APPLICATION GUIDE

Solutions for Power, Control, Safety & Energy Efficiency

2017

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CRITICAL POWER
POWER CONTROL & SAFETY
ENERGY EFFICIENCY
EXPERT SERVICES

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Application Guide

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L.V. distribution

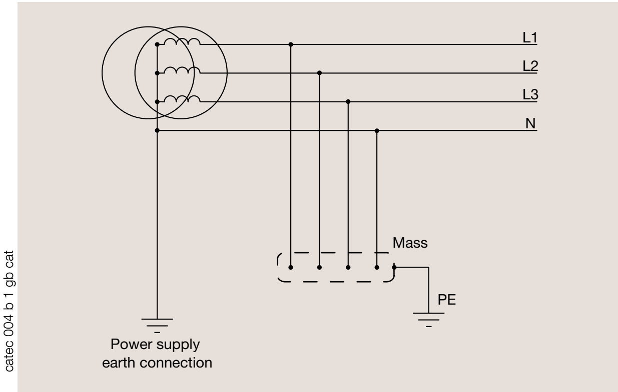
Earthing arrangements

An earthing, or “neutral load” arrangement on an LV network is defined by two letters:

The first defines the earth connection of the transformer’s secondary (in most cases neutral)	earthed	T	T	earthed	The **second** defines the masses connection to earth
	insulated from earth	I	T	earthed	
	earthed	T	N	connected to neutral	

TT: “neutral to earth” load

Use of this type of load is generally stipulated by the electricity board.
Should there be an insulation fault, all or part of the operational equipment is cut off.
Cut off is obligatory at first fault.
The operational equipment must be fitted with instantaneous differential protection.
Differential protection can be general or subdivided according to the type and size of the installation.
This type of load can be found in the following contexts: domestic, minor tertiary, small workshops/processes, educational establishments with practical workshops, etc.

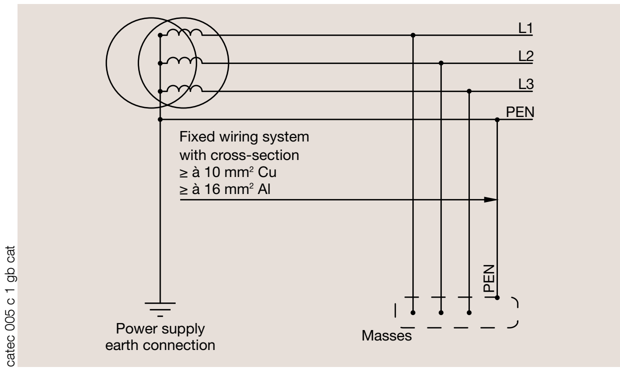


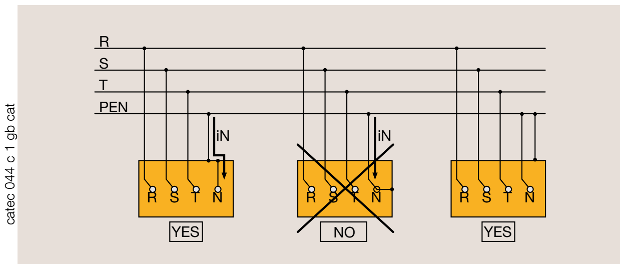
TN: “neutral connection” load

This distribution principle is suited to all networks which have a cut off system at first fault.
Installing and operating this type of network is economical but requires rigorous general circuit protection.
Neutral (N) and protective (PE) conductors can be common (TNC) or separated (TNS).

TNC arrangement

The protective and neutral conductor (PEN) must never be sectioned. Conductors must have a section over 10 mm^2 in copper and over 16 mm^2 in aluminium, and must not include mobile installations (flexible cables).

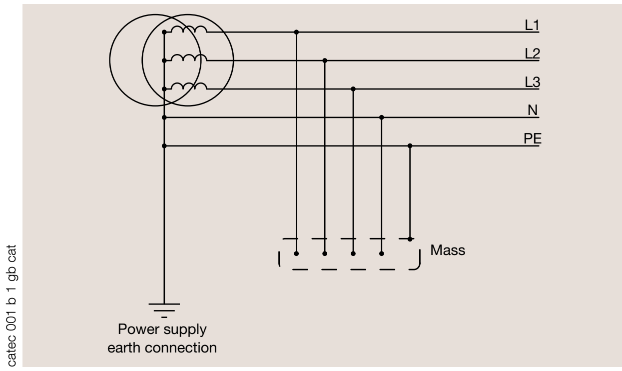




The "protection" function of the PEN conductor is essential to the "neutral" function.

TNS arrangement

A TNS network can be set up upstream of a TNC network, where as the opposite is forbidden. Neutral TNS conductors are generally sectioned, unprotected, and have the same sections as the corresponding phase conductors.



TNC-S arrangement

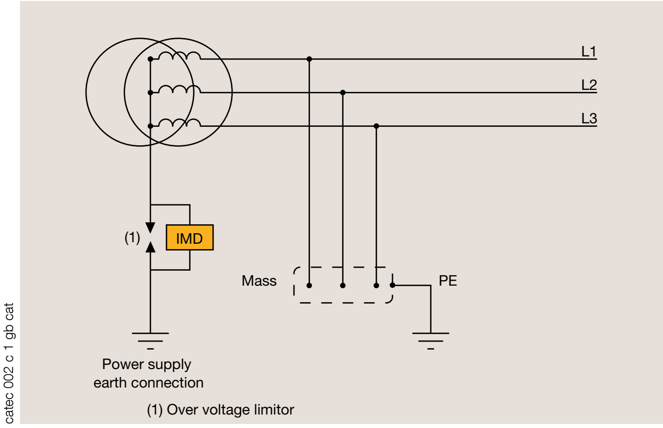
A TNC-S arrangement indicates distribution in which the neutral conductors and protection conductors are combined in one part of the installation and distinct in the rest of the ’installation.

IT: IT: “insulated neutral” load

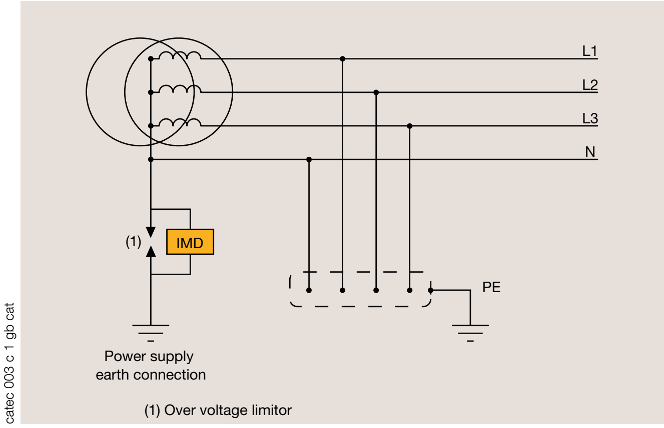
This neutral load is used when first fault cut off is detrimental to correct operation or personnel safety.
Implementing this type of installation is simple, but requires qualified personnel on-site to intervene quickly when faulty insulation is detected, to maintain continuous operation and before a possible second fault leads to cut-off.
An overvoltage limitor is compulsory to enable overvoltage caused by HV installations (such as HV/LV transformer breakdown, operations, lightning, etc.), to flow to earth.

Personnel safety is ensured by:
- Interconnecting and earthing of masses,
- monitoring first fault by IMD (Insulation Monitoring Device),
- using second fault cut off by overcurrent protection devices, or by differential devices.

This system can be found, for example, in hospitals (operating theatres), or in safety circuits (lighting) and in industries where continuity of operations is essential or where the weak default current considerably reduces the risk of fire or explosion.



IT arrangement without distributed neutral



IT arrangement with distributed neutral

Voltages, overvoltages

Voltage range

In LV, two ranges can be identified according to IEC364 standard (NF C 15100) and three ranges according to the decree of 14.11.88.

Domain		Nominal voltage U_n	
Decree	IEC	AC	DC
ELV: Extra Low Voltage	I	50 V	120 V
LVA: Low Voltage A	II	$50\ V < U_n \leq 500\ V$	$120\ V < U_n \leq 750\ V$
LVB: Low Voltage B	II	$500\ V < U_n \leq 1000\ V$	$750\ V < U_n \leq 1500\ V$

Standard AC voltages

Single phase: 230 V.

Three-phase: 230 V / 400 V and 400 V / 690 V.

Voltage and tolerance development (IEC 60038)

Periods	Voltages	Tolerances
Before 1983	÷ 380 660 V (220 V rating)	± 10 %
From 1983 to 2003	÷ 400 V (230 V rating)	+ 6 % / - 10 %
Since 2003	÷ 400 V (230 V rating)	± 10 %

Protection against transient overvoltages

This is achieved by:

Choosing the equipment according to U_{imp}

The NF C 15-100 and IEC 60364 standards stipulate 4 categories of use:

Category I	Equipment or components with low impulse withstand voltage. Ex: electronic circuits
Category II	Current-using devices intended to be connected to the building's fixed electrical installation. Ex: - portable tools etc., - computers, TV, Hi-fi, alarms, domestic electrical appliances with electronic programming etc.,
Category III	Equipment placed in distribution networks and other equipment requiring a higher level of reliability. Ex: - distribution enclosures etc., - fixed installations, motors etc.,
Category IV	Equipment placed at the head of an installation or in proximity to the head of the installation upstream of the distribution panel. Ex: - sensors, transformers etc., - main protection equipment against overcurrents

Overvoltage in kV according to utilisation class.

Three-phase network	Single-phase network	IV	III	II	I
230 V 400 V	230 V	6	4	2.5	1.5
400 V 690 V		8	6	4	2.5
690 V 1000 V		Xx			

(Xx) Values proposed by the equipment manufacturers. If not, the values given in the line above can be chosen.

Surge arresters *(see page 97)*

N.B.: Overvoltages caused by atmospheric conditions do not undergo significant downstream attenuation in most installations.
Therefore, the choice of the equipment's overvoltage category does not suffice to protect against overvoltages.
A suitable risk assessment should be done to define the necessary surge arresters at various levels of the installation.

Admissible voltage limitation at 50 Hz

Equipment in a LV installation must withstand the following temporary overvoltage:

Duration (s)	Admissible voltage limitation (V)
> 5	$U_0 + 250$
≤ 5	$U_0 + 1200$

Mains quality

The tolerances generally admitted (EN 50160) for the correct operating of a network comprising loads that are sensitive to mains distortion (electronic equipment, computers etc.,) are summarised under the following headings.

Voltage dip and cut-off

Definition

A voltage dip is a decrease of voltage amplitude for a period of time ranging from 10 ms to 1 s.
The voltage variation is expressed in percentage of nominal current (between 10% and 100%). A 100% voltage dip is termed a cut-off.
Depending on cut-off time t, the following can be distinguished:
- 10 ms < t < 1 s: micro cut-offs due, for example, to fast reset at transient faults, etc.,
- 1 s < t < 1 mn: short cut-offs due to protection device operation, switching-in of high start-up current equipment, etc.,
- 1 mn < t: long cut-offs generally due to HV mains.

Voltage dips according to standard EN 50160 (condition)

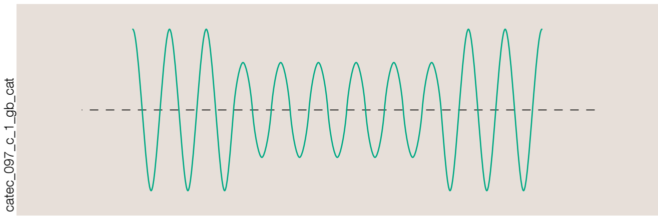
	Tolerances		
	normal	exceptional	according to operating loads
Number	from x 10 to x 1000	1000	high
Duration	< 1 s	>1 s	
Depth	< 60 %	> 60	between 10 and 15 %

Short cut-offs according to standard EN 50160 (per period of one year)

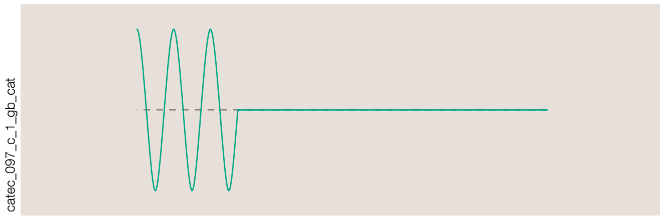
	Tolerances
Number	n from x 10 to x 1000
Duration	< 1 s for 70 % of n

Long cut-offs as per standard EN 50160 (per period of one year)

	Tolerances
Number	n from x 10 to x 1000
Duration	> 3



Voltage dip.



Cut-off.

Consequences of voltage dips and cut-offs

Opening of contactors (dip > 30 %).
Synchronous motor synchronism loss, asynchronous motor instability.
Computer applications: data loss, etc.
Disturbance of lighting with gas discharge lamps (quenching when 50% dips for 50 ms, relighting only after a few minutes).

Solutions

Whatever the type of load:
- use of a UPS (Uninterruptible Power Supply),
- modify mains structure *(see page 12)*.

Depending on the type of load:
- supply contactor coils between phases,
- increase motor inertia,
- use immediate-relighting lamps.

Mains quality (continued)

Frequency variations

This is generally due to generator set failure. Solution: use of static converter or UPS.

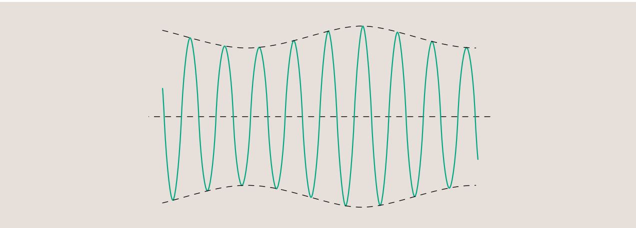
LV mains frequency (U_n = 230 V) and HV mains (1 < $U_n \leq$ 35 kV) as per standard EN 50160 (per period of ten seconds)

	Tolerances	
	Networked mains	Non-networked mains (split)
99.5 % of the year	50 Hz ± 1 %	50 Hz ± 2 %
100 % of the time	50 Hz ± 4 % to -6 %	50 Hz ± 15 %

Voltage variation and Flicker

Definition

Light flicker is due to sudden voltage variations, thus producing an unpleasant effect. Sudden voltage variations are due to devices whose consumed power varies quickly: arc furnaces, welding machines, rolling mills, etc.



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Solutions

- UPS (for small loads).
- Inductance or capacitor bank in the load circuit.
- Connection to a specific HV/LV transformer (arc furnaces).

Voltage variation as per standard EN 50160 (per period of a week)

x% of the number of 'Un rms averaged over 10 min	Tolerances
95 %	Un ± 10 %
100 %	Un + 10 % to Un - 15 %

Rapid voltage variation as per standard EN 50160

	Tolerances
Generally	5 % of Un
Possibly	10 % of Un

Flicker effect as per standard EN 50160 (per period of one week)

	Tolerances
95 % of the time	PLT ≤ I

Temporary overvoltages (due to shift in the point of phase-to-phase voltage)

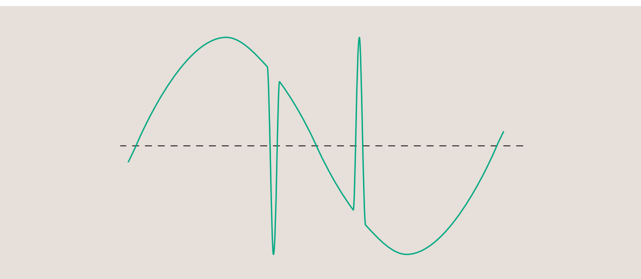
	Tolerances
Upstream transformer fault.	< 1.5 kV

Transients

Definition

Transient phenomena are essentially fast, very high voltages, due to:

- lightning,
- operations or fault on HV or LV mains,
- equipment electric arcs,
- inductive loads switching,
- highly capacitative circuits power on:
  - extended cable systems,
  - machines fitted with anti-stray capacitors.



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	Tolerances
Value	generally < 6 kV
Build-up time	from µs to x ms

Effects

- Intemperate tripping of protection devices,
- Destruction of electronic equipment (PLC cards, variable speed drives, etc.),
- Cable insulation rupture,
- Heat build-up and premature ageing of IT equipment.

Solutions

- Use of surge arrester and overvoltage limitors.
- Increase the short-circuit power of the source.
- Adequate earth connection of HVT/LV sets.

Mains quality (continued)

Harmonics

Definition

Harmonic current or voltage are mains “stray” currents or voltages. They distort the current or voltage wave and lead to the following:
- an increase in the current's rms value,
- a current passing the neutral being higher than the phase current,
- transformer saturation,
- disturbance in low current networks,
- intemperate tripping of protection devices, etc.,
- distorted measurements (current, voltage, power, etc.).

Harmonic currents can be caused by current transformers and electric arcs (arc furnaces, welding machines, fluorescent or gas-discharge lamps), but mainly by static rectifiers and converters (power electronics). Such charges are termed non-linear loads (see later). Harmonic voltage is caused by harmonic current passing through mains and transformer impedance.

Harmonic voltages

For a measurement period of one week and value set to 95%, the averaged 10 min harmonic voltages should not exceed the values given in the following table Total voltage distortion rate should not exceed 8% (including up to conventional number 40).

Maximum value of harmonic voltages at supply terminals in % in U_n.

Odd harmonic numbers				Even harmonic numbers	
not multiples of 3		multiples of 3			
Harmonic N°	% UC	Harmonic N°	% UC	Harmonic N°	% UC
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6 to 24.	0.5
13	3	21	0.5		
17	2				
19 to 25.	1.5				

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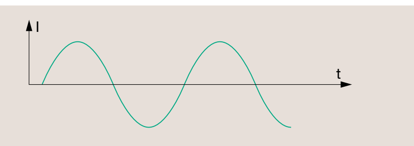

pure sinusoidal wave current

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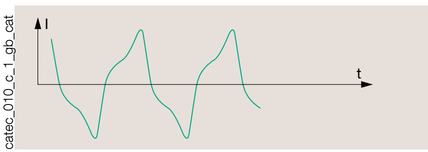

current distorted by harmonics

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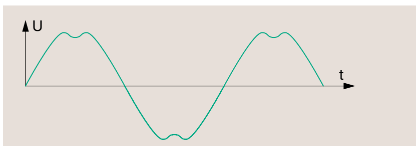

voltage distorted by harmonics

Solutions

- On line inductance.
- Use of rectifiers.
- Downgrading of equipment.
- Increase short-circuit power.
- Supply distorted loads with UPS.
- Use of anti-harmonic filters.
- Increase conductor cross-section.
- Device oversizing.

Linear and non-linear loads

A load is termed linear when current has the same wave-form as voltage:

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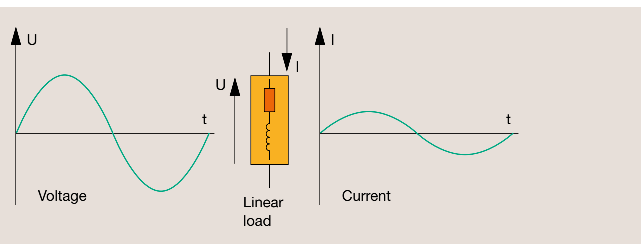

A load is termed non-linear when the current wave-form no longer corresponds to voltage wave-form:

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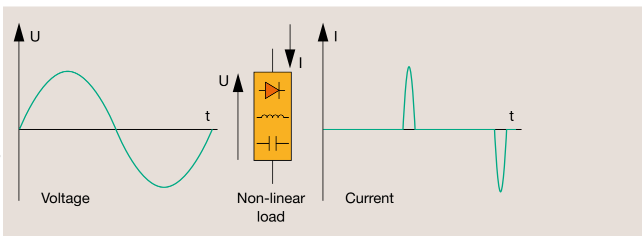


Non-linear loads to neutral current values which may be much higher than phase current values.

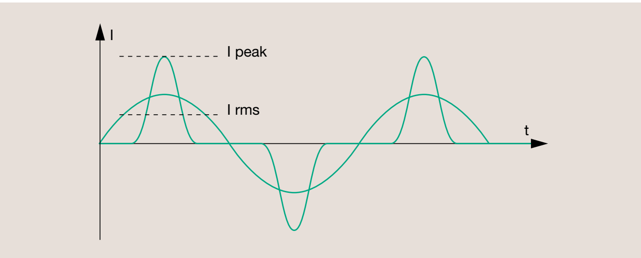
Mains quality (continued)

Harmonics (continued)

Current peak factor (fp)

With non-linear loads, current distortion can be expressed by peak factor:

$$fp = \frac{Ipeak}{I_{rms}}$$



Voltage distorted by harmonics

Examples of fp values:
- resistive charge (pure sinusoidal wave): 2 = 1.414.
- mainframe computer: 2 to 2.5.
- PC work station: 2.5 to 3.
- printers: 2 to 3.

