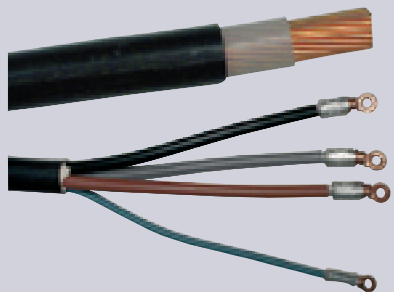
SELECTION AND USE OF CABLES AND CONDUCTORS

The requirements applicable to cables and conductors, their connections, supports and enclosures, and more generally, their protection from external stresses, must be considered when designing and implementing electrical installations.
Standard IEC 60364-5-51 defines installation configurations for cables and conductors known as "installation methods" (see p. 08) which determine the conditions for protection against external influences: temperature, presence of water, presence of pollution, risk of impact, vibration, fire, poor insulation conditions, etc.
The maximum permissible temperature of the insulation of the core is taken into account when sizing conductors (see p. 07 et seq.).
The generic name XLPE/PR is given to conductors whose insulation withstands 90°C (cross-linked polyethylene, elastomer)
The generic name PVC is given to conductors whose insulation withstands 70°C (PVC, rubber)

For industrial distribution applications, the use of cables with elastomer XLPE/PR insulation is especially recommended:
- Their insulation voltage is higher (up to 1000 V)
- Their permissible operating temperature (90°C) and max. short-circuit temperature (250°C) are suitable for the requirements of power distribution boards
- They have excellent mechanical properties
- They are highly resistant to atmospheric and chemical agents

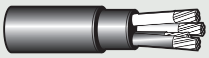
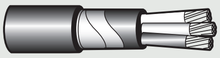
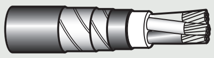
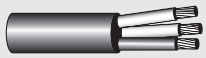
Some conductors and cables are considered to provide class II insulation (this degree of insulation can be achieved by placing insulated conductors in an insulated sheath or conduit). They must be used where there is a high risk of contact with the earth potential (conductive enclosures or those with a large number of conductive elements) or when the insulation conditions are poor (damp areas).
It may also be necessary to use them upstream of devices providing effective protection against indirect contact.

Class II cables
- **U_0 500 V: U-1000 R12N, U-1000 R2V, U-1000 RVFV[1], H07 RN-F, A07 RN-F, FR-N1 X1 X2, FR-N1 X1 G1, H07 VVH2-F**
- **U_0 250 V: H05 RN-F, H05 RR-F, H05 VV-F, H05 VVH2-F, FR-N05 VV5-F, A05 VVH2-F[1]**


U-1000 R2V single-core and multi-core cable

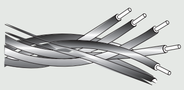
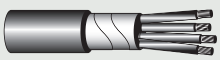
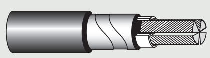
(1) Depending on the conditions of use

The most commonly used power conductors and cables

Designation	 **U-1000 R2V and U-1000 AR2V**	 **U-1000 RVFV and U-1000 ARVFV**	 **U-1000 RGPFV**	 **H07 RN-F**
Use	Fixed installation	Buried connection or enhanced mechanical protection	Immersed installation, chemical attack, high mechanical protection	Protected mobile or fixed installation
Number of conductors	1 to 4 (5 up to 50 mm^2)	1 to 4 (5 up to 50 mm^2)	2 to 4 (5 up to 225 mm^2)	1 to 4
Conductor cross-section	1.5 to 300 mm^2	1.5 to 300 mm^2	1.5 to 240 mm^2 (150 mm^2 for 3 cond.)	1.5 to 300 mm^2
Core	Copper or aluminium	Copper or aluminium	Copper	Flexible copper
Insulation	Cross-linked polyethylene	Cross-linked polyethylene	Cross-linked polyethylene	Cross-linked elastomer
Sheath	Black PVC	Black PVC	Black PVC	Cross-linked elastomer
Metal covering	-	2 steel sleeves	lead sheath + 2 steel sleeves	-
Nominal voltage	600/1000 V	600/1000 V	600/1000 V	450/750 V

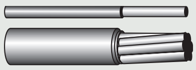
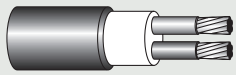
In poor insulation conditions, and also when there is a frequent risk of contact with earth, U-1 000 RVFV type cables with a metal covering can be used, connecting both ends of the sleeves to the protective conductor.
In very poor insulation conditions, or if people are in permanent contact with earth (conductive enclosure), or upstream of devices providing protection against indirect contact, and for all conditions requiring class II wiring systems, U-1 000 RVFV cables can be used, as long as the metal sleeves are not connected and are insulated from all contact.

Low voltage connection cables

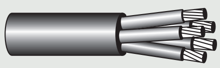
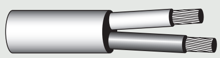
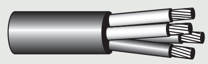
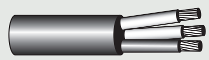
Designation	 **Twisted supply bundle with messenger NF C 33 209**	 **H1 XDV-AR**	 **H1 XDV-AS sector-shaped core, non-insulated PE conductor**
Use	Overhead connection	Underground connection NF C 32 210	
Number of conductors	-	-	
Conductor cross-section	25 to 150 mm^2	16 to 240 mm^2	
Core	Aluminium	Aluminium	
Insulation	Cross-linked polyethylene	Cross-linked polyethylene	
Sheath	-	PVC	
Metal covering	-	Steel sleeves	
Nominal voltage	600/1000 V	600/1000 V	

Conductors (continued)

Conductors and cables for domestic, residential, commercial or similar applications

Designation	 **H07 V-U and H07 V-R**	 **H07 V-K and H07 V-K**	 **FR-N05 VV-U/FR-N05 VV-R**
Use	Fixed installation (in conduit, trunking, wiring of terminal board)	Internal wiring or wiring fixed installation in trunking or conduit	Fixed installation on walls, empty construction compartments (flush-mounting in conduit)
Number of conductors	1	1	2 to 5
Conductor cross-section	Up to 400 mm^2	Up to 240 mm^2	1.5 to 6 mm^2
Core	Rigid copper: solid (V-U) or stranded (V-R)	Flexible copper	Rigid copper: solid (V-U) or stranded (V-R)
Insulation	PVC (numerous colours)	PVC	PVC
Sheath	-	-	PVC
Nominal voltage	450/750 V	H05: 300/500 V - H07: 450/750 V	300/500 V

Conductors and cables for domestic, residential, commercial or similar applications (continued)

Designation	 **H05 VV-F**	 **H03VVH2-F and H05 VVH2-F**	 **H05 RR-F and A05 RR-F**	 **H05 RN-F and A05 RN-F**
Use	Supplying mobile or removable domestic appliances	Power supply	Supplying mobile devices (in particular heating)	Supplying small machines, motors, inspection lamps
Number of conductors	2 to 5	2	2 to 5	2 or 3
Conductor cross-section	0.75 to 4 mm^2	0.5 to 6 mm^2	0.5 to 6 mm^2	0.75 and 1 mm^2
Core	Flexible copper	Flexible copper	Flexible copper (plain or tinned)	Flexible copper
Insulation	PVC	PVC	Elastomer	Elastomer
Sheath	PVC	PVC	Elastomer	Elastomer
Note	-	-	Good mechanical strength	Good mechanical strength
Nominal voltage	300/500 V	H03: 300 V - H05: 500 V	300/500 V	300/500 V

Characterised by ease of use, these cables have low or medium mechanical strength. Their insulation voltage is 500 or 750 V, their maximum temperature is 70°C in steady state (160°C in short-circuit). Their fire behaviour classification is C2.

There are many other types of standardised and non-standardised cables for specific applications: fire, control, command, lifts, handling, indicators, chemical industry, etc. Refer to the manufacturers' catalogues for their characteristics and selection.

Symbolic designation of cables: harmonised description

Type of range		Voltage U_0/U		Insulation		Metal covering		Sheath		Shape of cable		Type of core		Flexibility and shape of the core	
Harmonised range	H	< 100 V	00	PVC	V	Steel tape around the conductors	D	PVC	V	Round cable	no letter	Copper	-	Rigid, solid, round, class 1	U
		100/100 V	01											Rigid, stranded, round, class 2	R
														Rigid, stranded, sector-shaped	S
Recognised national range	A	300/300 V	03	Vulcanised rubber	R			Vulcanised rubber	R	Divisible flat cable	H			Rigid, solid, sector-shaped	W
		300/500 V	05											Tinsel conductor	Y
												Aluminium	-A	Flexible, class 5 for fixed installation	K
National range other than recognised range	N	450/750 V	07	Cross-linked polyethylene	X			Cross-linked polyethylene	N	Non-divisible flat cable	H2			Flexible, class 5	F
		0.6/1 kV	1											Extra flexible class 6	H