These few peak factor values show that the current wave can differ greatly from a pure sinusoid.

Harmonic number

Harmonic frequencies are multiples of mains frequency (50 Hz). This multiple is called the harmonic number.

Example: *The 5th harmonic current has a frequency of 5 x 50 Hz = 250 Hz. The 1st harmonic current is called the "fundamental".*

Mains harmonic currents

The current circulating in the network is the sum of pure sinusoidal current (called "fundamental") and a certain number of harmonic currents, depending on the load type.

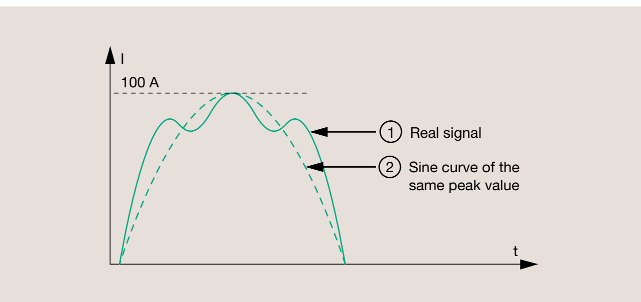
Table A: mains harmonic currents

Sources		Harmonic number																		
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rectifiers	1 half wave	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	2 half waves		•		•		•		•		•		•		•		•		•	
	3 half waves	•		•	•		•	•		•	•		•	•		•	•		•	•
	6 half waves				•		•				•		•				•		•	
	12 half waves										•		•							
Gas discharge lamp			•		•		•		•		•		•		•		•		•	
Arc furnace			•		•		•		•		•		•		•		•		•	

Example: A gas discharge lamp only produces the 3rd, 5th, 7th, 9th, 11th, and 13th harmonic currents. Even-number harmonic currents (2. 4. 6 etc.) are absent.

Measuring device distortion

Ferromagnetic measuring devices (ammeters, voltmeters, etc.) are designed to measure sinusoidal parameters of a given frequency (generally 50 Hz). The same applies to digital devices other than sampling devices. These devices give false readings when the signal is subjected to harmonic distortion (see example below).
Only devices giving true rms values integrate signal distortions and hence give real rms values, e.g. the DIRIS).



Measurement distortion

Example:
Signal 1 is distorted by the third harmonic. The rms value of a sine wave with the same peak value would be:

$$\frac{100\ A}{2} = 70\ A$$

Mains quality (continued)

Harmonics (continued)

Calculating rms current

In general, calculating rms current is only done for the first 10 to 20 significant harmonic currents.

Per phase

$$I_{eff} = I^2_n + I^2_2 + I^2_3 + \dots + I^2_k$$

I_n: distorter's nominal current

I2. I3…: harmonic currents numbers 2. 3 etc.,

On the neutral

$$I_{rms\ neutral} = \sqrt{I_2^{N3} + I^2_{N9} + \dots}$$

Odd number harmonic currents, which are also multiples of 3 are added together:

The rms values of harmonic currents 12. 13. etc. are difficult to establish. (Please consult us specifying load type, current peak factor, load power and network voltage).

Example

Calculating phase and neutral current in a network supplied by a double half-wave rectifier.

- Peak factor: 2.5
- 180 kVA load: 50 Hz rms current equivalent:

$$\frac{180kVA}{\sqrt{3}\ 400\ V}\ A = 260:$$

Calculated harmonics:

I2 =	182 A	50 Hz
I2 =	146 A	150 Hz
I2 =	96 A	250 Hz
I2 =	47 A	350 Hz
I2 =	13 A	450 Hz

- High range harmonic currents are negligible.

Current in one phase:

$$Ip = \sqrt{(182)^2 + (146)^2 + \dots}\ A = 260:$$

Current in the neutral:

$$I_{Neutral} = \sqrt{(3x146)^2 + (3\ x\ 13)^2}\ A = 440:$$

The neutral current is higher than the phase current. Connecting sections, as well as equipment choice, must take this into account.

Distortion and global harmonic rates

$$T = \frac{\sqrt{I_2^2 + I_3^2 + \dots + I_k^2}}{I_{rms}}$$

Improving mains quality

Substitute sources

The different substitute sources are described in the table below:

Source type	Eliminated distortion
Rotating set supplied by mains	• cut-off < 500 ms (according to flywheel) • voltage dip • frequency variations
UPS	Effective against all distortion, except long duration cut-offs > 15 mins. to 1 hour (according to installed power and UPS power)
Autonomous Gensets	Effective in all cases, but with power supply interrupted during normal/emergency switching
UPS + rotating sets	This solution covers all distortion types

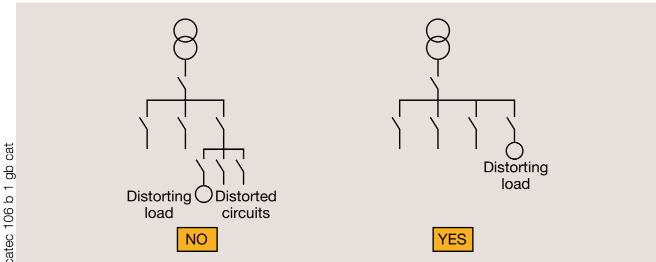
The emergency sources using gensets are classified into several categories, or classified according to the response time required before load recovery:

Category	Response time	Generator start up	Comments
D	not specified	manual	Speed and power build-up times dependent on ambient temperatures and motor
C	Long cut-off ≤ 15 s	At mains loss	Maintaining genset pre-heating for immediate start-up
B	shortcut-off ≤ 1 s	Permanent rotation	Rapid motor start-up thanks to motor inertia. Motor in pre-heating condition
A	without cut-off	coupled to the source	Immediate load recovery in case of mains supply cut-off.

Installation precautions

Isolate distorting loads

- with a separate mains, coming from a specific HV input (for high loads).
- By circuit subdivision: a circuit fault should affect other circuits as little as possible,
- By separating circuits consisting of distorting loads. These circuits are separated from other circuits at the highest possible level of the LV installation in order to benefit from disturbance reduction by cable impedance.



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Choose a suitable earthing system

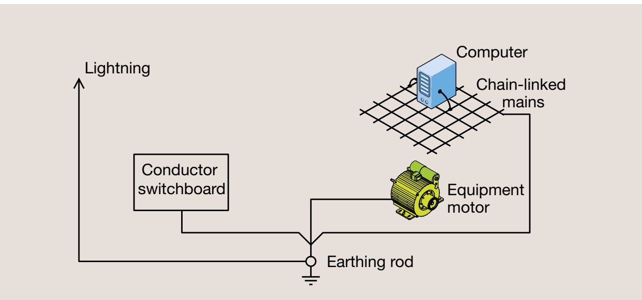
The IT system guarantees continuous operation, by avoiding, for example, differential device circuit breaking by intemperate tripping following transient disturbance.

Ensure protective devices discrimination

The discrimination of protective devices limits circuit fault breaking *(see pages 58 to 61 and 83).*

Take care over using earth mains:

- By setting up earth mains suitable for certain applications (computing, etc.); each mains being chain-linked to obtain maximum equipotentiality (the lowest resistance between different points of the earth mains).
- By linking these mains in star form, as close as possible to the earthing rod.
- By using interconnected cable trays, chutes, tubes, and metallic gutters connected to earth at regular points.
- By separating distorting circuits from sensitive circuits laid out on the same cable trays.
- By using mechanical earths (cabinets, structures, etc.) as often as possible in order to achieve equipotential masses.



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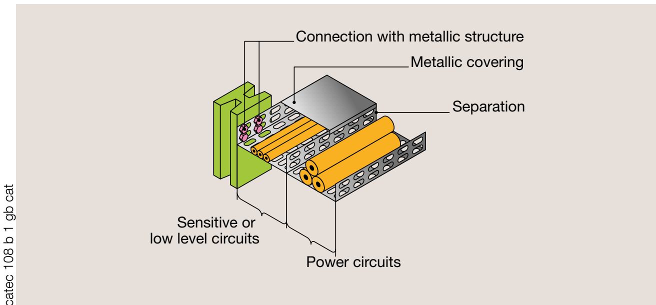

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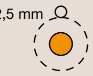
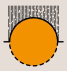
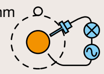
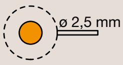
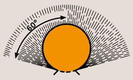
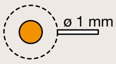
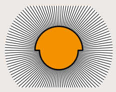
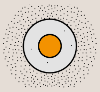
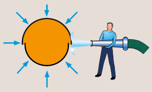
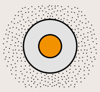
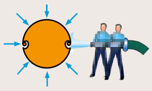
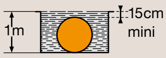
External influences

Degrees of protection (IP codes)

These are defined by two figures and possibly by an additional letter.
For example: IP55 or IPxxB (x indicating: any value).

The figures and additional letters are defined below:

1st figure Protection against solid body penetration			2nd figure Protection against liquid penetration			Additional letter[2]	Degree of protection
IP	Tests		IP	Tests			Brief description
0		No protection	0		No protection		
1		Protected against solid bodies greater than 50 mm	1		Protected against water drops falling vertically (condensation)	A	Protected against access with back of hand
2[1]		Protected against solid bodies greater than 12 mm	2		Protected against water drops falling up to 15° from the vertical	B	Protected against access with finger
3		Protected against solid bodies greater than 2.5 mm	3		Protected against water showers up to 60° from the vertical	C	Protected against access with tool
4		Protected against solid bodies greater than 1 mm	4		Protected against water splashes from any direction	D	Protected against access with wire
5		Protected against dust (excluding damaging deposits)	5		Protected against water jets from any hosed direction		
6		Total protection against dust	6		Protected against water splashes comparable to heavy seas		
The first two characterising figures are defined in the same way by NF EN 60 529. IEC 60529 and DIN 40050			7		Protected against total immersion		

Note

(1) Figure 2 is established by 2 tests:
- *non penetration of a sphere with the diameter of 12.5 mm*
- *non accessibility of a test probe with a diameter of 12 mm.*

(2) This additional letter only defines the access to dangerous components..

Example

A device has an aperture allowing access with a finger. This will not be classified as IP 2x. However, if the components which are accessible with a finger are not dangerous (electric shock, burns, etc.), the device will be classified as xx B.

Protection levels against mechanical shock

The IK index replaces the 3rd figure of the IP code that existed in some French standards NF EN 62262/C 20015 (April 2004).

IK/AG correspondence

Shock energy (J)	0	0.15	0.2	0.35	0.5	0.7	1	2	5	6	10	20
IK index	0	1	2	3	4	5	6	7	8		9	10
Classification AG (IEC 60 364)			AG1					AG1	AG1			AG1
Former 3rd IP figure	0		1		3			5		7		9

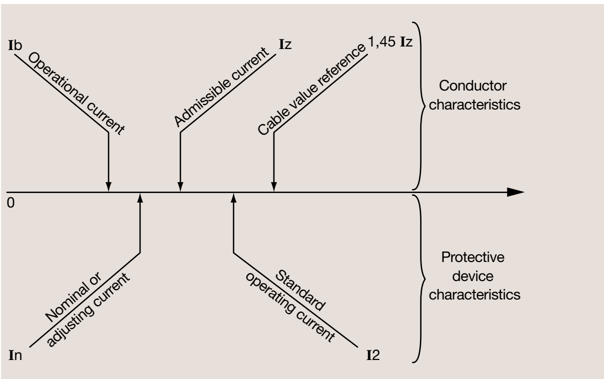
Overload currents

"Protective devices shall be provided to break any overload current flowing in the circuit conductors before such a current could cause a temperature rise detrimental to insulation, joints, terminations, or surroundings of the conductors" (NF C 15100 § 433. IEC 60364).

To do this, the following currents are defined:
- **Ib:** current for which the circuit is designed,
- **Iz:** continuous current-carrying capacity of the cable,
- **In:** nominal current of the protective device,
- **I2 :** current ensuring effective operation of the protective device; in practice I2 is taken as equal to:
- the operating current in conventional time for circuit breakers
- the fusing current in conventional time for type gG fuses.

Conductors are protected if these two conditions are met:

$1: I_b \leq I_n \leq I_z$
$2: I_2 \leq 1.45\ I_z$



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Example

Supplying a 150 kW load on a three-phase 400 V network.
Ib = 216 A current necessary for the load
In = 250 A gG fuse rating protecting the circuit
Iz = 298 A
maximum admissible current for a 3 x 95 mm² cable complying with installation method, and the external conditions defined by the method presented in the pages to follow
I2 = 400 A 250 A fuse melting current
(1.6 x 250 A = 400 A)

1.45 Iz = 1.45 x 298 = 432 A.

Conditions 1 and 2 have been satisfactorily met:
Ib = 216 A ≤ In = 250 A ≤ Iz = 298 A
I2 = 400 A ≤ 1.45 Iz = 432 A.

Defining I2 currents

This is the current which ensures effective protective device operating:

gG fuse (IEC 60269-2-1)	I2 current
Rating ≤ 4 A	2.1 In
4 A < Rating < 16 A	1.9 In
Rating ≥ 16 A	1.6 In
Industrial circuit breaker	1.45 In

Defining I_z currents (as per NF C 15100 and IEC 60364)

Continuous current-carrying capacity of cables

The following table gives maximum Iz current value for each copper and aluminium cable section. These values must be corrected according to the following coefficients:

- **Km:** installation method coefficient *(page 16)*
- **Kn:** coefficient taking into account the number of cables laid together *(see page 16)*
- **Kt:** coefficient taking into account ambient air temperature and cable type *(see page 18)*.

Coefficients Km, Kn and Kt are defined according to cable installation categories: B, C, E or F *(see page 18)*.

The chosen section must be:

$$I_z \geq I'_z = \frac{- I_b:}{K_m \times K_n \times K_t}$$

Cables are classified in two families: PVC and PR *(see table page 18)*. The following figure gives the number of loaded cables. Cables insulated with elastomere (rubber, butyl, etc.) are classified in family PR.

Example: PVC 3 indicates a cable from the PVC category with 34 loaded conductors (3 phases or 3 phases + neutral).

Table A

Category	Maximum Iz current in conductors (A)								
B	PVC3	PVC3		PR3		PR3			
C		PVC3		PVC3	PR3		PR3		
E			PVC3		PVC3	PR3		PR3	
F				PVC3		PVC3	PR3		PR3
S in mm^2 copper									
1.5	15.5	17.5	18.5	19.5	22	23	24	26	
2.5	**21**	**24**	**25**	**27**	**30**	**31**	**33**	**36**	
4	28	32	34	36	40	42	45	49	
6	36	41	43	48	51	54	58	63	
10	50	57	60	63	70	75	80	86	
16	68	76	80	85	94	100	107	115	
25	89	96	101	112	119	127	138	149	161
35	110	119	126	138	147	158	169	185	200
50	134	144	153	168	179	192	207	225	242
70	171	184	196	213	229	246	268	289	310
95	207	223	238	258	278	298	328	352	377
120	239	259	276	299	322	346	382	410	437
150		299	319	344	371	395	441	473	504
185		341	364	392	424	450	506	542	575
240		403	430	461	500	538	599	641	679
300		464	497	530	576	621	693	741	783
400					656	754	825		940
500					749	868	946		1083
630					855	1005	1088		1254
S in mm^2 aluminium									
2.5	16.5	18.5	19.5	21	23	24	26	28	
4	22	25	26	28	31	32	35	38	
6	28	32	33	36	39	42	45	49	
10	39	44	46	49	54	58	62	67	
16	53	59	61	66	73	77	84	91	
25	70	73	78	83	90	97	101	108	121
35	86	90	96	103	112	120	126	135	150
50	104	110	117	125	136	146	154	164	184
70	133	140	150	160	174	187	198	211	237
95	161	170	183	195	211	227	241	257	289
120	188	197	212	226	245	263	280	300	337
150		227	245	261	283	304	324	346	389
185		259	280	298	323	347	371	397	447
240		305	330	352	382	409	439	470	530
300		351	381	406	440	471	508	543	613
400					526	600	663		740
500					610	694	770		856
630					711	808	899		996

Defining I_z currents (as per NF C 15100 and IEC 60364) (continued)

K_m coefficient

Category	Method of installation		- K_m: (a)	(b)	(c)	(d)
B	1. In thermally insulating wall		0.77	-	0.70	0.77
	2. Visible assembly, embedded in wall or raised section		1	-	0.9	-
	3. In building construction cavities/spaces or false ceilings		0.95	-	0.865	0.95
	4. In cable troughs		0.95	0.95	-	0.95
	5. In chutes, mouldings, skirting or baseboards		-	1	-	0.9
C	1. Mono or multi-conductor cables embedded directly in a wall without mechanical protection		-	-	-	1
	2. Cables	• on a wall	-	-	-	1
		Ceiling-fixed cables	-	-	-	0.95
	3. Open-mounted or insulated conductors		-	1.21	-	-
	4. Cables mounted on non-perforated cable trays		-	-	-	1
E or F	Multi-conductor cables on or Mono-conductor cables on	1. Perforated cable trays	-	-	-	1
		2. Brackets, ladders				
		3. Wall-jutting clamps				
		4. Suspended cables on suspension cable				

(a) Insulated conductor placed in a conduit.
(b) Insulated conductor not placed in a conduit.
(c) Cable placed in a conduit.
(d) Cable not placed in a conduit

K_n coefficient

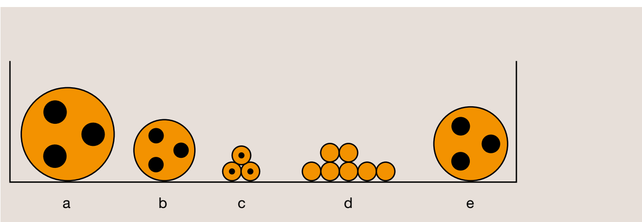
Table A

Category	Joined cable layout	Kn corrective factors – Number of circuits or multiconductor cables: 1	2	3	4	5	6	7	8	9	12	16	20
B, C	Embedded or sunk in to walls	1.00	0.80	0.70	0.65	0.60	0.55	0.55	0.50	0.50	0.45	0.40	0.40
C	Single layer on walls or flooring or non perforated racks	1.00	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	No additional reduction factor for more than 9 cables		
E, F	Single layer onto ceiling	0.95	0.81	0.72	0.68	0.66	0.64	0.63	0.62	0.61			
	Single layer on horizontal perforated racks or vertical racks	1.00	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72			
	Single layer on cable ladders, brackets, etc	1.00	0.88	0.82	0.80	0.80	0.79	0.79	0.78	0.78			

When cables are laid out in several layers the K_n value must be multiplied by:

Table B

Number of layers	2	3	4 and 5	6 to 8.	9 and more
Coefficient	0.80	0.73	0.70	0.68	0.66



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Example

The following are laid out on a perforated rack:
- 2 three-pole cables (2 circuits a and b),
- single-pole three-cable set (1 circuit, c),
- set made up of 2 conductors per phase (2 circuits, d),
- 1 three-pole cable for which Kn must be defined (1 circuit, e).

The total number of circuits is 6. The reference method is method E (perforated rack). Kn = 0.55.

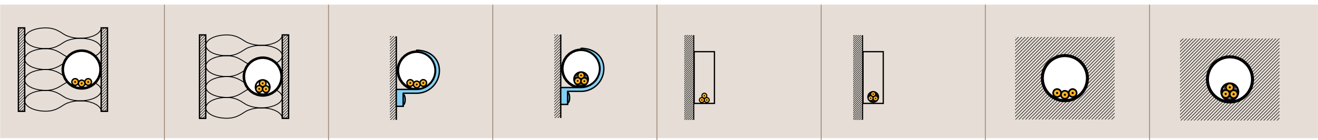
NF C 15100523.6

As a general rule, it is recommended to use as few cables as possible in parallel. In all cases, their number must not exceed four. Beyond that, it is preferable to use prefabricated wiring systems.

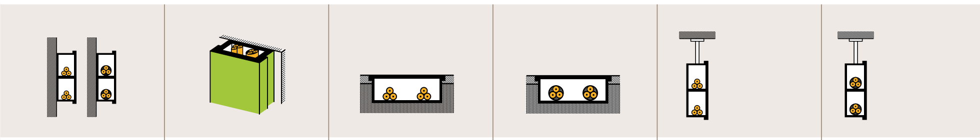
N.B.: particularly interesting methods of fuse protection against overload currents for conductors in parallel are given in the IEC 60364-4-41 publication.

Defining I_z currents (as per NF C 15100 and IEC 60364) (continued)

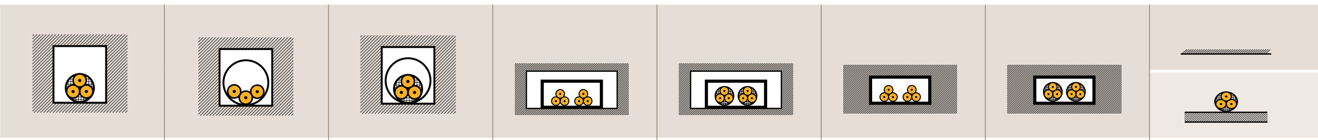
Method of installation



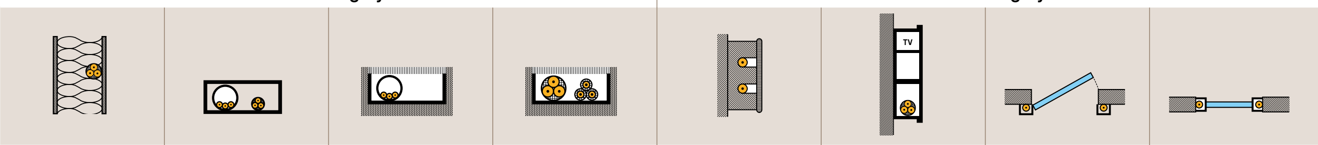
B - 1 category							
Insulated conductors in embedded conduits within thermally insulating walls.	Multiconductor cables in embedded conduits within thermally insulating walls.	Insulated conductors in visibly-assembled conduits.	Mono or multi-conductor cables in visibly-assembled conduits.	Insulated conductors in visibly assembled raised-section conduits.	Mono or multi-conductor cables is visibly-assembled raised-section conduits.	Insulated conductors in conduits embedded in walls.	Mono or multi-conductor cables in conduits embedded in walls.



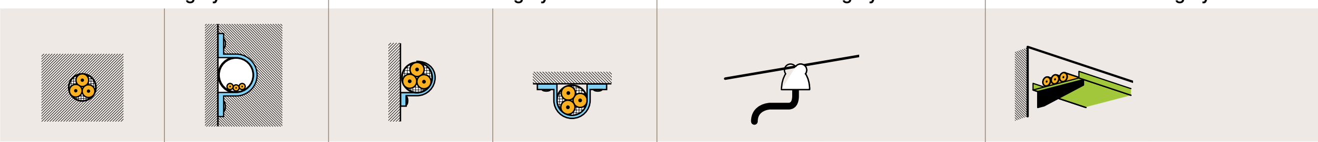
B - 2 category							
Insulated conductors or mono or multi-conductor cables in wall-fixed chutes: - horizontal path	Insulated conductors or mono or multi-conductor cables in wall-fixed chutes: - vertical path.	Insulated conductors in chutes embedded in floors.	Mono or multi-cable conductors in chutes embedded in floors.	Insulated conductors in suspended chutes.	Mono or multi-conductor cables in suspended chutes.		



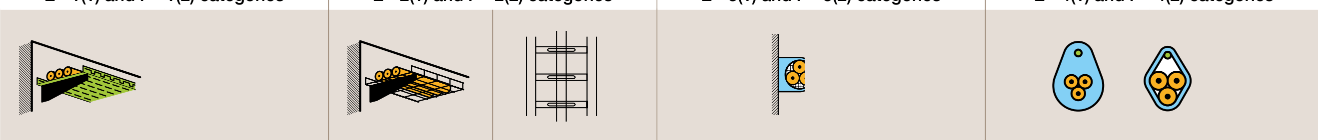
B - 3 category							
Mono or multi-conductors in building construction cavities.	Insulated conductors in building construction cavities.	Mono or multi-conductor cables in conduits in building construction cavities.	Insulated conductors in section conduits in building construction cavities.	Mono or multi-conductor cables in section conduits in building construction cavities.	Insulated conductors in section conduits embedded in construction.	Mono or multi-conductor cables in section conduits embedded in construction.	Mono or multi-conductor cables: • in false ceilings • in suspended ceilings.



B - 4 category				B - 5 category			
Multi-conductor cables directly embedded in thermally insulating walls.	Insulated conductors in conduits or multi-conductor cables in closed cable troughs, vertical or horizontal path.	Insulated conductors in conduits in ventilated cable troughs.	Mono or multi-conductor cables in open or ventilated cable troughs.	Insulated conductors in mouldings.	Insulated conductors or mono or multi-conductors in grooved skirting.	Insulated conductors in conduits or mono or multi-conducting cables in jamb linings.	Insulated conductors in conduits or mono or multi-conductor cables in window frames.



C - 1 category		C - 2 category		C - 3 category	C - 4 category
Mono or multi-conductor cables embedded directly in a wall without any extra mechanic protection	Mono or multi-conductor cables embedded directly in a wall with extra mechanic protection	Mono or multi-conductor cables with or without sheathing. wall-fixed cables,	Mono or multi-conductor cables with or without sheathing. ceiling-fixed cables.	Open-mounted or insulated on insulator conductors.	Mono or multi-conductor cables on non-perforated cable trays or racks.



E - 1(1) and F - 1(2) categories	E - 2(1) and F - 2(2) categories		E - 3(1) and F - 3(2) categories	E - 4(1) and F - 4(2) categories
On perforated cable trays or racks, horizontal or vertical path.	On brackets.	On cable ladders.	Wall-jutting clamp-fixed.	Mono or multi-conductor cables suspended on suspension or self-supporting cable.

(1) Multi-conductor cables. *(2) Mono-conductor cables.*

Defining I_z currents (as per NF C 15100 and IEC 60364) (continued)

K_t coefficient

Table C

Ambient temperature (°C)	Insulation		
	Elastomere (rubber)	PVC	PR/EPR
10	1.29	1.22	1.15
15	1.22	1.17	1.12
20	1.15	1.12	1.08
25	1.07	1.06	1.04
35	0.93	0.94	0.96
40	0.82	0.87	0.91
45	0.71	0.79	0.87
50	0.58	0.71	0.82
55	-	0.61	0.76
60	-	0.50	0.71
65	-	-	0.65
70	-	-	0.58

Example

For an insulated PVC cable where the ambient air temperature reaches 40 °C. Kt = 0.87.

Cable identification

Table A:
Equivalence between the old and the new name (cables)

Old name (national standard)	New name (harmonised standard)
U1000	A 05VV - U (or R)
U 1000 SC 12 N	H 07 RN - F
500 0 V	DEFYS 05 A GB
500 1 V	

Table B: cable classification

PR cables		PVC cables	
U1000	N 12	N 05	W-U, R
U1000	R2V	N 05	W-AR
U1000	RVFV	N 05	VL2V-U, R
U1000	RGPFV	N 05	VL2V-AR
07 h	RN-F	07 h	VVH2-F
N 07	RN-F	07 h	VVD3H2-F
07 A	RN-F	05 h	VV-F
N 1	X1X2	05 h	VVH2-F
N 1	X1G1	N 05	VV5-F
N 1	X1X2Z4X2	N 05	VVC4V5-F
N 1	X1G1Z4G1	05 A	VV-F
N 07	X4X5-F	05 A	VVH2-F
0.6/1	twisted		
N 1	XDV-AR, AS, AU		
05 h	RN-F		
05 A	RN-F		
05 h	RR-F		
05 A	RR-F		

Examples

A three-phase load with neutral and 80 A nominal current, is to be supplied (therefore Ib = 80 A). Cable type U 1000 R2V is used on a perforated rack with three other circuits at an ambient temperature of 40 °C.
I_z must be:

$$I_z \geq I'_z = \frac{- I_b:}{K_m \times K_n \times K_t}$$

Defining I'z

- method of installation: "E", therefore Km = 1 (see table *page 16*)
- total number of circuits: 4. therefore Kn = 0.77 (see table A *page 16*)
- ambient air temperature: 40 °C, thereforeKt = 0.91 (see table C).

Therefore

$$I'_z = \frac{80\ A}{1 \times 0.77 \times 0.91} = 114\ A$$

Defining Iz

Cable U 1000 R2V has a PR classification (see table B). The number of charged conductors is 3. Turn to table A *page 15* and find column PR3 corresponding to category E.
The Iz value immediately higher than I'z must be chosen, therefore I_z = 127 A, this corresponding to a 3 x 25 mm^2 copper cable, protected by a 100 A gG fuse, or a 3 x 35 mm^2 aluminium cable, protected by a 100 A gG fuse.

Protection of wiring systems against overloads using gG fuses

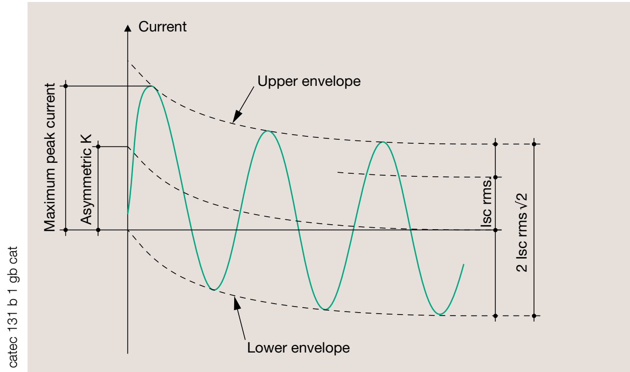
The Iz column gives the maximum admissible current for each copper and aluminium cable cross section, as per standard NF C 15100 and the guide UTE 15105.
Column F gives the rating of the gG fuse associated with this cross section and type of cable.
Categories B, C, E and F correspond to the different methods of cable installation *(see page 17)*.
Cables are classified in two families: PVC and PR *(see table page 18)*. The figure that follows gives the number of loaded conductors (PVC 3 indicates a cable from the PVC family with 3 loaded conductors: 3 phases or 3 phases + neutral).
Example: a PR3 25 mm² copper cable installed in category E is limited to 127 A and protected by a 100 A gG fuse.

Category	Admissible (I_z) current and associated protective fuse (F)																	
B	PVC3		PVC3				PR3				PR3							
C			PVC3				PVC3		PR3				PR3					
E					PVC3				PVC3		PR3				PR3			
F							PVC3				PVC3		PR3				PR3	
S mm2																		
Copper	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F
1.5	15.5	10	17.5	10	18.5	16	19.5	16	22	16	23	20	24	20	26	20		
2.5	21	16	24	20	25	20	27	20	30	25	31	25	33	25	36	32		
4	28	25	32	25	34	25	36	32	40	32	42	32	45	40	49	40		
6	36	32	41	32	43	40	46	40	51	40	54	50	58	50	63	50		
10	50	40	57	50	60	50	63	50	70	63	75	63	80	63	86	63		
16	68	50	76	63	80	63	85	63	94	80	100	80	107	80	115	100		
25	89	80	96	80	101	80	112	100	119	100	127	100	138	125	149	125	161	125
35	110	100	119	100	126	100	138	125	147	125	158	125	171	125	185	160	200	160
50	134	100	144	125	153	125	168	125	179	160	192	160	207	160	225	200	242	200
70	171	125	184	160	196	160	213	160	229	200	246	200	269	160	289	250	310	250
95	207	160	223	200	238	200	258	200	278	250	298	250	328	250	352	315	377	315
120	239	200	259	200	276	250	299	250	322	250	346	315	382	315	410	315	437	400
150			299	250	319	250	344	315	371	315	399	315	441	400	473	400	504	400
185			341	250	364	315	392	315	424	315	456	400	506	400	542	500	575	500
240			403	315	430	315	461	400	500	400	538	400	599	500	641	500	679	500
300			464	400	497	400	530	400	576	500	621	500	693	630	741	630	783	630
400									656	500	754	630	825	630			840	800
500									749	630	868	800	946	800			1083	1000
630									855	630	1005	800	1088	800			1254	1000
Aluminium																		
2.5	16.5	10	18.5	10	19.5	16	21	16	23	20	24	20	26	20	28	25		
4	22	16	25	20	26	20	28	25	31	25	32	25	35	32	38	32		
6	28	20	32	25	33	25	36	32	39	32	42	32	45	40	49	40		
10	39	32	44	40	46	40	49	40	54	50	58	50	62	50	67	50		
16	53	40	59	50	61	50	66	50	73	63	77	63	84	63	91	80		
25	70	63	73	63	78	63	83	63	90	80	97	80	101	80	108	100	121	100
35	86	80	90	80	96	80	103	80	112	100	120	100	126	100	135	125	150	125
50	104	80	110	100	117	100	125	100	136	125	146	125	154	125	164	125	184	160
70	133	100	140	125	150	125	160	125	174	160	187	160	198	160	211	160	237	200
95	161	125	170	125	183	160	195	160	211	160	227	200	241	200	257	200	289	250
120	188	160	197	160	212	160	226	200	245	200	263	250	280	250	300	250	337	250
150			227	200	245	200	261	200	283	250	304	250	324	250	346	315	389	315
185			259	200	280	250	298	250	323	250	347	315	371	315	397	315	447	400
240			305	250	330	250	352	315	382	315	409	315	439	400	470	400	530	400
300			351	315	381	315	406	315	440	400	471	400	508	400	543	500	613	500
400									526	400	600	500	663	500			740	630
500									610	500	694	630	770	630			856	630
630									711	630	808	630	899	800			996	800

Short circuit currents

A short circuit current is a current triggered by a negligible impedance fault between points of an installation normally having a potential difference. 3 levels of short circuit currents can be identified:

- **peak short-circuit** current (I_{sc} peak) corresponds to the top of the current wave, generating heightened electrodynamic forces, notably at the level of busbars and contacts or equipment connections,
- **rms short-circuit current** (I_{sc} rms): rms value of the fault current which leads to equipment and conductor overheating, and may raise the potential difference of the electrical earth to a dangerous level,
- **minimum short-circuit current** (I_{sc} min): rms value of the fault current establishing itself in high impedance circuits (reduced cross-section conductor and long conductors, etc.). It is necessary to quickly eliminate this type of fault, known as impedant, by appropriate means.



Calculating a source's I_{SC}

With 1 transformer

- Simplified calculation according to transformer power:

Mains supply	I_n:	I_{cc} eff
127 220 V	2.5 x (S)	I_n x 20
220 380 V	1.5 x (S)	I_n x 20

- Simplified calculation according to transformer short-circuit voltage (u):

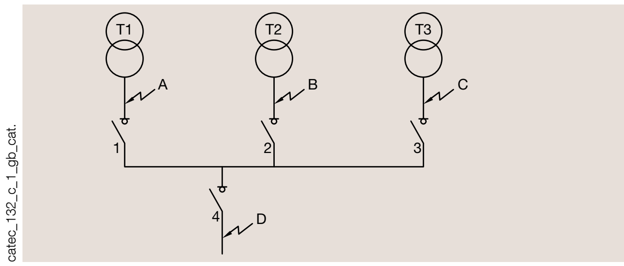
$$I_{sc} \text{ (A rms)} = \frac{S}{U\sqrt{3}} \times \frac{100}{u} \times k$$

S: power (VA)
U: phase to phase voltage (V)
U: short circuit voltage (%)
k: coefficient allowing for upstream impedance (for example, 0.8).

With “n” transformers in parallel

“n” being the number of transformers.

- T1 ; T1 ; T3 identical.
- Short circuit in A, B or C device 1. 2 or 3 must withstand:
  I_{scA} = (n-1) x Isc of a transformer (i.e. 2 I_{sc}).
- Short circuit in D, device 4 must withstand:
  I_{scD} = n x I_{sc} of a transformer (i.e. 3 I_{sc}).



Short circuit with several transformers in parallel

Batteries I_{SC}

I_{sc} values downstream of an accumulator bank are approximately:
I_{sc} = 15 x Q (open lead acid)
I_{sc} = 40 x Q (air-tight lead acid)
I_{sc} = 20 x Q (Ni-Cd)
Q (Ah): capacity in Amps - hour

Calculating a source's I_{SC} (continued)

Generator sets I_{SC}

An alternator's internal impedance depends on its manufacture. This can be characterised as values expressed in %:

X'd transient reactance:

- 15 to 20% for a turbo-generator,
- 25 to 35% for salient polar alternator (subtransient reactance is negligible).

X'o homopolar reactance:

This can be estimated at 6% in the absence of more precise indications. The following may be calculated:

$$I_{sc3} = \frac{k_3 \times P}{U_0 \times X'd}$$

$$I_{sc2} = 0.86 \times I_{sc3}$$

$$I_{sc1} = \frac{k_1 \times P}{U_0\,(2X'd + X'0)}$$

D — *alternator power in kVA*
U0: — *phase to neutral voltage*
X'd: — *transient reactance*
k3 = — *0.37 pour I_{sc3} max*
k3 = — *0.33 pour I_{sc3} min*
0x — *homopolar reactance*
k1 = — *1.1 for I_{sc1} max*
k1 = — *1.1for I_{sc1} min*

Example:

P = 400 kVA X'd = 30 % X'0 = 6 % U0 = 230 V

$$I_{sc3}\ \text{max} = \frac{0.37 \times 400}{230 \times \frac{30}{100}} = 2.14\ \text{kA}$$

$$I_{sc1}\ \text{max} = \frac{1.1 \times 400}{230 \times \left[2 \times \frac{30}{100} + \frac{6}{100}\right]} = 2.944\ \text{kA} \qquad I_{sc2}\ \text{max} = 1.844\ \text{kA}$$

Calculating an LV installation's I_{SC}

General points

Calculating short-circuit currents enables the following to be defined:

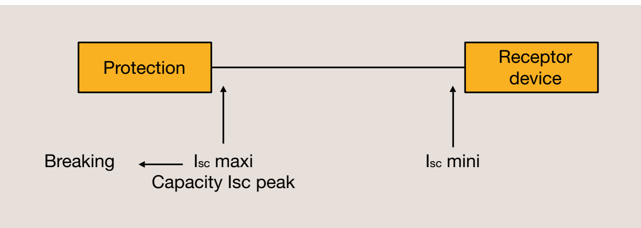
the protection device's breaking capacity,

- the cross-section of conductors enabling:
  - to withstand short circuit temperature stress,
  - to guarantee protection device opening against indirect contact within the time stipulated by NF C 15100 and IEC 60364 standards,
- the mechanical withstand of conductor supports (electrodynamic stress).

The protection device's breaking capacity is established from the maximum Isc calculated at its terminals.

The conductor cross-section depends on the minimum Isc calculated at receptor terminals.

The conductor support mechanical withstand is established by calculating Isc peak deducted from maximum Isc.



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Calculating short-circuit current can be performed by one of the three following methods:

Conventional method

This method gives the minimum I_{sc}.

Impedance method

This method consists of calculating the default loop's impedance **Z**, taking the power source into account (mains, battery bank, generator sets, etc.). This is an accurate method which enables the minimum and maximum I_{sc} to be calculated, but also requires that circuit fault parameters should be known *(see page 22)*.

Quick method

This method is used when circuit fault parameters are known. Short-circuit current I_{sc} is defined on one point of the network, where upstream I_{sc} as well as length and connecting cross-section to upstream point is known *(see page 25)*. This method only gives the maximum I_{sc} value.

Short circuit currents

Calculating an LV installation's I_{SC} (continued)

Conventional method

This method gives the minimum Isc value at the end of the installation not supplied by an alternator:

$$I_{sc} = A \times \frac{0.8\,U \times S}{2\,\rho\,L}$$

U: voltage between phases in V

L: wiring system length in m

S: conductor cross-section in mm²

ρ = 0.028 mW.m for copper with fuse protection
0.044 mW.m for aluminium with fuse protection
0.023 mW.m for copper with protection by circuit breaker
0.037 mW.m for aluminium with protection by circuit breaker

A = 1 for circuits with neutral (neutral cross-section = phase cross-section)
1.73 for circuits without neutral
0.67 for circuits with neutral (neutral cross-section = 1/2 phase cross-section)

For cable cross-sections of 150 mm² and over, account must be taken of the reactance by dividing the I_{sc} value by: 150 mm² cable: 1.15 ; 185 mm² cable: 1.2 ; 240 mm² cable: 1.25 ; 300 mm² cable: 1.3

Impedance method

This method consists of adding all the circuit's resistance R and reactance X upstream of the short-circuit (see next page) and then calculating impedance Z.

$$Z_{(m\Omega)} = \sqrt{R^2_{(m\Omega)} + X^2_{(m\Omega)}}$$

This method enables the following to be calculated:

I_{sc3}: three phase short-circuit current

$$I_{sc3} = 1.1 \times \frac{U_0:}{Z_3}$$

U_0: phase-to-neutral voltage (230 V on a 230/400 network)
Z_3:three-phase loop impedance (see page 24).