Example: H07 V-K
H: harmonised range; 07: 450/750 insulation; V: PVC insulation; -K: class 5 flexible copper core

Symbolic designation of cables: harmonised description

Type of range		Voltage Uo		Flexibility of the core		Type of core		Insulation		Filler		Protective sheath		Metal covering		Shape of cable	
Cable subject to a UTE standard	U	250 V	250	Rigid	no letter	Copper	no letter	Vulcanised rubber	C	Filler sheath	G	Thick sheath	2	Lead sheath	P	Round cable	no letter
								Cross-linked polyethylene	R			Very thick grease	3				
		500 V	500							No filler or filler not forming a sheath	O	Vulcanised rubber	C	Steel sleeves	F		
				Flexible	A	Alumin.	A	PVC	V			Polychloroprene	N			Flat cable	M
		1000 V	1000					Mineral insulation	X	Grouping and protective sheath forming filler	I			Zinc or metal	Z		
												PVC	V				

Example: U-1000 RO2V
U: Covered by a UTE standard; 1000: insulation voltage 1000 V; R: cross-linked polyethylene insulation; O: no filler; 2: thick sheath; V: PVC protective sheath

Conductors (continued)

Conditions of use of the most

External influences (abbreviated

Cables	Ambient temperature (AA)						Presence of water (AD)					Presence of foreign solid bodies or dust (AE)			Presence of corrosive or polluting substances (AF)			Mechanical shock (AG)			
	-60°C to +5°C	-40°C to +5°C	-25°C to +5°C	-5°C to +40°C	+5°C to +40°C	+5°C to +60°C	Negligible	Splashes (IP x4)	Waves (IP x6)	Immersion (IP x7)	Submersion (IP x8)	Light dust	Moderate dust	Heavy dust	Negligible	Atmospheric	Intermittent or accidental	Low severity (IK 03)	Medium severity (IK 07)	High severity (IK 08)	Very high severity (IK 10) [6]
	AA1	AA2	AA3	AA4	AA5	AA6	AD1	AD4	AD6	AD7	AD8	AE4	AE5	AE6	AF1	AF2	AF3	AG1	AG2	AG3	AG4
U-1000R2V U-1000AR2V				● (1)	●	●			●	● (2)		●	●	●			●	●	●	●	
U-1000RVFV U-1000ARVFV				● (1)	●	●			●	● (2)		●	●	●			●				●
U-1000RGPFV				● (1)	●	●			●	● (2)	o	●		●			●				●
H07 RN-F H05 RN-F			●	●	●				●	● (2)		●	●				●				●
Torsades 0,6/1 kV	●	●	●	●	●				●			●	●				●	●			
H1 XDV-AR H1 XDV-AS					● (1)				●	● (2)		●		●			●	●	●	●	
H07 V-U H07 VR					● (1)	●	●					●		●	●			●			
H07 V-K					● (1)	●	●					●		●	●			●			
FR-N 05 VV-U FR-N 05 VV-R					●	●			●			●					●	●	●		
H05 VV-F					●				●			●					●	●	●		
H03 VVH2-F H05 VVH2-F					● (1)	●			●			●					●	●	●		
H05 RR-F A05 RR-F			●	●	●			●					●				●	●	●		

(1) These cables can be used in other temperature conditions if they are not subject to any mechanical stress

(2) Cumulative immersion period limited to 2 months a year

(3) If metallic coverings earth connected

(4) Cables permanently fixed and U_0 tension limited to 250 V

(5) According to protection conduit

(6) The level IK10 according to IEC 62262 is only used in France (NF C 15-100)

(7) The matter is under consideration in the IEC 60364-5-51 but used in France (NF C 15-100)

common cables and conductors

designations according to IEC 60364-5-51)