I_{sc2}: short-circuit current between two phases

$$I_{sc2} = 0.86 \times I_{sc3}$$

I_{sc1}: single phase short-circuit current

$$I_{sc1} = 1.1 \times \frac{U_0:}{Z3}$$

U_0: phase-to-neutral voltage (230 V on a 230/400 network)
Z_3:single-phase loop impedance (see page 24).

I_{sc} peak

I_{sc} peak must be calculated when it is necessary to know electrodynamic stress (on busbar supports for example):

$$I_{sc}\text{ peak}_{(kA)} = I_{sc}\text{ rms}_{(kA)} \times \sqrt{2} \times k$$

k: asymmetric coefficient given below

k = 1 for symmetric short circuit current (cos. φ = 1).

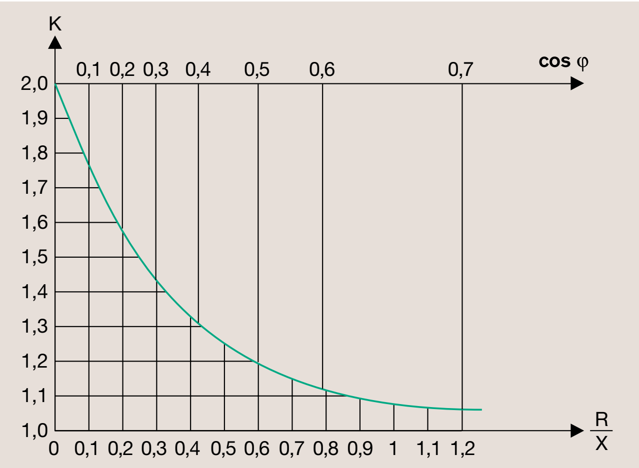

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Fig. 1

Note: Value R/X is more often used, as this is more exploitable in this diagram.

Impedance method (continued)

Defining "R" and "X" (network) values   R = resistance   X = reactance

The table below gives R and X values for different parts of the circuit up to the short-circuit point.
To calculate the default loop impedance, R and X values must be added separately *(see example on page 24)*.

Schema / drawing	R and X values

Network upstream

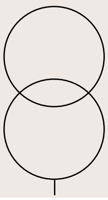
"R" and "X" values upstream of HV/LV transformers (400 V) according to network short-circuit power (Psc in MVA).

MVA	Network	R (mΩ)	X (mΩ)
500	> 63	0.04	0.35
250	> 24 kV close to power plants	0.07	0.7
125	> 24 kV far from power plants	0.14	1.4

If short-circuit power (Pcc) is known
Off-load voltage Uo (400 V or 230 V AC 50 Hz).

$R_{(m\Omega)} = 0.1 \times X_{(m\Omega)}$

$X_{(m\Omega)} = \frac{3.3 \times U_0^2}{P_{sc}\ \text{kVA}}$



Oil-immersed transformers with 400 V secondaries

Values of "R" and "X" according to the power of the transformer.

P (kVA)	50	100	160	200	250	400	630	1000	1250	1600	2000	2500
Isc3 (kA)	1.80	3.60	5.76	7.20	9.00	14.43	22.68	24.01	30.03	38.44	48.04	60.07
R (mΩ)	43.7	21.9	13.7	10.9	8.7	5.5	3.5	3.3	2.6	2.0	1.6	1.31
X (mΩ)	134	67	41.9	33.5	26.8	16.8	10.6	10.0	8.0	6.3	5.0	4.01

Conductors

$R_{(m\Omega)} = \frac{\rho \times l_{(m)}}{S_{(mm^2)}}$ where $\rho = \frac{m\Omega \times mm^2}{M}$

	Resistivity ρ 10		
	mx. I_{sc}	min. I_{sc}	
		Fuse protection	Protection by circuit breaker
Copper	18.51	28	23
Aluminium	29.4	44	35

$X_{(m\Omega)} = 0.08 \times l_{(m)}$ (multi-pole cables or trefoil single-pole cables)(1)
$X_{(m\Omega)} = 0.13 \times l_{(m)}$ (single-pole cables in flat formation)(1)
$X_{(m\Omega)} = 0.09 \times l_{(m)}$ (separate mono-conducting cables)

$X_{(m\Omega)} = 0.15 \times l_{(m)}$ (busbars)(1)

(1) Copper and aluminium

Device in closed position

R = 0 and X = 0.15 mΩ

Calculating an LV installation's I_{SC} (continued)

Impedance method (continued)

Max. I_{sc} calculation example

ρ copper = 18.51	ρ aluminium = 29.4	U_o = 230 V	Phases R	Phases X:	Neutral R	Neutral X:	Protection R	Protection X:
Network 250 MVA	R = 0.07 mΩ	X = 0.7 mΩ	0.07	0.7				
Transformer (630 kVA)	R = 3.5 mW	X = 10.6 mΩ	3.5	10.6				
Cables: aluminium								
Ph: l = 10 m, 4 x 240 mm²	Ph: $R = \frac{29.4 \times 10}{240 \times 4} = 0.306\ m\Omega$	$X = \frac{0.13 \times 10}{4} = 0.325\ m\Omega$	0.306	0.325				
N: l = 10 m, 2 x 240 mm²	N: $R = \frac{29.4 \times 10}{240 \times 2} = 0.612\ m\Omega$	$X = \frac{0.13 \times 10}{2} = 0.65\ m\Omega$			0.612	0.65		
PE: l = 12 m, 1 x 240 mm²	PE: $R = \frac{29.4 \times 12}{240} = 1.47\ m\Omega$	$X = 0.13 \times 12 = 1.56\ m\Omega$					1.47	1.56
Device	(transformer protection)	X = 0.15 mΩ		0.15				
Icc	**Sub-total: LVSB "input" level (∑)**		**3.87**	**11.77**	**0.612**	**0.65**	**1.47**	**1.56**
Busbars copper l = 3 m	Icc							
Ph: 2 x 100 x 5	Ph: $R = \frac{18.51 \times 3}{2 \times 100 \times 5} = 0.055\ m\Omega$	$X = 0.15 \times 3 = 0.45\ m\Omega$	0.055	0.45				
N: 1 x 100 x 5	N: $R = \frac{18.51 \times 3}{1 \times 100 \times 5} = 0.011\ m\Omega$	$X = 0.15 \times 3 = 0.45\ m\Omega$			0.11	0.45		
PE: 1 x 40 x 5	PE: $R = \frac{18.51 \times 3}{40 \times 5} = 0.277\ m\Omega$	$X = 0.15 \times 3 = 0.45\ m\Omega$					0.277	0.45
Total at busbars level (∑):			**3.925**	**12.22**	**0.722**	**1.1**	**1.75**	**2.01**

At LVSB input

- Three-phase loop impedance:

$$Z_3 = \sqrt{R_{ph}^2 + X_{ph}^2}$$

$Z_3 = \sqrt{(3.7)^2 + (11.7)^2} = 12.39\ m\Omega$

$I_{s3}\ max. = \frac{1.1 \times 230\ V}{12.39\ m\Omega} = 20.5\ kA$

$I_{s2}\ max. = 0.6 \times 20.\ kA = 17.6\ kA$

- Single-phase loop impedance:

$$Z_1 = \sqrt{(R_{ph} + R_n)^2 + (X_{ph} + X_n)^2}$$

$Z_1 = \sqrt{(3.87 + 0.612)^2 + (11.77 + 0.5)^2} = 13.2\ m\Omega$

$I_{sc1} = \frac{1.1 \times 230\ V}{13.2\ m\Omega} = 19.2\ kA$

Calculating minimum I_{sc} example

Calculating minimum I_{sc} is identical to the previous calculation, replacing copper and aluminium resistivities by:

$\rho_{copper} = 28$ $\rho_{alu} = 44$

- Phase/neutral single-phase loop impedance:

$Z1 = \sqrt{(4.1 + 1.85)^2 + (12.2 + 1.)^2} = 14.3\ m\Omega$

$I_{s1}\ min. = \frac{230\ V}{14.\ m\Omega} = 16\ kA$

- Phase/protection single-phase loop impedance:

$Z1 = \sqrt{(4.11 + 2.62)^2 + (12.22 + 2.01)^2} = 15.74\ m\Omega$

$I_{s1}\ min. = \frac{230\ V}{15.74\ m\Omega} = 14.6\ kA$

At busbar input

- Three-phase loop impedance:

$$Z_3 = \sqrt{R_{ph}^2 + X_{ph}^2}$$

$Z_3 = \sqrt{(3.925)^2 + (12.22)^2} = 12.8\ m\Omega$

$I'_{sc3}\ max. = \frac{1.1 \times 230\ V}{12.8\ m\Omega} = 19.8\ kA$

$I'_{sc2}\ max. = 0.86 \times 19.8\ kA = 17\ kA$

$\frac{R}{X:} = \frac{3.925}{12.22} = 0.32$ *(according to fig.1 page 22)*, k = 1.4

$$I'_{sc}\ peak = \frac{19.8}{x2} \sqrt{2} x\ 1.4 = 39.2\ kA$$

This 39.2 kA peak value is necessary to define the dynamic withstand of the bars and of the piece of equipment.

- Single-phase loop impedance:

$$Z_1 = \sqrt{(R_{ph} + R_n)^2 + (X_{ph} + X_n)^2}$$

$Z_1 = \sqrt{(3.925 + 0.722)^2 + (12.22 + 1.1)^2} = 14.1\ m\Omega$

$I'_{sc1} = \frac{1.1 \times 230\ V}{14.1\ m\Omega} = 18\ kA$

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Quick method

This quick though approximate method enables the I_{sc} on a network point to be defined, knowing upstream I_{sc} as well as the upstream length and cross-section connection according to guide UTE 15105).

The tables below are valid for networks with 400 V between phases (with or without neutral).

Proceed therefore as follows: In parts 1 (copper conductors) or 3 (aluminium) of the tables, select the line denoting conductor phase cross-section. Read across the line until reaching the value immediately below the wiring system length. Read down (for copper) or up (for aluminium) until reaching part 2. and stop on the line corresponding to the upstream I_{sc}. The value read at this intersection gives the required I_{sc} value.

Example: Upstream I_{sc} = 20 kA, wiring system: 3 x 35 mm^2 copper,17 m length. In the line denoting 35 mm^2 the length immediately less than 17 m is 15 m. The intersection of the 15 m column and the 20 kA line gives upstream I_{sc} = 12.3 kA.

Phase conductor cross-section (mm2)										Wiring system length in m													
Copper	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	14.0	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						
	3 x 185	4.4	6.2	8.8	12.4	17.5	25	35	49	70	99	140	198	280	396	560							

Isc upstream (kA)										I_{sc} at chosen point (kA)													
Isc	100	93.5	91.1	87.9	83.7	78.4	71.9	64.4	56.1	47.5	39.01	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	161	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	4.0	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	0.38	0.7	0.7	0.6	0.5

Phase conductor cross-section (mm2)										Wiring system length in m													
Aluminium	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	11.0	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	585					
	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					
	3 x 240	3.4	4.8	6.9	9.7	13.7	19	27	39	55	78	110	155	219	310	439	621						

Short circuit currents

Protection of wiring systems

Short-circuit currents lead to temperature stress in conductors. To avoid damaging or eroding cable insulation (which may in turn lead to insulation faults) or busbar supports, conductors having the following indicated minimal cross-sections must be used.

Busbars

Short-circuit thermal effects on busbars are caused by conductor temperature rise. This temperature rise must be compatible with busbar support characteristics.

Example: for a SOCOMEC busbar support (with a busbar temperature of 80 °C prior to short-circuit).

$$S\ \text{min. (mm}^2) = 1000 \times \frac{I_{sc}\ \text{(kA)}}{70} \times \sqrt{t}\ \text{(s)}$$

S min.: minimum phase cross-section
I_{sc}: rms short-circuit current
t: protective device breaking time
Also see the busbar calculation on page 122.

Insulated conductors

The minimum cross-section is established as follows(NF C 15100):

$$S\ \text{min. (mm}^2) = 1000 \times \frac{I_{sc}\ \text{(kA)}}{k} \times \sqrt{t}\ \text{(s)}$$

I_{sc} min.: minimum short-circuit current in kA rms. *(see page 20)*
t: protective device tripping time in secs.
k: constant, depending on the insulation (see table B).

Table B: constant k (NF C 15100)

	Insulation	Conductors: Copper		Conductors: Aluminium	
Live conductors or protective conductors which are part	PVC	115		76	
	PR/EPR	143		94	
Protective conductors which are part of the wiring system	PVC	143		95	
	PR/EPR	176		116	
	uninsulated(1)	159(1)	138(2)	105(1)	91(2)

1) Premises without fire risk. *2) Premises with fire risk.*

To avoid doing the calculation, please refer to table A which gives the coefficient by which the short circuit current must be multiplied to obtain the minimum cross-section.

$$\text{Section min. (mm}^2) = k_{sc} \times I_{sc}\ \text{min. (kA)}$$

Maximum conductor length

Having already established minimum conductor length, ensure that the protective device placed upstream of conductors has a tripping time compatible with the conductors' maximum temperature stress. To do this, the minimum short circuit current must be sufficient to trip the protection device. Conductor length must be within the limits given by tables A and B *page 27* (fuse protection).

Table A: Ksc coefficient

Cut-off time in ms	Live copper conductor minimum cross-section: INSULATION PVC	Live copper conductor minimum cross-section: PR/EPR	For a **1 kA rms** short-circuit current – Copper conductor minimum cross section – Conductors forming part of a wiring system: PVC	Conductors forming part of a wiring system: PR	Conductors not forming part of a wiring system: PVC	Conductors not forming part of a wiring system: PR	Conductors not forming part of a wiring system: UNINSULATED
5	0.62	0.50	0.62	0.50	0.50	0.40	0.45
10	0.87	0.70	0.87	0.70	0.70	0.57	0.63
15	1.06	0.86	1.06	0.86	0.86	0.70	0.77
20	1.37	1.10	1.37	1.10	1.10	0.89	0.99
35	1.63	1.31	1.63	1.31	1.31	1.06	1.18
50	1.94	1.58	1.94	1.56	1.56	1.27	1.40
60	2.13	1.72	2.13	1.72	1.72	1.40	1.54
75	2.38	1.89	2.38	1.89	1.89	1.54	1.72
100	2.75	2.21	2.75	2.21	2.21	1.79	1.99
125	3.07	2.47	3.07	2.47	2.47	2.00	2.22
150	3.37	2.71	3.37	2.71	2.71	2.20	2.44
175	3.64	2.93	3.64	2.93	2.93	2.38	2.63
200	3.89	3.13	3.89	3.13	3.13	2.54	2.81
250	4.35	3.50	4.35	3.50	3.50	2.84	3.15
300	4.76	3.83	4.76	3.83	3.83	3.11	3.44
400	5.50	4.42	5.50	4.42	4.42	3.59	3.98
500	6.15	4.95	6.15	4.95	4.95	4.02	4.45
1000	8.70	6.99	8.70	6.99	6.99	5.68	6.29

For aluminium conductors: multiply the values in the table by 1.5.

Fuse protection of wiring systems

Maximum length of conductors protected by fuses

Tables A and B indicate maximum lengths in the following conditions:
- 230 / 400 V three-phase circuit
- contact line neutral cross-section = phases cross-section,
- minimal short-circuit current,
- copper conductors.

These tables are valid whatever the cable insulation (PVC, PR, EPR). When two values are given, the first corresponds to PVC cables and the second to PR/EPR cables.
The lengths must be multiplied by the coefficients in table C for the other loads.
For aluminium cable: multiply the lengths in the tables by 0.41.

Table A: maximum cable lengths in m protected by gG fuses.

HP C / S (mm^2)	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	9/12	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	45/74	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

Table B: maximum cable lengths in m protected by aM fuses.

HP C / S (mm^2)	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						
25								135	108	86	67	47/54	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	58/60	38/45	25/30	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	51
240																	123	97	78	62

Table C: corrective coefficients for other networks

Uses	Coefficient
Neutral cross-section = 0.5 x phase cross-section	0.67
Circuit without neutral	1.73

(1) Entry to the table is through the phase cross-section.

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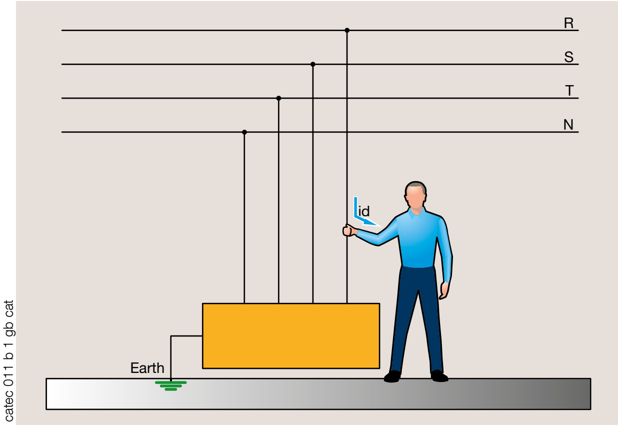
Direct and indirect contact

Protection against indirect contact

Definition

«direct contact» is the contact of persons with active parts (phases, neutral) which are normally live (busbars, terminals, etc.).



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Direct contact.

Protective measures

Protecting against direct contact is ensured by one of the following measures:

- placing live conductors out of reach by using obstacles or placing at a distance,
- insulating live conductors,
- using barriers or enclosures: the minimum degree of protection offered by the enclosure must be IP 2x or xxB for live parts,
- enclosure opening shall only be possible in one of the following instances:
  - with a key or other tool,
  - after switching off active parts,
  - if a second barrier with IP > 2x or xxB is employed inside the enclosure *(see IP definition on page 13)*,
- using 30 mA residual differential-current devices (see "Complementary protection against direct contact" hereafter),
- using ELV (Extra-Low Voltage).

Using ELV

Use of ELV *(Extra Low Voltage, see definition page 6)* represents protection against both direct and indirect contact. The following can be distinguished:

SELV ($U_n \leq$ 50 VAC and ≤ 120 VDC)
Security Extra-Low Voltage. This must be:
- produced by certain sources such as security transformers, inverters, battery banks, and generator sets, etc.,
- completely independent from elements liable to undergo differential potential (another installation’s earth, or another circuit, etc.).

PELV
Protection Extra-Low Voltage. This is identical SELV, except that it has earth connection for operating reasons (electronics, computing, etc.). The use of PELV may entail , as compared to SELV, the use of protection against direct contact from 12 V AC and 30 V DC (insulation, barriers, enclosures, NF C 15100 § 414),

FELV
Functional Extra-Low Voltage. This covers all other ELV applications. It does not offer protection against direct or indirect contact.

Complementary protection against direct contact

Whatever the neutral load, complementary protection against direct contact is provided, in particular by the use of high sensitivity RCD (≤ 30 mA).

Standards NF C 15100 and IEC 60364 require the use of such devices in the following cases in particular:

- circuits supplying ≤ 32 A socket outlets,
- temporary installations, fairground installations,
- worksite installations,
- washrooms, swimming pools,
- caravans, pleasure boats,
- vehicle power supply,
- agricultural and horticultural establishments,
- heating cables and coverings embedded in the floor or walls of a building.

These complementary protective measures against direct contact, according to standard IEC 60479. are no longer acceptable when the contact voltage risks reaching 500 V: human impedance risks allowing a dangerous current higher than 500 mA to pass through the body.

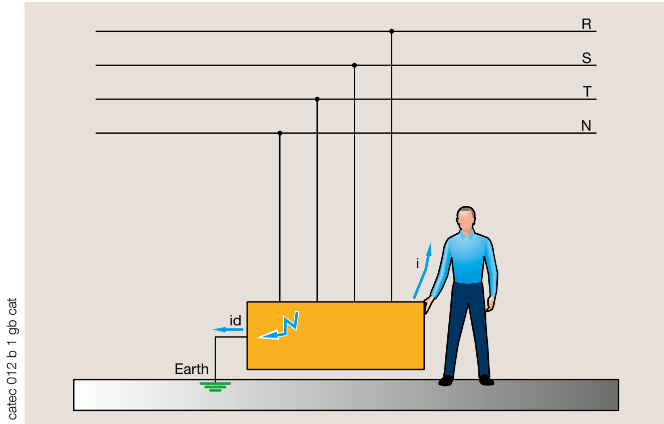
Protection against indirect contact

Definition

"Indirect contact" is the contact of persons with conductive parts which have been accidentally made live following an insulation fault.