	Vibration (AH)			Presence of flora and/or moulds growth (AK)		Presence of fauna (AL)		Solar radiation (AN)			Electrical resistance of the human body[7] (BB)			Nature of processed or stored materials (BE)			Construction materials (CA)		Building design (CB)			
	Low severity	Medium severity (industrial)	High severity	No hazard	Hazard	No hazard	Hazard	Low (<500 W/m²)	Medium (500 to 700 W/m²)	High (700 m²)	Dry condition	Wet Condition	Immersed condition	No significant risks	Fire risks	Explosion risks	Non combustible	Combustible	Negligibles risks	Propagation of fire	Movement	Flexible or unstable
	AH1	AH2	AH3	AK1	AK2	AL1	AL2	AN1	AN2	AN3	BB1	BB2	BB3	BE1	BE2	BE3	CA1	CA2	CB1	CB2	CB3	CB4
	●			●		●				●	●	●	●	●	●	●		●	●			
	●				●	●	●			●	●	● (3)		●	●	●		●	●			
	●				●	●	●	●			●	● (3)		●	●	●		●	●			
			●	●		●			●		●	●	●	●	●	●		●	●		●	●
	●			●		●				●	●	●	●	●			●		●			
	●			●		●		●			●	● (3)		●			●		●			
	●			●		●		●			●			●			(5)		●			
			●	●		●		●			●			●			(5)				● (5)	● (5)
	●			●		●					●	●	● (4)	●	●			●	●			
			●	●		●					●	●	● (4)	●	●			●	●			
			●	●		●		●			●	●	●	●	●			●	●			
			●	●		●			●		●	●	● (4)	●			●		●		●	●

Conductors (continued)

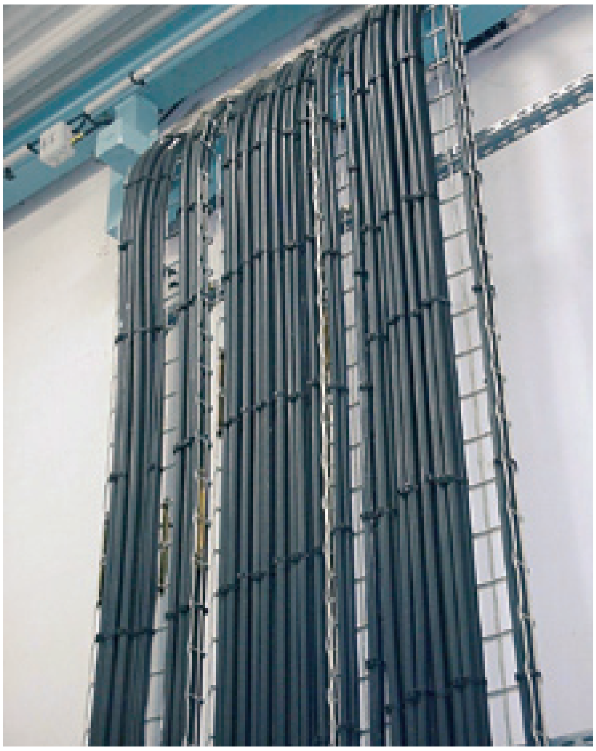
Maximum permitted temperatures (°C)						
Insulation	**PVC**	**High temperature PVC**	**Rubber**	**High temperature rubber**	**Ethylene-propylene (EPR) and cross-linked polyethylene (XLPE)**	**Silicone rubber (SIR)**
Under constant normal conditions	70	90	60	85	90	180
Under short-circuit conditions	160 140 when S > 300 mm^2	160	200	220	250	350

Fire behaviour of cables and conductors

Classification of fire behavior is based on a number of tests that are defined by international standards (IEC 60331 and IEC 60332), European (EN 50200) or national for some types of cables (for example NF C 32070 for C1 category).

The following "reaction to fire" categories are distinguished:
- C3: no special characteristics
- C2: flame retardant. Most cables in installations belong to this category.
- C1: fire retardant. Using this class limits the risk of spreading in flat layers and cable ducting.
FR N1 X1... series cables, and FR-N05 G2 (U, R or K) and FR-N07 X3 (U, R or K) series conductors belong to this category.

The following "fire resistance" categories are distinguished:
- CR2: no special characteristics
- CR1: fire resistant.
U500 X, XV, 1000 X or XV series conductors with mineral insulation, "Lyonotox" and "Pyrolyon" type "fire resistant" conductors, and certain (central) power or signalling cables belong to this category.
Class CR1 is for example required in fire safety installations in public buildings.



^ A neat cable layout is essential with regard to the fire risk

CABLE CORES IDENTIFICATION

Identification colors of cores in cables have been subject to developments that results in the harmonization document HD 308 S2.
These rules do not apply to conductors used in the materials and sets assembled at the factory although compliance is strongly recommended (see next page). For information, old national habits are reminded in the table below.
These cables are still widely present in existing installations.

Colors of rigid and flexible cable cores according to HD 324 S2 standard

Number of conductors	2	3	4	5	Color	Function
With PE					Green-Yellow	PE
					Blue	Neutral
					Brown Black Gray	Phases
Without PE					Blue	Neutral
					Brown Black Gray Black	Phases

Old fixed cables colors in european countries (CENELEC - feb. 1996)

	Austria	Belgium	Czech Republic	Denmark	Finland	France	Germany	Hungary	Ireland	Italy	Norway	Portugal	Slovak Republic	Sweden	Switzerland	United Kingdom
PE																
N																
L1				no requirements						IEC 445	no requirements			no requirements		
L2									any exept above							
L3																
Prohibited																

G-Y and Blue   G-Y with Blue marking   Black or brown

Conductors (continued)

WIRING IN ASSEMBLIES

1 CROSS-SECTIONS OF CONDUCTORS

The table on the next page has been drawn up based on the work practices of a great many professionals and tests on wired assemblies.
As with the sizing of wiring systems, the conductors have been divided into two types:
- PVC for conductors with PVC or rubber insulation (generally used for wiring conductors up to 35 mm²).
- XLPE/PR for polyethylene or elastomer conductors (in practice these are usually reserved for cross-sections greater than 35 mm²).
The installation and ambient temperature conditions have been empirically named:
- IP ⩽ 30 for conductors installed with good cooling conditions (enclosure open or naturally ventilated, low to medium wiring density, enclosure internal temperature similar to the ambient temperature up to 35°C).
- IP > 30 pour les conductors installed in poor cooling conditions (sealed enclosure, high wiring density, multi-core cables, enclosure internal temperature that may reach 50°C).

The U columns apply when the conductors or cables are separated, not touching or touching in the same circuit (installed on supports, with guide rings, or simple holding devices).
The G columns are to be applied when conductors from different circuits are installed touching one another and grouped together (for example, installation in trunking or in strands.)
The current-carrying capacities of flexible bars are given on p. 67, while those of rigid bars can be found in the "Distribution" book. The usual cross-sections of protective conductors (PE) in assemblies are given on p. 31.

Identification of conductors

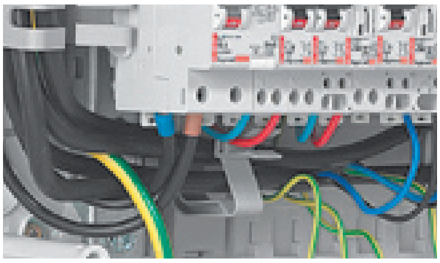
Three phases distribution inevitably raises the question of phase rotation direction, essentially for circuits including engines. So, the adherence to a unique and constant color code throughout an installation is primodial. Building site installations, by nature likely to dismantling and random connections, are even more sensitive to this problem whose consequences can be severe including for security.

The cross-sections of the conductors to be used for wiring inside assemblies are not subject to a single standard document.
• It is difficult to determine the cross-sections according to the installation methods in IEC 60364-5-52 as this requires, for the application of the correction factors, information that will only be known after the installation has been carried out: parts which run vertically, parts which run horizontally, groups, number of layers, separate conductors or cables, not to mention knowledge of the ambient temperature in the enclosure, which is always difficult.
• Standard EN 60439-1 does not recommend cross-sections but stipulates a "current range" for the temperature rise tests. The conductors taken into consideration have PVC insulation and the ambient temperature is not specified.
These conditions do not therefore cover all applications.

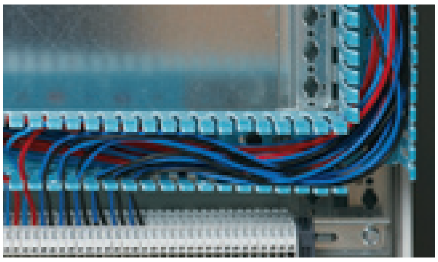
Guide values for minimum cross-sections in mm²

		IP ⩽ 30				IP > 30				Values acc. to EN 60439-1
Type of insulation		PVC		PR		PVC		PR		
Installation		U	G	U	G	U	G	U	G	
In (A) or rating of the protection device	6	1	1.5	0.7511	1	1.5	1.5	1	1	1
	10	1.5	2.5	1	1.5	2.5	2.5	1.5	1.5	1.5
	16	2.5	2.5	1.5	2.5	2.5	4	1.5	1.5	2.5
	20	2.5	4	2.5	2.5	4	6	2.5	4	2.5
	25	4	6	2.5	4	6	10	4	6	4
	32	6	10	4	6	10	16	6	10	6
	40	10	16	6	10	16	25	10	10	10
	50	10	16	10	10	16	35	10	16	10
	63	16	25	10	16	25	50	16	25	16
	80	25	35	16	25	35	70	25	35	25
	100	25	50	25	35	50	95	35	50	35
	125	35	70	25	50	70	120	50	70	50
	160	70	120	50	70	95		70	95	70
	200	95		70		120		95	120	95
	250	120		95		150		120		120
	315	185		120		240		185		185
	400	240		185		300		240		240