Protection against indirect contact can be performed:

- either without automatic disconnection of supply,
- or with automatic disconnection of supply.



Indirect contact.

Protection without automatic disconnection of supply

Protection against indirect contacts without automatic disconnection of supply can be ensured by:

- using ELV (Extra-Low Voltage) *(see page 28),*
- separating masses so that none can be simultaneously in contact with both masses,
- double or reinforced insulation of material (class II),
- non earth linked equipotential connection of all simultaneously accessible masses,
- electric separation (by transformer for circuits < 500 V).

Protection with automatic disconnection of supply

Protection against indirect contact with automatic disconnection of supply consists of separating from the supply circuits or equipment, with an insulation fault between an active part and the mass.

To prevent hazardous physiological effects for personnel who would be in contact with the faulty part, contact voltage U_c is limited to a limit value U_L.

The latter is determined according to:

- admissible current I_L for the human body,
- current flow time *(see page 31),*
- earth-link arrangement,
- installation specifications.

Presumed contact voltage (V)	Protection device maximum breaking time (s) $U_L = 50$ V
25	5
50	5
75	0.60
90	0.45
110	-
120	0.34
150	0.27
220	0.17
230	-
280	0.12
350	0.08
500	0.04

This installation switch-off is performed differently according to linking arrangements (neutral loads).

Standards NF C 15100 and IEC 60364 stipulate the protection device's maximum cut-off time in normal conditions (U_L = 50 V). U_L is the highest contact voltage that people can withstand without danger (see table).

Protection against indirect contact (continued)

Protection with automatic disconnection of supply (continued)

TN and IT loads

When the network is not protected by a differential device, correct co-ordination between the protection device and the choice of conductors must be ensured. Indeed, if the conductor impedance is too high, there is a risk of a limited fault current tripping the protection device over a longer period of time than is stipulated by NF C 15100 standard. The resulting current may thus cause a dangerous contact voltage that lasts too long. To limit loop impedance, conductor length for a given section should be adapted.

Note:
protection against overcurrents is only effective in the presence of dead faults. In practice, an insulation fault, where established, can have a not inconsiderable impedance that will limit the default current.
A RESYS differential device or an ISOM DLRD used as a pre-alarm, are effective means of preventing impedance faults and the maintaining of dangerous voltages.

Maximum breaking time

NF C 15100 and IEC 60364 standards specify a maximum breaking time according to the electrical network and voltage limit of 50 V.

Table A: protection device's maximum breaking time (in seconds) for final circuits ≤ 32 A

	$50\ V < U_n \leq 120\ V$		$120\ V < U_n \leq 230\ V$		$230\ V < U_n \leq 400\ V$		$U_0 > 400\ V$	
Breaking time (s)	AC	DC	AC	DC	AC	DC	AC	DC
TN or IT loads	0.8	5	0.4	5	0.2	0.4	0.1	0.1
TT arrangement	0.3	5	0.2	0.4	0.07	0.2	0.04	0.1

Special case

With a TN load, breaking time can be greater than the time given by table A (but still less than 5 sec.) if:

- the circuit is not a terminal circuit and does not supply a mobile or portable load > 32 A,
- one of the following 2 conditions is met:
  - the principal equipotential link is doubled by an equipotential link identical to the principal link,
  - the protection conductor's Rpe resistance is:

$$Rpe < \frac{50}{U_o} \times (Rpe + Za)$$

U_o: network phase to neutral voltage
Z_a: impedance including the source and the live conductor up to fault point.

Maximum conductor length (L in ml)

The conductor's limit length can be determined by an approximate calculation, valid for installations supplied by a star-delta or zigzag coupling transformer.

$$L = K \frac{U_o \times S}{(1 + m)\, I_d}$$

U_o: phase-to-neutral voltage (230 V on a 230/400 network)
S: phase conductors cross section in mm^2 with TN and IT loads without neutral
$m = {}^{S}/_{Spe}$ (Spe: PE or PEN section
Id: fault current A
Fuse protection: current reached for melting time equal to protection device's opening time *(maximum lengths are given in table B page 32)*
k: variable according to the neutral load and the conductor (see table B).

Table B: K values

Arrangement Conductor	TN	IT	
		without neutral	with neutral
Copper	34.7	30	17.3
Aluminium	21.6	18.7	11

The influence of reactance is negligible for cross-sections less than 120 mm^2. Beyond that resistance has to be increased by:
- 15 % for 150 mm cross section$^{2.}$
- 20 % for 185 mm cross section$^{2.}$
- 25 % for 240 mm cross section$^{2.}$
- 30 % for 300 mm cross section$^{2.}$

For cross sections greater than the above: an exact impedance calculation must be performed using X = 0.08 mΩ/m.

Protection against indirect contact (continued)

Protection with automatic disconnection of supply (continued)

TT load

With TT load, protection is ensured by differential devices. In this case, the conductor cross-section and length are not taken into consideration.

Ensure that earth connection is as follows:

$$RT < \frac{U_L}{I_{\Delta n}}$$

UL limit voltage

IΔn differential device adjustment current

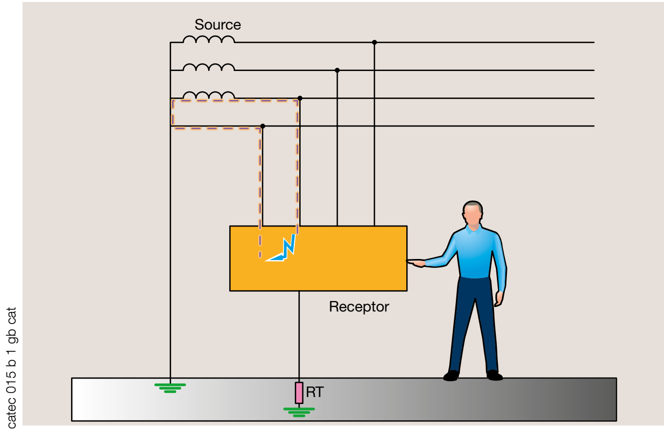
Example:

should there be a fault, contact voltage can be limited to <F>UL = 50 V.

The differential device is adjusted to IΔn = 500 mA = 0.5 A.

Earth connection resistance must not exceed:

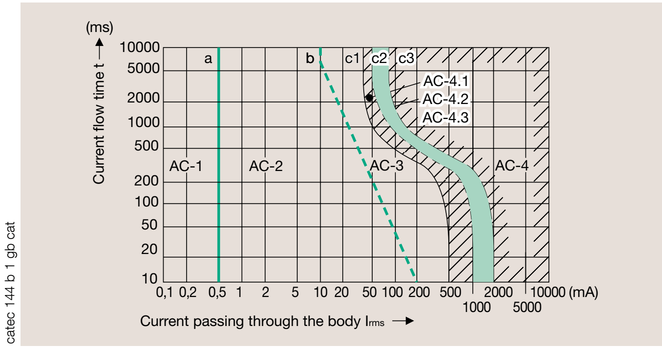
$$R_{T\ maxi} = \frac{50\ V}{0.5\ A} = 100$$



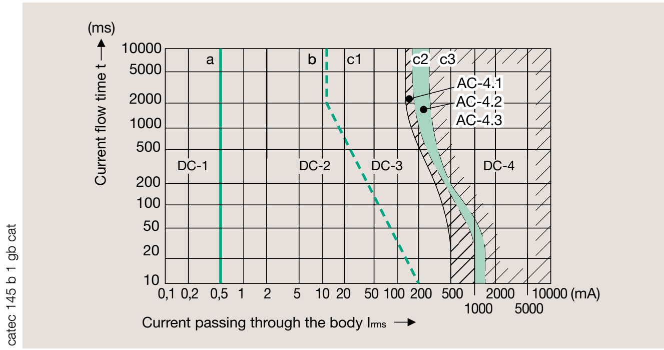
TT load fault current.

Effect of electrical current on the human body

The current passing through the human body, by its physiopathological effect, affects the circulatory and respiratory functions and can lead to death.



Alternating current (15 to 100 Hz).



Direct current.

Zones -1 to -4 correspond to the different levels of effect:

AC/DC-1: non-perception

AC/DC-2: perception, without physiological effects,

AC/DC-3: reversible effects, sharp muscle contraction,

AC/DC-4: serious burns, cardiac fibrillation, possibility of irreversible effects.

Fuse protection against indirect contacts

Maximum length of conductors protected by fuses

The length of conductors protected against indirect contacts must be limited.
Tables B and C give a direct reading of the maximum lengths of copper conductors. They are determined in the following conditions:
- 230 / 400 V network,
- TN load,
- maximum contact voltage UL = 50 V,
- $\frac{\text{Ø ph}}{\text{Ø PE}} = m = 1$.

For other uses, the value read in tables B and C must be multiplied by the coefficient in table A.

Table A

		Correction coefficient
Aluminium conductor		0.625
Neutral cross section (PE) = 1/2 phase cross section (m = 2)		0.67
IT load	without neutral	0.86
	with neutral	0.5
Breaking time 5s admissible. (distribution circuit)	for wiring systems protected with gG fuses	1.88
	for wiring systems protected with aM fuses	1.53

Table B: maximum lengths (in m) of conductors protected by gG fuses (rated in A)

S (mm²) \ (A)	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
1.5	53	40	32	22	18	13	11	7	8	4	3									
2.5	88	66	53	36	31	21	18	12	9	7	6	4								
4	141	106	85	58	49	33	29	19	15	11	9	6	6	4						
6	212	159	127	87	73	50	43	29	22	16	14	10	8	6	4					
10	353	265	212	145	122	84	72	48	37	28	23	16	14	10	7	6	4			
16	566	424	339	231	196	134	116	77	59	43	36	25	22	15	12	9	7	5	4	
25	884	663	530	361	306	209	181	120	92	67	57	40	35	24	18	14	11	8	6	4
35		928	742	506	428	293	253	169	129	94	80	56	48	34	26	20	15	11	9	6
50				687	581	398	343	229	176	128	108	76	66	46	35	27	20	15	12	8
70					856	586	506	337	259	189	159	111	97	67	52	39	30	22	17	11
95						795	687	458	351	256	216	151	131	92	70	53	41	29	23	16
120							868	578	444	323	273	191	166	116	89	67	62	37	23	20
150								615	472	343	290	203	178	123	94	71	54	39	31	21
185								714	547	399	336	235	205	145	110	82	64	46	36	24
240									666	485	409	286	249	173	133	100	77	55	44	29
300										566	477	334	290	202	155	117	90	65	51	34

Table C: maximum lengths (in m) of conductors protected by aM fuses (rated in A)

S (mm²) \ (A)	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
1.5	28	23	18	14	11	9	7	6	5	4										
2.5	47	38	30	24	19	15	12	9	8	6	5									
4	75	60	48	38	30	24	19	15	12	10	8		6	5	4					
6	113	90	72	57	45	36	29	23	18	14	11	9	7	6	5	4				
10	188	151	121	94	75	60	48	38	30	24	19	15	12	10	8	6	5	4		
16	301	241	193	151	121	96	77	60	48	39	30	24	19	15	12	10	8	6	5	4
25	470	377	302	236	188	151	120	94	75	60	47	38	30	24	19	16	12	9	8	6
35	658	527	422	330	264	211	167	132	105	84	66	53	42	33	26	21	17	13	11	8
50	891	714	572	447	357	285	227	179	144	115	90	72	57	46	36	29	23	18	14	11
70			845	660	527	422	335	264	211	169	132	105	84	67	53	42	33	26	21	17
95				895	716	572	454	358	286	229	179	143	115	91	72	57	45	36	29	23
120					904	723	574	462	362	289	226	181	145	115	90	72	57	45	36	29
150						794	630	496	397	317	248	198	159	126	99	79	63	50	40	32
185							744	586	469	375	293	234	188	149	117	94	74	59	47	38
240								730	584	467	365	292	234	185	146	117	93	73	58	47
300									702	562	439	351	281	223	175	140	11	88	70	56

Example: a circuit consists of a 3 x 6 mm^2 copper cable and is protected by a 40 A gG fuse. Its length must be less than 73 m so that protection against indirect contact is guaranteed in TN 230 V/400 V.

- if the cable is an aluminium one, maximum length is: 0.625 x 73 m = 45.6 m
- in IT load with neutral and an aluminium cable, the length is: 0.625 x 0.5 x 73 m = 22.8 m
- in IT load with neutral and an aluminium cable for supplying a section enclosure, the length is: 0.625 x 0.5 x 1.88 = 42.8 m.

Protection against indirect contacts by differential relay

TT load

To avoid, for example, a contact voltage higher than 50 V, the current IΔn must be such that:

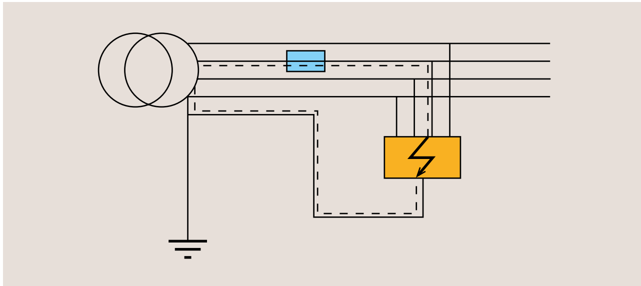
$$I_{\Delta n} \quad \frac{50}{R_p}$$

Rp LV earth connection resistance in Ω

Where the earth connection is particularly difficult to make and where the values may exceed a hundred ohms (high mountain, arid areas, etc.), installation of high sensitivity (H.S.) devices is an answer to the previous situation.

TNS load

In this load, the fault current is equivalent to a short circuit current between phase and neutral. The latter is eliminated by the appropriate devices (fuses, circuit breakers, etc.) in a time compatible with the protection against indirect contacts. When this time cannot be respected (wiring systems that are too long, hence insufficient minimum I_{sc}, protection device reaction time too long, etc.), it is necessary to accompany the overcurrent protection with a differential protection device. This measure provides protection against indirect contacts, for practically any wiring system length.



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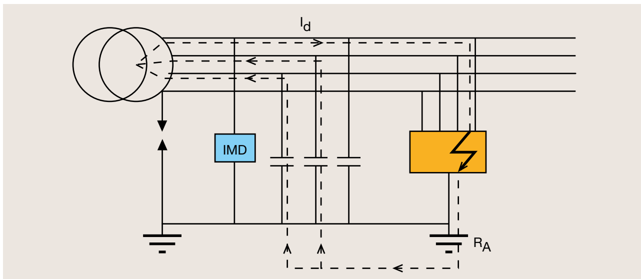
IT load

Circuit breaking is normally not necessary at the first fault. A dangerous contact voltage can occur on the second fault or where masses are connected to non-interconnected or distant earth connections or between simultaneously accessible masses connected to the same earth connection and whose protection circuit impedance is too high.

For these reasons, in IT load, a differential device is obligatory:
- at the origin of the parts of the installation whose protection networks or masses are connected to non-interconnected earth connections,
- in the same situation as that mentioned in TNS load (breaking conditions on second fault not provided by the overcurrent protection devices in the required safety conditions).



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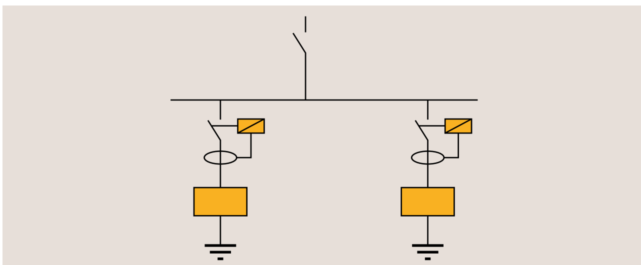
Protection against indirect contact of the mass groups connected to independent earth connections

In TT neutral load as in IT, when the masses of the electrical equipment are connected to separate earth connections downstream of the same power supply, each group of masses must be protected by its own dedicated device.



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Exemption from high sensitivity (H.S.) protection of computer equipment sockets

As agreed by the decree of 08/01/92 for the use of H.S. protective measures on ≤ 32 A sockets supplying computer equipment, the exemption has been revoked by article 3 of the decree of 8 December 2003 on installations realised since the 1st January 2004.

Voltage drops

Voltage drop is the voltage difference observed between the installation's point of origin and the receptor's connection point. To ensure correct receptor operating, standards NF C 15100 and IEC 60364 define a maximum voltage drop (see table A).

Table A: NF C 15100 maximum voltage drop

	Lighting	Other uses
Direct public mains LV supply	3 %	5 %
HV/LV substation supply	6 %	8 %

Calculating voltage drop for cable with length L

Δ u = Ku x I (Amperes) x L (km)

Table B: Ku values

Cable cross section mm²	DC current	Multiconductor cables or trefoil monoconductor cables			Single-conductor joined cable layout in flat formation			mono-conductor cables separate		
		cos 0.3	cos 0.5	cos 0.8	cos 0.3	cos 0.5	cos 0.8	cos 0.3	cos 0.5	cos 0.8
1.5	30.67	4.68	7.74	12.31	4.69	7.74	12.32	4.72	7.78	12.34
2.5	18.40	2.84	4.67	7.41	2.85	4.68	7.41	2.88	4.71	7.44
4	11.50	1.80	2.94	4.65	1.81	2.95	4.65	1.85	2.99	4.68
6	7.67	1.23	1.99	3.11	1.24	1.99	3.12	1.27	2.03	3.14
10	4.60	0.77	1.22	1.89	0.78	1.23	1.89	0.81	1.26	1.92
16	2.88	0.51	0.79	1.20	0.52	0.80	1.20	0.55	0.83	1.23
25	1.84	0.35	0.53	0.78	0.36	0.54	0.78	0.40	0.57	0.81
35	1.31	0.27	0.40	0.57	0.28	0.41	0.58	0.32	0.44	0.60
50	0.92	0.21	0.30	0.42	0.22	0.31	0.42	0.26	0.34	0.45
70	0.66	0.17	0.23	0.31	0.18	0.24	0.32	0.22	0.28	0.34
95	0.48	0.15	0.19	0.24	0.16	0.20	0.25	0.20	0.23	0.27
120	0.38	0.13	0.17	0.20	0.14	0.17	0.21	0.18	0.21	0.23
150	0.31	0.12	0.15	0.17	0.13	0.15	0.18	0.17	0.19	0.20
185	0.25	0.11	0.13	0.15	0.12	0.14	0.15	0.16	0.17	0.18
240	0.19	0.10	0.12	0.12	0.11	0.13	0.13	0.15	0.16	0.15
300	0.15	0.10	0.11	0.11	0.11	0.12	0.12	0.15	0.15	0.14
400	0.12	0.09	0.10	0.09	0.10	0.11	0.10	0.14	0.14	0.12

Single-phase circuits: multiply the values by 2.

Example

A 132 kW motor consumes 233 A with a voltage of 400 V. It is supplied by 3 x 150 mm² flat-formation copper monoconductor cables, 200 mm long (0.2 km).

- Under normal operating conditions cos φ = 0.8 ; Ku = 0.18
  Δu = 0.18 x 233 x 0.2 = 8.4 V or 3.6 % of 230 V.
- With on-line start-up cos φ = 0.3 and Id = 5 In = 5 x 233 A = 1165 A ; Ku = 0.13
  Δu = 0.13 x 1165 x 0.2 = 20.3 V or 8.8 % of 230 V.

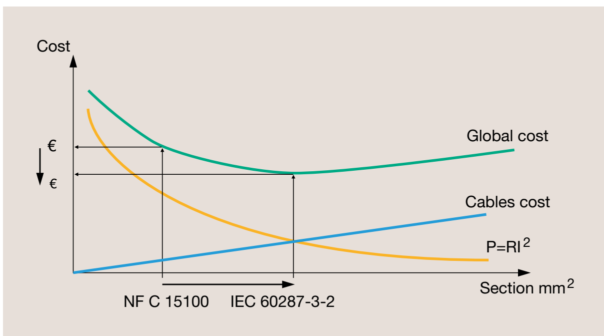
The conductor cross section is sufficient to meet the maximum voltage drop imposed by standard NF C 15100.

Note

This calculation is valid for 1 cable per phase. For n cables per phase, simply divide the voltage drop by n.