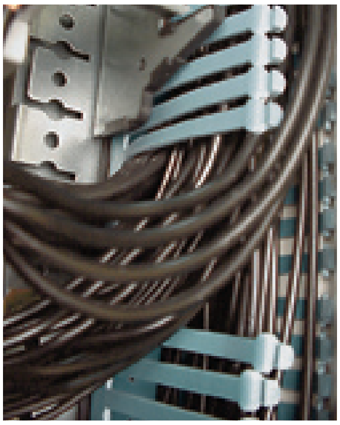
NB: The values in the IP > 30 column correspond to the application of a correction factor of 0.71 (PVC) and 0.82 (PR) to the current value.
The values in the G columns correspond to the application of a correction factor of 0.7 for groups of several circuits.



< Conductors not touching, held in place with guide rings: U installation



< Several circuits in the same trunking and all wiring in vertical and horizontal trunking: G installation



< Horizontal circulation "in free air", only the vertical conductors are grouped in trunking: U installation. If, as here, the packing ratio of the vertical trunking is high: G installation.

Conductors (continued)

2 DETERMINING FLEXIBLE BARS

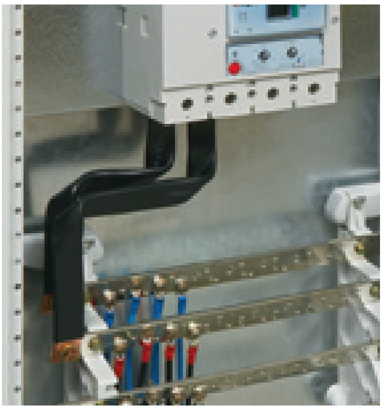
Flexible bars can be used for making connections on devices or for creating links that can be adapted to virtually any requirement. Guaranteeing safety and high quality finish, they provide an undeniably attractive touch.
Based on the most commonly used sizes and the electrical capacities of the usual nominal values, the Legrand range of flexible bars is suitable for most connection or linking requirements.
As with any conductors, the current-carrying capacities of flexible bars may vary according to the conditions of use:
- Ambient temperature (actual in enclosure)
- Period of use (continuous or cyclic load),
or installation conditions:
- Bars on their own or grouped together (side by side in contact or with spacers)
- Ventilation: natural (IP ≤ 30), forced (fan) or none (IP > 30)
- Vertical or horizontal routing

The considerable variability of all these conditions leads to very different current-carrying capacities (in a ratio of 1 to 2, or even more).

Flexible bars have higher current-carrying capacities than cables or rigid bars with the same cross-section, due to their lamellar structure (limitation of eddy currents), their shape (better heat dissipation) and their permissible temperature (105°C high temperature PVC insulation).

Incorrect use can result in temperature rises that are incompatible with the insulation, disturbance or even damage to connected or surrounding equipment. Flexible bars are shaped manually without the need for any special tools, although some dexterity is required to achieve a perfect finish.

Currents Ie (A) and Ithe (A) of Legrand flexible bars are given for the following conditions:
- Ie (IP ≤ 30): maximum permanent current-carrying capacity in open or ventilated enclosures, the positions of the bars and relative distance between them allow correct cooling.
The temperature in the enclosure must be similar to the ambient temperature.
- Ithe (IP > 30): maximum permanent current-carrying capacity in sealed enclosures. The bars can be installed close to one another, but must not be in contact.
The temperature in the enclosure can reach 50°C.



< Connection of a DPX on a distribution block using flexible bars

Current-carrying capacities of Legrand flexible bars

Cat. No.	374 10	374 16	374 11	374 67	374 17	374 12	374 44	374 57	374 58
Cross-section	13 x 3	20 x 4	24 x 4	20 x 5	24 x 5	32 x 5	40 x 5	50 x 5	50 x 10
Ie (A) IP ≤ 30	200	320	400	400	470	630	700	850	1250
Ithe (A) IP > 30	160	200	250	250	520	400	500	630	800

POWER GUIDE:
A complete set of technical documentation

EX29008

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