"Economic optimisation" of power cable size

The IEC 15100 standard governing the installation authorises a power cable sizing with voltage drops that can go up to 16% on single-phase circuits. For the majority of distribution circuits, it is customary to accept 8 % corresponding to the proportion of energy that is lost. For defining a wiring system, IEC 60287-3-2 proposes a complementary approach that takes into account the cost of investment and the projected energy consumption.



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Innovative Power Solutions

Switching and isolating devices

Product standards NF EN 60947 and IEC 60947

Definitions

Switch (IEC 60947.3 § 2.1)

"A mechanical connection device capable of:
- making, carrying and breaking currents under normal circuit conditions*, possibly including specified operating overload conditions,,
- carrying currents in abnormal circuit conditions - such as short-circuit conditions - for a specified duration (a switch may be able to make short-circuit currents, but it cannot break them).

** Normal conditions generally correspond to the use of a piece of equipment at an ambient temperature of 40 °C for a period of 8 hours.*

Disconnector (IEC 60947.3 § 2.2)

"A mechanical switching device which, when open, complies with the requirements specified for the isolating function. This device can carry currents in normal circuit conditions as well as currents in abnormal conditions for a specified duration.

Disconector (working definition): a device without on-load making and breaking capacity.

Switch disconnector (IEC 60947.3 § 2.3)

Switch, which in its breaking position meets the specific insulation conditions for a switch-disconnector.

Fuse switch-disconnector (IEC 60947.3 § 2.9)

Switch-disconnector in which one or more poles include an-in series fuse in a combined device.

Actions \ Device				
Making	Normal, Overload, Short-circuit (1)		Normal, Overload, Short-circuit (1)	Normal, Overload, Short-circuit (1)
Withstanding	Normal, Overload, Short-circuit	Normal, Overload, Short-circuit	Normal, Overload, Short-circuit	Normal, Overload, Short-circuit
Breaking	Normal, Overload		Normal, Overload	Normal, Overload, Short-circuit (2)

(1) Threshold not imposed by standard. (2) By the fuse.

Normal current
Overload current
Short-circuit current

Functions

Separation of contacts

As stipulated by the mechanical switching device standard NF EN 60947-3. or NF C 15100 § 536. All disconnection devices must ensure adequate contact separation of contacts.

Testing contact separation capacity as per standard NF EN 60947-3 is carried out in three tests:
- the dielectric test will define sparkover resistance (U_{imp}: impulse withstand voltage) dependent on the distance of the air gap between contacts. Generally, U_{imp} = 8 kV for U_e = 400/690 V,
- the measurement of leakage current (I_p) will define insulation resistance in the open position partly depending on the creepage distances. At 110% of U_e, I_f < 0.5 mA (new device) and I_f < 6 mA (device at end of life span),
- checking the strength of the actuator and the position indication device is aimed at validating the "mechanical" reliability of position indications. The device is locked in the "I" position, and a force three times the standard operating force is applied to the operating mechanism.
  During the course of this test, locking the device on the "0" position must not be possible, nor should the device remain the the "0" position after the test. This test is not necessary when contact opening is shown by other means than an operating mechanism, such as: a mechanical indicator, or direct visibility of contacts, etc.
  This third test meets the definition of "fully visible" breaking required by the decree of 14 November 1988 to provide the isolation function in low voltage B systems (500 V < U ≤ 1000 VAC and 750 V < U ≤ 1500 VDC).
  The latter characteristic is required by NF C 15100 except for SELV or PELV (U ≤ 50 VAC or 120 VDC).

Load and overload interruption

This is ensured by devices defined for making and breaking in normal load and overload conditions.

Type tests characterise devices able to make and break specific loads, and these can have high overload currents under a low cos φ (a starting motor or a locked rotor).

The type of load or load duty defines the device's load duty category.

Breaking action in the event of a short-circuit

A switch is not intended to cut off a short-circuit current. However its dynamic withstand must be such that it withstands the fault until it is eliminated by the corresponding protective device.

On fuse combination switches, the short-circuit is cut-off by the fuses (see chapter "Fuse protection" on pages 53 and 55) with the considerable advantage of limiting high fault currents.

Product standards NF EN 60947 and IEC 60947 (continued)

Characteristics

Application condition and load duty category as per standard IEC 60947-3

Table A

Load duty category		Use	Application
AC-20	DC-20	Off-load making and breaking	Disconnector (1)
AC-21	DC-21	Resistive loads including moderate overloads.	Switches at installation head or for resistive circuits (heating, lighting, except discharge lamps, etc.).
AC-22	DC-22	Inductive and resistive mixed loads including moderate overloads.	Switches in secondary circuits or reactive circuits (capacitor banks, discharge lamps, shunt motors, etc.).
AC-23	DC-23	Loads made of motors or other highly inductive loads.	Switches feeding one or several motors or inductive circuits (electric carriers, brake magnet, series motor, etc.).

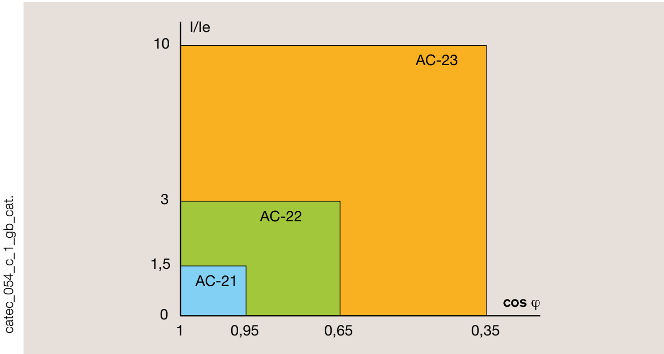
(1) Today these devices are replaced by load break switches for obvious safety of use reasons..

Breaking and making capacities

Unlike circuit breakers, where these criteria indicate tripping or short-circuit making characteristics and perhaps requiring device replacement, switch making and breaking capacities correspond to utilization category maximum performance values.
In such extreme uses, the switch must still maintain its characteristics, in particular its resistance to leakage current and temperature rise.

Table B

	Making		Breaking		N° of operating cycles
	I/I_e	cos φ	I/I_e	cos φ	
AC-21	1.5	0.95	1.5	0.95	5
AC-22	3	0.65	3	0.65	5
AC-23 Ie ≤ 100 A	10	0.45	8	0.45	5
Ie > 100 A	10	0.35	8	0.35	3
	L/R (ms)		L/R (ms)		
DC-21	1.5	1	1.5	1	5
DC-22	4	2.5	4	2.5	5
DC-23	4	15	4	15	5



Electrical and mechanical endurance

This standard establishes the minimum number of electrical (at full load) and mechanical (off-load) operating cycles that must be performed by devices. These characteristics also specify the device's theoretical lifespan during which it must maintain its characteristics, particularly resistance to leakage current and temperature rise. This performance is linked to the device's use and rating. According to anticipated use, two additional application categories are offered:
- category A: frequent operations (in close proximity to the load)
- category B: infrequent operations (at installation head or wiring system).

Table C

Ie (A)	≤ 100	≤ 315	≤ 630	≤ 2500	> 2500
N° cycles/hour	120	120	60	20	10
N° of operations in category A					
without current	8500	7000	4000	2500	1500
with current	1500	1000	1000	500	500
Total	10000	8000	5000	3000	2000
N° of operations in category B					
without current	1700	1400	800	500	300
with current	300	200	200	100	100
Total	2000	1600	1000	600	400

Operating current I_e

Operational current (Ie) is determined by endurance tests (both mechanical and electrical), and by making and breaking capacity tests.

Short-circuit characteristics

- Short-time withstand current (Icw): admissible rms current lasting for 1 second.
- Short circuit making capacity (Icm): peak current value which the device can withstand due to short circuit closure.
- Conditional shirt-circuit current: the rms current the switch can withstand when associated with a protection device limiting both the current and short circuit duration.
- Dynamic withstand: peak current the device can support in a closed position.

The characteristic established by this standard is the short-time withstand current (I_{cw}) from which minimal dynamic withstand is deduced. This essential withstand value corresponds to what the switch can stand without welding.

Installation standards IEC 60364 or NF C 1510035

Isolating § 536-2

This function is designed to ensure disconnection of the total or partial installation from the power supply for safety reasons.

The isolating function requires actions as follows:
- breaking across all live conductors,
- **assured off-load breaking**, provided additional measures (such as pre-break auxiliary contact, “do no operate on-load” indicator panel, etc.) are in place to ensure that the operational current is not cut on-load. For greater safety, today on-load breaking is provided by switching devices able to break on-load in addition to their isolation function,
- contacts separation.

Switching off for mechanical maintenance § 536-4

This function is designed to switch off and maintain a machine in the off position in order to carry out mechanical maintenance operations without risk of physical injury, or for longer shutoffs.
The devices should be easily identifiable and used appropriately.
The switching off device for mechanical maintenance requires both isolating and emergency switching functions.
This function is also offered by a local safety-breaking enclosure.
In these enclosures, visible breaking switches are generally used where external switch verification is required. Visible breaking is used for greater safety for personnel working in hazardous areas, particularly on sites where mechanical risks are very high, and where a damaged handle would no longer safely indicate the switch position.

Emergency switching § 536-3

This function ensures disconnection of circuit terminals. The aim of this function is to disconnect loads, thus preventing risk of fire, burns or electric shock. This entails fast easy access and identification of device to be switched.
Fast intervention depends on installation site layout, the equipment being operated, or the personnel present.

The emergency breaking function requires actions as follows:
- assured on-load breaking,
- breaking across all live conductors.

Emergency stop IEC 60204 § 10-7

This function differs from emergency switching in that it takes into account the risks connected with moving machine parts.

The emergency stop requires actions as follows:
- assured on-load breaking,
- breaking across all live conductors,
- possible retention of the supply, for example, for braking of moving parts.

Functional switching § 536-5

In terms of practical operation of an electrical installation, it should be possible to operate locally without disconnecting the entire installation. In addition to selective control, functional control also comprises commutation, load shedding etc.

The functional control function requires actions as follows:
- assured on-load breaking,
- breaking across certain live conductors (e.g. 2 out of 3 phases of a motor).

Switching and isolating devices

Choosing a switching device

Choice according to insulation voltage

This describes the device's maximum operational voltage in normal network conditions.

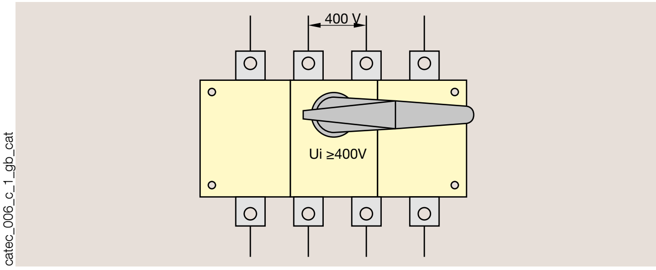


Fig. 1

Example

On a 230 V / 400 V network, a device with insulation voltage $U_i \geq 400$ V must be chosen (see fig.1).
On a 400 V / 690 V network, a device with insulation voltage U_i 690 V must be chosen.

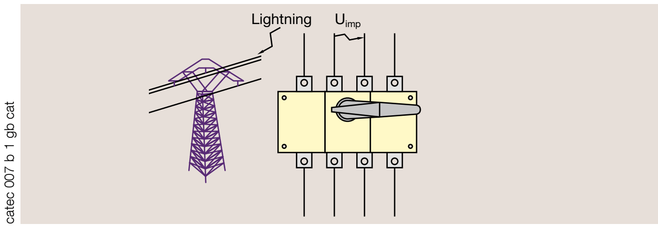
Dielectric tests

In order to define a device's dielectric insulation quality, IEC 947-3 standard stipulates the following measures:
- U_{imp} withstand on new devices before testing (short-circuits, endurance, etc.),
- verification of dielectric withstand after testing at voltage 1.1 x U_i.

Impulse withstand voltage U_{imp}

This defines the device's use in abnormal network conditions with overvoltage due to:
- lightning on overhead wires,
- device operating on High Voltage circuits.

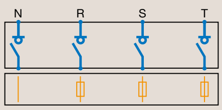
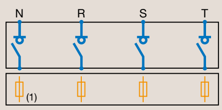
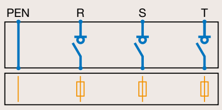
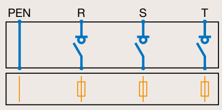
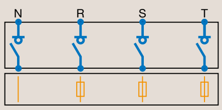
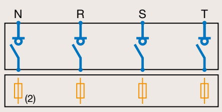
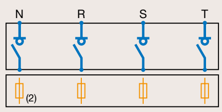
This characteristic also defines the device's dielectric quality (e.g.: U_{imp} = 8 kV).



Device withstand to U_{imp}.

Choice according to neutral arrangement

Three-phase network with distributed neutral

Load	NEUTRAL CROSS SECTION ≥ PHASE CROSS SECTION	NEUTRAL CROSS SECTION < PHASE CROSS SECTION
TT		
TNC		
TNS		
IT with neutral		

——— *Switch-disconnector* ——— *Protection*

(1) The neutral does not have to be protected if the neutral conductor is protected against short circuits by the phase protection device and if the maximum fault current on the neutral is much lower than the admissible current for the cable (NF C 15100 § 431.2).

(2) Use of a fuse on the neutral must be combined with a fuse-blown detector, which in the event shall trigger the opening of the corresponding phases to avoid operating the installation without neutral.

Choosing a switching device (continued)

Sizing of the neutral pole according to the presence of harmonics

Neutral section < Phases section

Presence of number 3 harmonic currents and multiple of 3 where the rate is under 15%.

Neutral section < Phases section

Presence of number 3 harmonic currents and multiple of 3 where the rate is between 15 and 33% (for example, distribution for gas discharge lamps, fluorescent tubes).

Neutral section < Phases section

For the presence of number 3 harmonic currents and multiple of 3 where the rate is higher than 33% (for example, office equipment and computer circuits), § 524.2 of standard NFC 15100 proposes a section of 1.45 of the phase section.

Application types in a DC network

The operational current characteristics indicated in the general catalogue are defined for fig. 1. except where "2-pole in series" is specified (in this case, see fig. 2).

Example 1: poles in series
A 400 A SIRCO device, used in a 500 V DC network with a 400 A operational current in DC 23 category, must have 2 poles in series per polarity.

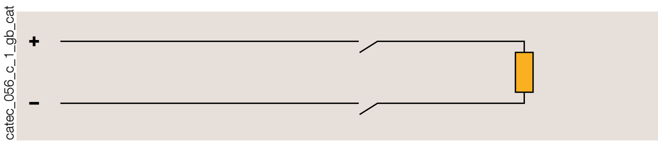


Fig. 1 1 pole per polarity

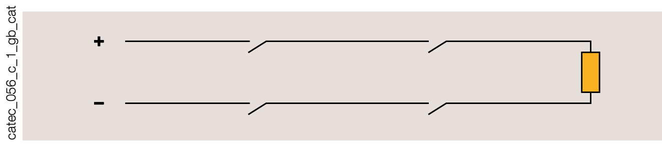
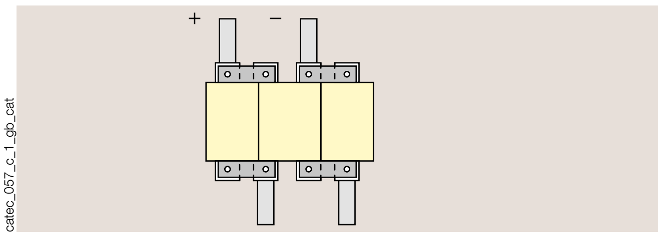


Fig. 2 2 poles in series per polarity

Example 2: poles in parallel
4-pole device with 2 pole in series by polarity.
Connecting precaution: ensure correct current distribution in both branches.



Uses

Protection

Circuit breaking time must be taken into account when using SIDERMAT, FUSOMAT or IDE tripping devices to protect against indirect contact and short circuits. The time between operation and effective contact breaking is less than 0.05 sec.

Power supply change over

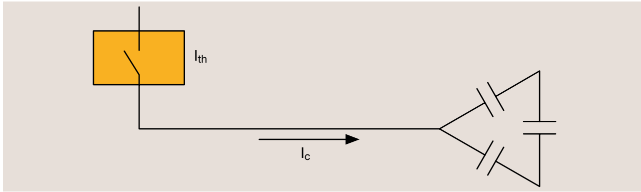
The 0-I or 0-II operation time is 0.7 to 2.1 s depending on the devices.
The I - II switching time is 1.1 to 3.6 s.

Uses (continued)

Upstream of capacitor bank

As a general rule, choose a switch rating 1.5 times higher than the nominal current value of the capacitor bank (I_c).

$I_{th} > 1.5\ I_c$



At transformer primary

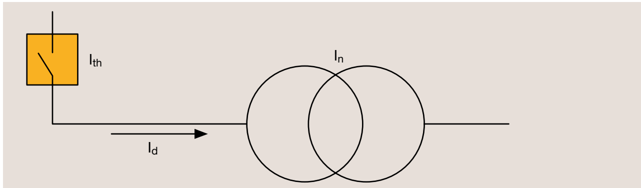
Ensure that the switch making capacity is greater than the no-load current (I_d) of the transformer.

Making capacity > I_{th}

Table A

P (kVA)	50	100	160	250	400	630	1000	1250	1600
Id / In	15	14.5	14	13	12	11	10	9	8.5

I_d: transformer no-load current.
In: transformer nominal current



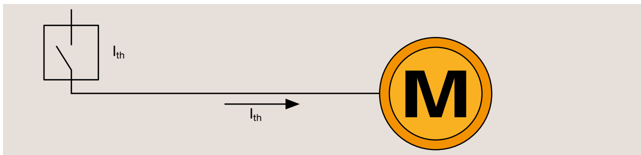
Upstream of motor

Local security switching

The switch must be rated at AC23 to the nominal current (I_n). of the motor.

In frequent motor start-up currents

It is necessary to calculate the equivalent thermal current (I_{thq}).
Currents and start-up times vary widely according to motor inertia. For direct start-up they are generally between the following values:
- peak current: 8 to 10 I_n,
- 20 to 30 ms,
- start-up current I_d: 4 to 8 I_n,
- start-up time t_d: 2 to 4 sec.



Examples of de-rating according to start-up type.

$I_{thq} = I_n \times K_d$ et $I_{th} \geq I_{thq}$

Table B

Start-up type	I_d(4) / I_n	t_d(4)(s)	n (1)	K_d(2)
Direct up to 170 kW	6 to 8	0.5 to 4	n > 10	$\frac{\sqrt{n}}{3.16}$
Y - Δ (I_d/3)	2 to 2.5	3 to 6	n > 85	$\frac{\sqrt{n}}{9.2}$
Direct high-inertia motors(3)	6 to 8	6 to 10	n > 2	$\frac{\sqrt{n}}{1.4}$

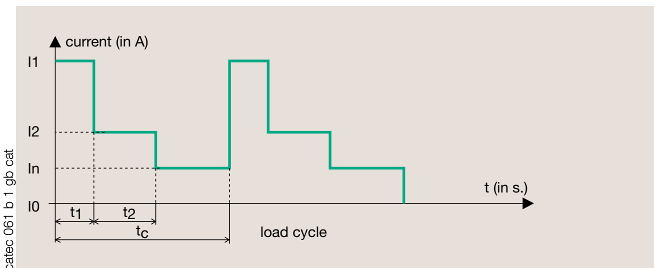
(1) n: number of start-ups per hour for which de-rating is required.
(2) K_d: start-up factor ≥ 1.
(3) Fans, pumps…
(4) Average values very variable according to type of motor and receiver.

In cases of cyclic overloads (excluding start-ups).

For specific machines (welding machines, motors), and generators with a peak cyclic current, the calculation of equivalent current (I_{thq}) is as follows:

$$I_{thq} = \sqrt{\frac{(I^2 1 \times t1) + (I^2 2 \times t2) + I_n^2 \times (t_c - [t1 + t2])}{t_c}}$$

I1: overload current.
I2: possible intermediate overload.
I_n: nominal operating current.
t1 and t2: respective duration in seconds of currents I1 and I2.
tc: cycle duration in seconds with lower limit set at 30 seconds



Cyclic overload.

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Limits of use

Certain operating conditions necessitate modification of thermal current using a correction factor.

Kt correction due to ambient air temperature

Ambient air temperature surrounding the device

Table A: correction factors according to ambient air temperature ta

Kt: correction factor	
0.9	40 °C to 50 °C
0.8	50 °C to 60 °C
0.7	60 °C to 70 °C

- Simplified method.

$$I_{thu} \leq I_{th} \times K_t$$

- A more accurate calculation can be made for each application: please consult us.

Use with fuse combination unit

- Simplified method.
  A switch must be de-rated by a factor of 0.8 when fuse bases are directly connected to its terminals.
  Example: A 1250 A fuse set will consist of a 1600 A switch and 3 1250 A gG fuses.
- A more accurate calculation can be made for each application: please consult us.

Other de-rating due to temperature

- Switch fuses fitted with high speed fuses.
- Rated continuous duty. In certain cases, de-rating is necessary for 24-hour full-load operation: please consult us.

Kf correction due to frequency

Table B: correction factors according to frequency f

Kf: correction factor	
0.9	100 Hz < f ≤ 1000 Hz
0.8	1000 Hz < f ≤ 2000 Hz
0.7	2000 Hz < f ≤ 6000 Hz
0.6	6000 Hz < f ≤ 10000 Hz

$$I_{thu} \leq I_{th} \times Kt$$

Ka correction factor due to altitude

Table C: correction factors according to altitude A

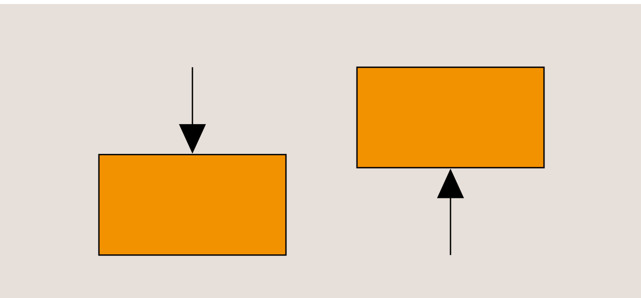
	2000 m < A ≤ 3000 m	3000 m < A ≤ 4000 m
Ue	0.95	0.80
Ie	0.85	0.85

- No de-rating of I_{th}.
- Ue and Ie de-rating in both AC and DC currents.

Kp correction due to device position

Top or bottom connection

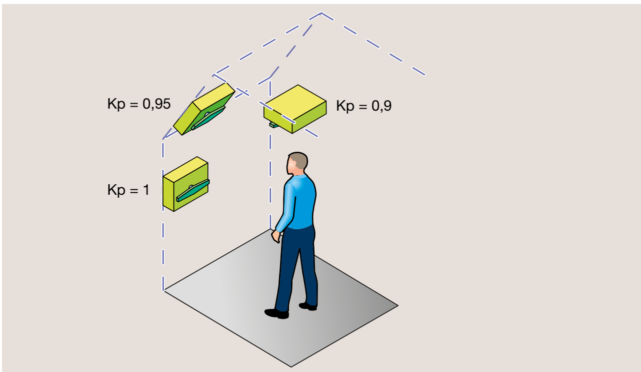
As the entire SOCOMEC range of switches have a double breaking system per pole (except FUSERBLOC 1250 A, FUSOMAT 1250 A and SIDERMAT combination units), the power source can be connected to the top or bottom of the device, except in those cases where regulations of identification stipulate power supply from below.



Direction of supply.

De-rating according to switch position

$$I_{thu} \leq I_{th} \times Kt$$



Position de-rating.

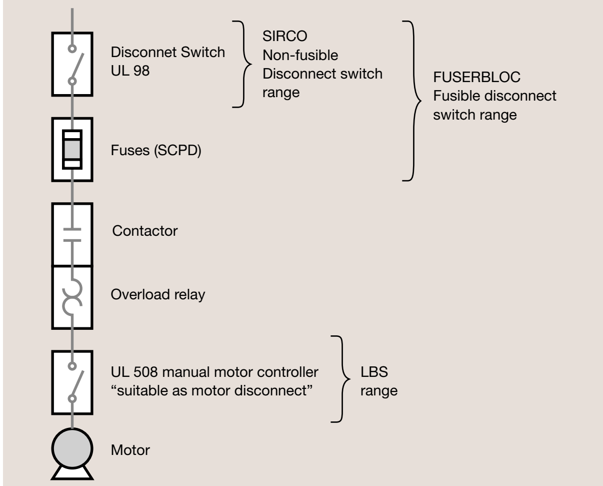
UL and NEMA specifications

General information about motor protection

Typical construction of a motor starter

Essential parts of a motor branch circuit required by the national electrical code

- Disconnect means.
- Branch-circuit short-circuit protective device.
- Motor-controller.
- Motor overload protective devices.



Disconnect means

The disconnect means can be a manual disconnect switch according to UL 98.
A manual motor controller (according to UL 508) additionally marked “suitable as motor disconnect” is only permitted as a disconnecting means where installed between the final branch-circuit short-circuit and ground-fault protective device and the motor
(NEC 2002 Article 430.109).

Branch-circuit short-circuit protective device

The short-circuit protective device can be either a fuse or an inverse-time circuit-breaker.

Motor-controller

Any switch or device that is normally used to start and stop a motor according to the National Electrical Code article 430.81.

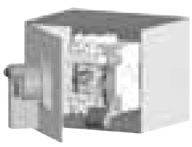
Motor overload protective devices

The national electrical code permits fuses to be used as the sole means of overload protection for motor branch circuits. This approach is often practical only with small single phase motors.
Most integral horsepower 3 phase motors are controlled by a motor starter which includes an overload relay. Since the overload relay provides overload protection for the motor branch circuit, the fuses may be sized for short-circuit protection.

Wire size cross reference

AWG	mm^2	kcmil/mcm	mm^2
14	2.1	250	127
12	3.3	300	152
10	5.3	350	177
8	8.4	400	203
6	13.3	500	253
4	21.2	600	304
3	26.7	700	355
2	33.6	750	380
1	42.4	800	405
1/0	53.5	900	456
2/0	67.4	1000	507
3/0	85.0	1250	633
4/0	107.2	1500	760
		1750	887
		2000	1014

New NFPA 79 requirements and solutions



As defined in the NFPA 79 Standard section 5.3.3.1 and 6.2.3.1.2, our disconnecting devices fully comply with all of the following requirements:

1. Isolate the electrical equipment from the supply circuit and have one off (open) and one on (closed) position only.
2. Have an external operating means (e.g., handle).
3. Be provided with a permanent means permitting it to be locked in the off (open) position only (e.g., by padlocks) independent of the door position. When so locked, remote as well as local closing is be prevented.
4. Be operable, by qualified persons, independent of the door position without the use of accessory tools or devices.

However the closing of the disconnecting means while door is open is not permitted unless an interlock is operated by deliberate action.
Flange and side operation:
Our flange operated and side operated switches meet the requirements of the NFPA 79 without any additional parts being added.

General information about motor protection (continued)

Nema ratings and IP cross-reference

Nema type	Intended use and description	Nema ratings and ip cross-reference
1	Indoor use primarily to provide a degree of protection against contact with the enclosed equipment and against a limited amount of falling dirt	NEMA 1 meets or exceeds IP10
2	Indoor use to provide a degree of protection against a limited amount of falling water and dirt	NEMA 2 meets or exceeds IP11
3	Intended for outdoor use primarily to provide a degree of protection against rain, sleet, windblown dust, and damage from external ice formation.	NEMA 3 meets or exceeds IP54
3R	Intended for outdoor use primarily to provide a degree of protection against rain, sleet, and damage from external ice formation.	NEMA 3R meets or exceeds IP14
3S	Intended for out door use primarily to provide a degree of protection against rain, sleet, windblown dust, and to provide for operation of external mechanisms when ice laden.	NEMA 3S meets or exceeds IP54
4	Intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.	NEMA 4 meets or exceeds IP56
4X	Intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed water, and damage from ice formation.	NEMA 4X meets or exceeds IP56
6	Intended for indoor or outdoor use primarily to provide a degree of protection against hose-directed water, the entry of water during occasional temporary submersion at a limited depth, and damage from external ice formation.	NEMA 6 meets or exceeds IP67
6P	Intended for indoor or outdoor use primarily to provide a degree of protection against hose-directed water, the entry of water during prolonged submersion at a limited depth, and damage from external ice formation.	NEMA 6P meets or exceeds IP67
12	Intended for indoor use primarily to provide a degree of protection against circulating dust, falling dirt, and dripping non-corrosive liquids.	NEMA 12 meets or exceeds IP52
12K	Type 12 with knockouts.	NEMA 12K meets or exceeds IP52

This table provides a guide for converting from NEMA enclosure type numbers to IP ratings. The NEMA types meet or exceed the test requirements for the associated european classifications; for this reason the table should not be used to convert "from IP rating to NEMA" and the "NEMA to IP rating" should be verified by test.

Fusible disconnect switches' association chart with UL fuses (according to typical motor acceleration times)

Three phase motor fuse and fusible disconnect switch selection UL class CC

Motor hp	Full load amperes	Recommended fuse ampere rating for typical* 5 secs. Motor acceleration times	Recommended fusible disconnect switch
208 V		Ampere rating (A)	Ampere rating (A)
1/2	2.4	8	30
3/4	3.5	10	
1	4.6	15	
1-1/2	6.6	20	
2	7.5	20	
3	10.6	30	
240 V		Ampere rating (A)	Ampere rating (A)
1/2	2.2	7	30
3/4	3.2	10	
1	4.2	12	
1-1/2	6	17-1 / 2	
2	6.8	20	
3	9.6	30	
480 V		Ampere rating (A)	Ampere rating (A)
1/2	1.1	3-1/2	30
3/4	1.6	5	
1	2.1	6-1/4	
1-1/2	3	9	
2	3.4	10	
3	4.8	15	
5	7.6	25	
7-1/2	11	30	
600 V		Ampere rating (A)	Ampere rating (A)
1/2	0.9	2-8/10	30
3/4	1.3	4	
1	1.7	5-6/10	
1-1/2	2.4	8	
2	2.7	8	
3	3.9	12	
5	6.1	17-1/2	
7-1/2	9	30	
10	11	30	

Fusible disconnect switches' association chart with UL fuses (according to typical motor acceleration times) (continued)

Three phase motor fuse and fusible disconnect switch selection UL class J

Motor hp	Full load amperes	Recommended fuse ampere rating for typical* 5 secs. Motor acceleration times	Recommended fusible disconnect switch
208 V		Ampere rating (A)	Ampere rating (A)
1/2	2.4	3-1/2	30
3/4	3.5	5	
1	4.6	7	
1-1/2	6.6	10	
2	7.5	10	
3	10.6	15	
5	16.7	25	
7-1/2	24.2	35	60
10	30.8	45	
15	46.2	70	100
20	60	90	
25	75	110	200
30	88	150	
40	114	175	
50	143	225	400
60	169	250	
75	211	350	
100	273	400	
125	343	500	600
150	396	600	
240 V		Ampere rating (A)	Ampere rating (A)
1/2	2.2	3-1/2	30
3/4	3.2	5	
1	4.2	6-1/4	
1-1/2	6	9	
2	6.8	10	
3	9.6	15	
5	15.2	25	
7-1/2	22	35	60
10	28	40	
15	42	60	100
20	54	80	
25	68	100	
30	80	125	200
40	104	150	
50	130	200	
60	154	225	400
75	192	300	
100	248	350	
125	312	450	600
150	360	500	

** Typical: suggested for most applications. Will coordinate with NEMA class 20 overload relays. Suitable for motor acceleration times up to 5 seconds.*

Three phase motor fuse and fusible disconnect switch selection UL class J (continued)

Motor hp	Full load amperes	Recommended fuse ampere rating for typical* 5 secs. Motor acceleration times	Recommended fusible disconnect switch
480 V		Ampere rating (A)	Ampere rating (A)
1/2	1.1	1-6/10	
3/4	1.6	2-1/4	
1	2.1	3-2/10	
1-1/2	3	4-1/2	
2	3.4	5	
3	4.8	8	30
5	7.6	12	
7-1/2	11	17-1/2	
10	14	20	
15	21	30	
20	27	40	
25	34	50	60
30	40	60	
40	52	80	100
50	65	100	
60	77	125	
75	96	150	200
100	124	200	
125	156	225	
150	180	250	400
200	240	350	
250	302	450	600
300	361	600	
600 V		Ampere rating (A)	Ampere rating (A)
1/2	0.9	1-1/2	
3/4	1.3	2	
1	1.7	2-1/2	
1-1/2	2.4	3-1/2	
2	2.7	4	
3	3.9	6	30
5	6.1	10	
7-1/2	9	15	
10	11	17-1/2	
15	17	25	
20	22	35	
25	27	40	60
30	32	50	
40	41	60	
50	52	80	100
60	62	90	
75	77	125	
100	99	150	200
125	125	200	
150	144	225	
200	192	300	400
250	240	350	
300	289	450	600

** Typical: suggested for most applications. Will coordinate with NEMA class 20 overload relays. Suitable for motor acceleration times up to 5 seconds.*

Fuse protection

General characteristics

Fuses are designed to break an electric circuit in cases of abnormal currents. They also have the added advantage of being able to limit high current faults (see example below). The fuse's essential characteristics are its reliability in terms of protection, its simplicity and its economical price.

Optimising fuse choice depends on the fuse's technical features as follows:

- Pre-arcing time
  This is the time necessary for the current to bring the fuse element to vaporisation point before melting.
  Pre-arcing time is independent from network voltage.
- Arcing time
  This is defined as the period between the instant of arc appearance and its total extinction (zero current). Arc time depends on network voltage, but is negligible compared to pre-arcing time for total melting time > 40 ms.
- Operation time
  This is the sum of pre-arcing and arcing times.
- Breaking capacity
  This is the prospective short circuit current value that the fuse can blow under a specified operational voltage.
- Joule integral, $\int_0^t I^2\,dt$
  This is the integral value of the current cut during total melting time, expressed as A^2s (Amps squared seconds).

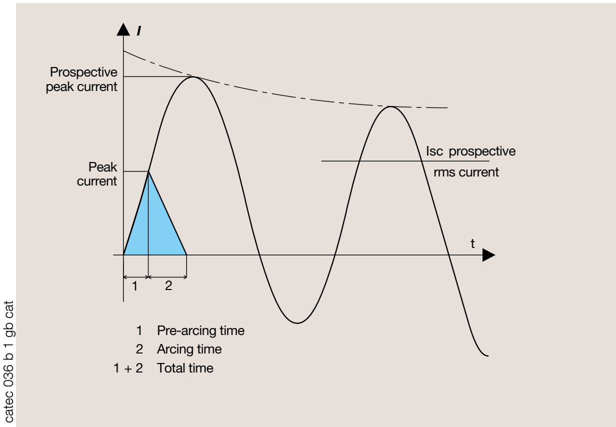
Short-circuit current cut-off

The two parameters to be considered for short-circuit current cut-off are:

- the true current peak reached in the protected circuit,
- the prospective rms current that would develop in the absence of fuses in the circuit.

The cut-off current diagram indicates the correspondence between these two parameters *(see pages 53 and 55)*. The following actions should be performed to know peak current (which can increase in fuse-protected electric circuits):

- calculate maximum rms short circuit current *(see page 22)*,
- plot this current value on the cut-off current diagram, and read off peak value according to the fuse rating protecting the circuit.



Comments: There is only one cut-off if $t_{pre\text{-}arcing}$ < 5 ms (50 Hz network).

Example: A symmetric 100 kA rms short-circuit current cut-off with 630 A gG fuse is required.
The prospective 100 kA rms current results in a prospective peak current as follows: 100 x 2.2 = 220 kA.
The fuse cuts-off peak current at 50 kA, representing 23% of its prospective value (see figure 1); this leads to a reduction of 5% of unprotected value in electrodynamic forces (see figure 2) and a reduction in the joule integral limited to 2.1% of its value (see figure 3).

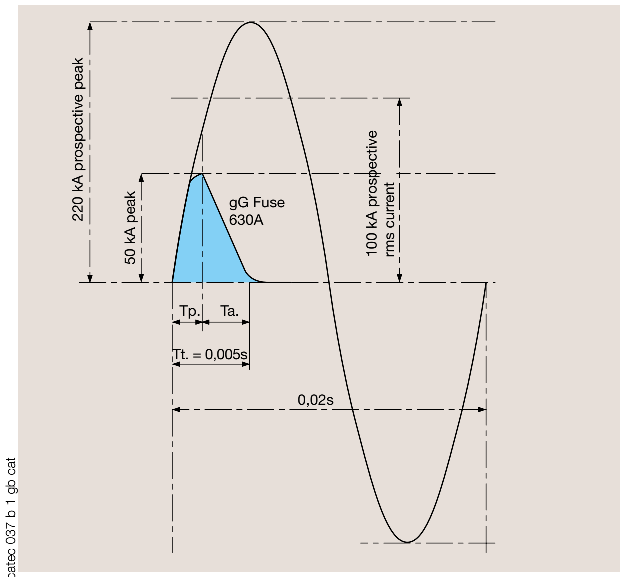


Fig. 1 cut-off peak current.

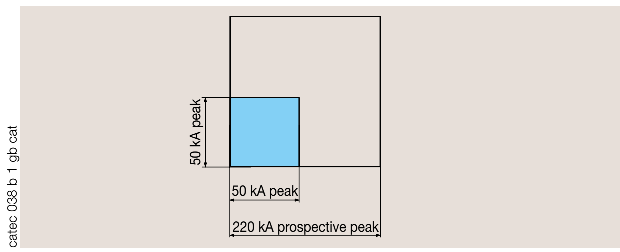


Fig. 2 limiting electrodynamic forces proportional to squared current

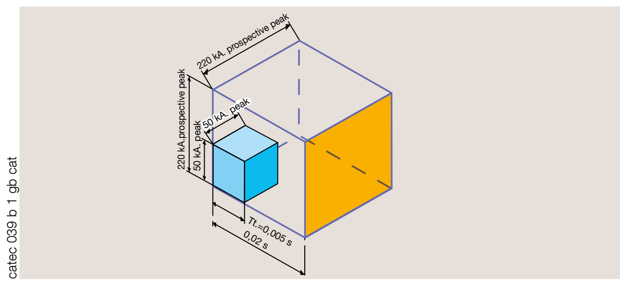


Fig. 3 limiting joule integral I x I x t.

Choosing “gG” and “aM” fuses

Three parameters should be taken into account when selecting a protection system:
- network characteristics,
- installation specifications,
- the circuit characteristics in question.

The calculations given hereafter are for information purposes only. Please contact us for equipment requiring special applications.

Network characteristics

Voltage

A fuse can never be used with an rms voltage above its rated voltage. It operates normally at lower voltages.

Frequency

- f < 5 Hz: the operational voltage (Ue) is considered equivalent to DC voltage and U_e = U peak
- 5 ≤ f < 48 Hz.
- 48 Hz < f ≤ 1000 Hz no voltage de-rating

$$U_e \leq ku \times U_n$$

f (in Hz)	5	10	20	30	40
ku	0.55	0.65	0.78	0.87	0.94

ku voltage de-rating coefficient due to frequency.

Short circuit current

Once established, its values must be checked to ensure they are less than the fuses’ breaking capacity: 120 kA eff.

Installation specifications

Use of a fuse on the neutral *(see page 38)*.

Earthing arrangements

Fuses have one or two protection functions according to the neutral load:
- against overcurrents: (A)
- against indirect contact: B.

Arrangement	Protection
TT	A
IT	A/B
TNC	A/B
TNS	A/B

Circuit characteristics

- Fuse use is limited according to ambient temperature (ta) surrounding the device.

$$I_{th} u \leq Kt \times I_n$$

I_{th} u: operating thermal current: maximum permanent current accepted by the device for 8 hours in specific conditions

I_n: fuse rated current

Kt: coefficient given in table below

	Kt			
	gG fuse		aM Fuse	
ta	Fuse base	Equipment and combination	Fuse base	Equipment and combination
40°C	1	1	1	1
45°C	**1**	**0.95**	**1**	**1**
50°C	0.93	0.90	0.95	0.95
55°C	**0.90**	**0.86**	**0.93**	**0.90**
60°C	0.86	0.83	0.90	0.86
65°C	**0.83**	**0.79**	**0.86**	**0.83**
70°C	0.80	0.76	0.84	0.80

If the fuse is installed in a ventilated enclosure Kt and Kv values must be multiplied.
- Air speed V < 5 m/s Kv = 1 + 0.05 V
- Air speed V ≥ 5 m/s Kv = 1.25

Example: A gG fuse is mounted in a base within a ventilated enclosure
- temperature in the enclosure: 60 °C
- air speed: 2 m/s

Kv = 1 + 0.05 x 2 = 1.1
Kt = 1.1 x 0.86 = 0.95.

Choosing “gG” and “aM” fuses (continued)

Circuit characteristics (continued)

Precautions for use at altitudes > 2000 m

- No current de-rating.
- Breaking capacity is limited: please consult us.
- Size de-rating is recommended.

Upstream of isolating transformer

Switching on an off-load transformer triggers a large current inrush. An aM fuse will be needed at primary coil which is able to withstand repeated overload. The secondary will be protected by gG fuses.

Upstream of motor

Motor protection is usually ensured by thermal relay. The protection of motor power supply conductors is ensured by aM or gG fuses. Table A shows fuse ratings to be linked to thermal relay according to motor power.

Note:
- Motor nominal current varies from one manufacturer to another. Table A shows standard values.
- aM fuses are preferred to gG fuses for this application.
- In cases of frequent or heavy start-up (direct start-up > 7 I_n for more than 2 seconds or start-up > 4 I_n for more than 10 seconds), it is recommended to select a bigger size than that indicated in the table. It will nevertheless be necessary to check to co-ordination of discrimination between the fuse and the circuit breaker (see page 59).
- In cases of aM fuse melting, replacing the fuses on the other two phases is advised.

Table A: protecting motors with aM fuses

Motor						Ratings	Recommended size
400 V			500 V				
Kw	Ch	In A	Kw	Ch	In A		
7.5	10	15.5	11	15	18.4	20	10 x 38 or 14 x 51
11	**15**	**22**	**15**	**20**	**23**	**25**	**10 x 38 or 14 x 51**
15	20	30	18.5	25	28.5	40	14 x 51
18.5	**25**	**37**	**25**	**34**	**39.4**	**40**	**14 x 51**
22	30	44	30	40	45	63	22 x 58
25	**34**	**51**	**40**	**54**	**60**	**63**	**22 x 58**
30	40	60	45	60	65	80	22 x 58
37	**50**	**72**	**51**	**70**	**75**	**100**	**22 x 58**
45	60	85	63	109	89	100	22 x 58
55	**75**	**105**	**80**	**110**	**112**	**125**	**T/00**
75	100	138	110	150	156	160	T/0
90	**125**	**170**	**132**	**180**	**187**	**200**	**T/1**
110	150	205	160	220	220	250	T/1
132	**180**	**245**	**220**	**300**	**310**	**315**	**T/2**
160	218	300				315	T/2
200	**270**	**370**	**250**	**340**	**360**	**400**	**T/2**
250	340	475	335	450	472	500	T/3
315	**430**	**584**	**450**	**610**	**608**	**630**	**T/3**
400	550	750	500	680	680	800	T/4

Upstream of capacitor bank

Fuse rating must be greater than, or equal to, twice the nominal current of the capacitor bank (I_c).

$$I_n \geq 2\, I_c$$

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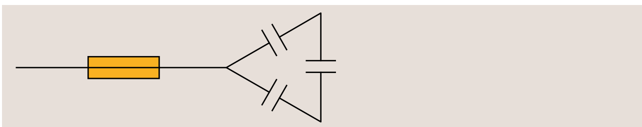

Table B: fuse rating for 400 V capacitor bank

Capacity in Kvar	5	10	20	30	40	50	60	75	100	125	150
gG fuse in A	20	32	63	80	125	160	200	200	250	400	400

Choosing “gG” and “aM” fuses (continued)

Circuit characteristics (continued)

- **Connecting fuses in parallel**
- Connecting fuses in parallel is only possible between two fuses of the same size and rating.

$I_{the} = I'_{the} \times 2$
Total limited peak I_{sc} = limited peak $I'_{sc} \times 1.59$
Total $i^2t = i'^2t \times 2.52$

i^2t: fuse temperature stress

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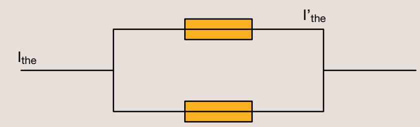


Use in DC

- DC pre-arcing time is identical to AC pre-arcing time. Time/current characteristics and the cut-off current remain valid for the use of fuses in DC. On the other hand, arcing time is much higher in DC because there is no return to 0 voltage
- The heat energy to be absorbed will be much higher than in AC. To maintain the fuse's joule integral, its serviceable voltage needs to be limited.

Maximum voltage	
In AC	In DC
400 V	260 V
500 V	350 V
690 V	450 V

Use of cylindrical gG-type fuses.

Size	Voltage	DC current	Breaking capacity in DC
10 x 38	500 VAC / 250 VDC	16 A	15 kA
14 x 51	500 VAC / 250 VDC	32 A	15 kA
	690 VAC / 440 VDC	32 A	10 kA
22 x 58	500 VAC / 250 VDC	80 A	15 kA
	690 VAC / 440 VDC	80 A	10 kA

Employing bigger fuses than usual is recommended, whereas the rating remains the same; sizes 10 x 38 and 14 x 51 being reserved for circuits ≤ 12 A.
For highly inductive circuits, placing two fuses in series on the + pole is recommended.
For photovoltaic applications, specific PV fuses with adecuate time/breaking capacity characteristics must be used. These fuses are marked with the gPV symbol and must comply with standard IEC 60269-6.
It is not possible to use aM fuses in DC.
The use of high speed fuses is possible for voltages between 450 and 800 VDC: please consult us for specific application.

Fuse protection

Protection of wiring systems against overloads using gG fuses

The Iz column gives the maximum admissible current for each copper and aluminium cable cross section, as per standard NF C 15100 and the guide UTE 15105.
Column F gives the rating of the gG fuse associated with this cross section and type of cable.
Categories B, C, E and F correspond to the different methods of cable installation *(see page 17)*.
Cables are classified in two families: PVC and PR *(see table page 18)*. The figure that follows gives the number of loaded conductors (PVC 3 indicates a cable from the PVC family with 3 loaded conductors: 3 phases or 3 phases + neutral).

Example: a PR3 25 mm2 copper cable installed in category E is limited to 127 A and protected by a 100 A gG fuse.

Category	Admissible (Iz) current and associated protective fuse (F)																	
B	PVC3		PVC3				PR3				PR3							
C			PVC3				PVC3		PR3				PR3					
E					PVC3				PVC3		PR3				PR3			
F							PVC3				PVC3		PR3				PR3	
S mm2																		
Copper	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F	- Iz:	F
1.5	15.5	10	17.5	10	18.5	16	19.5	16	22	16	23	20	24	20	26	20		
2.5	21	16	24	20	25	20	27	20	30	25	31	25	33	25	36	32		
4	28	25	32	25	34	25	36	32	40	32	42	32	45	40	49	40		
6	36	32	41	32	43	40	46	40	51	40	54	50	58	50	63	50		
10	50	40	57	50	60	50	63	50	70	63	75	63	80	63	86	63		
16	68	50	76	63	80	63	85	63	94	80	100	80	107	80	115	100		
25	89	80	96	80	101	80	112	100	119	100	127	100	138	125	149	125	161	125
35	110	100	119	100	126	100	138	125	147	125	158	125	171	125	185	160	200	160
50	134	100	144	125	153	125	168	125	179	160	192	160	207	160	225	200	242	200
70	171	125	184	160	196	160	213	160	229	200	246	200	269	160	289	250	310	250
95	207	160	223	200	238	200	258	200	278	250	298	250	328	250	352	315	377	315
120	239	200	259	200	276	250	299	250	322	250	346	315	382	315	410	315	437	400
150			299	250	319	250	344	315	371	315	399	315	441	400	473	400	504	400
185			341	250	364	315	392	315	424	315	456	400	506	400	542	500	575	500
240			403	315	430	315	461	400	500	400	538	400	599	500	641	500	679	500
300			464	400	497	400	530	400	576	500	621	500	693	630	741	630	783	630
400									656	500	754	630	825	630			840	800
500									749	630	868	800	946	800			1083	1000
630									855	630	1005	800	1088	800			1254	1000
Aluminium																		
2.5	16.5	10	18.5	10	19.5	16	21	16	23	20	24	20	26	20	28	25		
4	22	16	25	20	26	20	28	25	31	25	32	25	35	32	38	32		
6	28	20	32	25	33	25	36	32	39	32	42	32	45	40	49	40		
10	39	32	44	40	46	40	49	40	54	50	58	50	62	50	67	50		
16	53	40	59	50	61	50	66	50	73	63	77	63	84	63	91	80		
25	70	63	73	63	78	63	83	63	90	80	97	80	101	80	108	100	121	100
35	86	80	90	80	96	80	103	80	112	100	120	100	126	100	135	125	150	125
50	104	80	110	100	117	100	125	100	136	125	146	125	154	125	164	125	184	160
70	133	100	140	125	150	125	160	125	174	160	187	160	198	160	211	160	237	200
95	161	125	170	125	183	160	195	160	211	160	227	200	241	200	257	200	289	250
120	188	160	197	160	212	160	226	200	245	200	263	250	280	250	300	250	337	250
150			227	200	245	200	261	200	283	250	304	250	324	250	346	315	389	315
185			259	200	280	250	298	250	323	250	347	315	371	315	397	315	447	400
240			305	250	330	250	352	315	382	315	409	315	439	400	470	400	530	400
300			351	315	381	315	406	315	440	400	471	400	508	400	543	500	613	500
400									526	400	600	500	663	500			740	630
500									610	500	694	630	770	630			856	630
630									711	630	808	630	899	800			996	800

Fuse protection of wiring systems

Maximum length of conductors protected by fuses

Tables A and B indicate maximum lengths in the following conditions:

- 230 / 400 V three-phase circuit
- contact line neutral section = phases section,
- minimal short-circuit current,
- copper conductors.

These tables are valid whatever the cable insulation (PVC, PR, EPR). When two values are given, the first corresponds to PVC cables and the second to PR/EPR cables.
The lengths must be multiplied by the coefficients in table C for the other loads.
For aluminium cable: multiply the lengths in the tables by 0.41.

Table A: maximum cable lengths in m protected by gG fuses.

S (mm^2) \ HP C	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	9/12	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	45/74	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

Table B: maximum cable lengths in m protected by aM fuses.

S (mm^2) \ HP C	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						
25								135	108	86	67	47/54	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	58/60	38/45	25/30	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	51
240																	123	97	78	62

Table C: corrective coefficients for other networks

Uses	Coefficient
Neutral section = 0.5 x phase section	0.67
Circuit without neutral	1.73

(1) Entry to the table is through the phase section.

Fuse protection against indirect contacts

Maximum length of conductors protected by fuses

The length of conductors protected against indirect contacts must be limited.
Tables B and C give a direct reading of the maximum lengths of copper conductors. They are determined in the following conditions:

- 230 / 400 V network,
- TN load,
- maximum contact voltage $U_L = 50$ V,
- $\frac{\text{Ø ph}}{\text{Ø PE}} = m = 1.$

For other uses, the value read in tables B and C must be multiplied by the coefficient in table A.

Table A

		Correction coefficient
Aluminium conductor		0.625
Neutral cross section (PE) = 1/2 phase cross section (m = 2)		0.67
IT load	without neutral	0.86
	with neutral	0.5
Breaking time 5s admissible. (distribution circuit)	for wiring systems protected with gG fuses	1.88
	for wiring systems protected with aM fuses	1.53

Table B: maximum lengths (in m) of conductors protected by gG fuses (rated in A)

S (mm²) \ (A)	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
1.5	53	40	32	22	18	13	11	7	8	4	3									
2.5	88	66	53	36	31	21	18	12	9	7	6	4								
4	141	106	85	58	49	33	29	19	15	11	9	6	6	4						
6	212	159	127	87	73	50	43	29	22	16	14	10	8	6	4					
10	353	265	212	145	122	84	72	48	37	28	23	16	14	10	7	6	4			
16	566	424	339	231	196	134	116	77	59	43	36	25	22	15	12	9	7	5	4	
25	884	663	530	361	306	209	181	120	92	67	57	40	35	24	18	14	11	8	6	4
35		928	742	506	428	293	253	169	129	94	80	56	48	34	26	20	15	11	9	6
50				687	581	398	343	229	176	128	108	76	66	46	35	27	20	15	12	8
70					856	586	506	337	259	189	159	11	97	67	52	39	30	22	17	11
95						795	687	458	351	256	216	151	131	92	70	53	41	29	23	16
120							868	578	444	323	273	191	166	116	89	67	62	37	23	20
150								615	472	343	290	203	178	123	94	71	54	39	31	21
185								714	547	399	336	235	205	145	110	82	64	46	36	24
240									666	485	409	286	249	173	133	100	77	55	44	29
300										566	477	334	290	202	155	117	90	65	51	34

Table C: maximum lengths (in m) of conductors protected by aM fuses (rated in A)

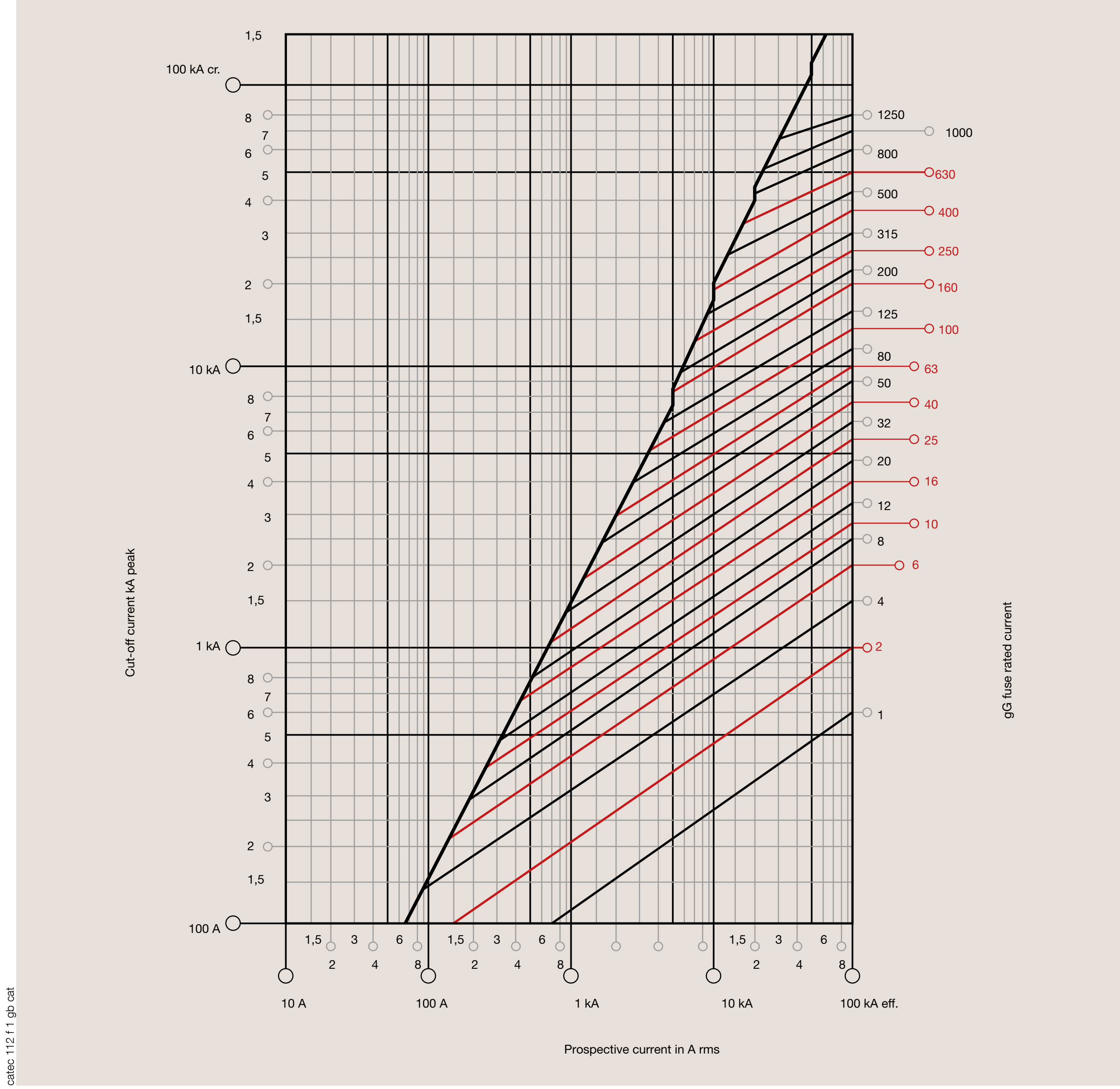
S (mm²) \ (A)	16	20	25	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250
1.5	28	23	18	14	11	9	7	6	5	4										
2.5	47	38	30	24	19	15	12	9	8	6	5									
4	75	60	48	38	30	24	19	15	12	10	8		6	5	4					
6	113	90	72	57	45	36	29	23	18	14	11	9	7	6	5	4				
10	188	151	121	94	75	60	48	38	30	24	19	15	12	10	8	6	5	4		
16	301	241	193	151	121	96	77	60	48	39	30	24	19	15	12	10	8	6	5	4
25	470	377	302	236	188	151	120	94	75	60	47	38	30	24	19	16	12	9	8	6
35	658	527	422	330	264	211	167	132	105	84	66	53	42	33	26	21	17	13	11	8
50	891	714	572	447	357	285	227	179	144	115	90	72	57	46	36	29	23	18	14	11
70			845	660	527	422	335	264	211	169	132	105	84	67	53	42	33	26	21	17
95				895	716	572	454	358	286	229	179	143	115	91	72	57	45	36	29	23
120					904	723	574	462	362	289	226	181	145	115	90	72	57	45	36	29
150						794	630	496	397	317	248	198	159	126	99	79	63	50	40	32
185							744	586	469	375	293	234	188	149	117	94	74	59	47	38
240								730	584	467	365	292	234	185	146	117	93	73	58	47
300									702	562	439	351	281	223	175	140	11	88	70	56

Example: a circuit consists of a 3 x 6 mm² copper cable and is protected by a 40 A gG fuse. Its length must be less than 73 m so that protection against indirect contact is guaranteed in TN 230 V/400 V.

- if the cable is an aluminium one, maximum length is: 0.625 x 73 m = 45.6 m
- in IT load with neutral and an aluminium cable, the length is: 0.625 x 0.5 x 73 m = 22.8 m
- in IT load with neutral and an aluminium cable for supplying a section enclosure, the length is: 0.625 x 0.5 x 1.88 = 42.8 m.

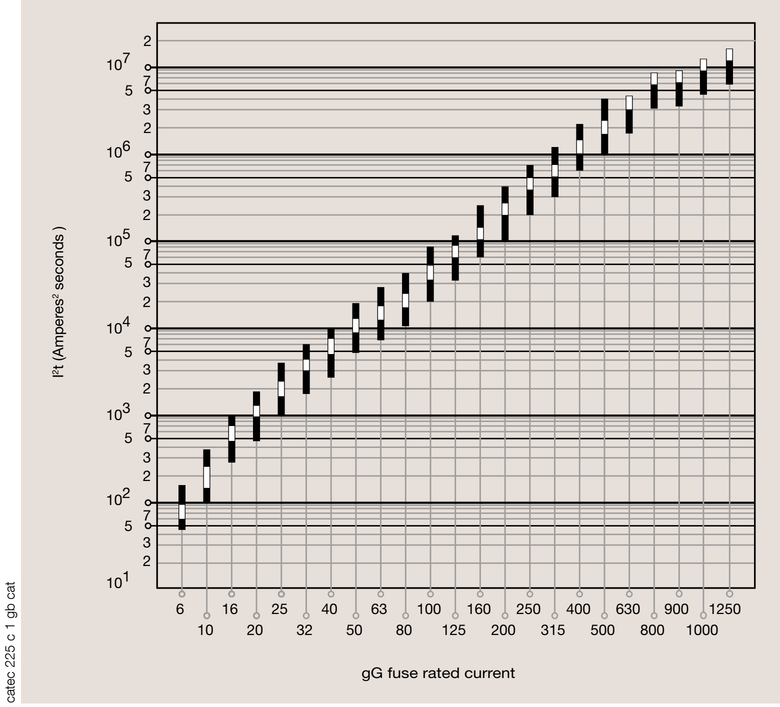
Characteristic curvesof NF and NH "gG" fuses

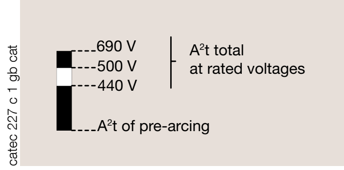
Cut-off current diagram



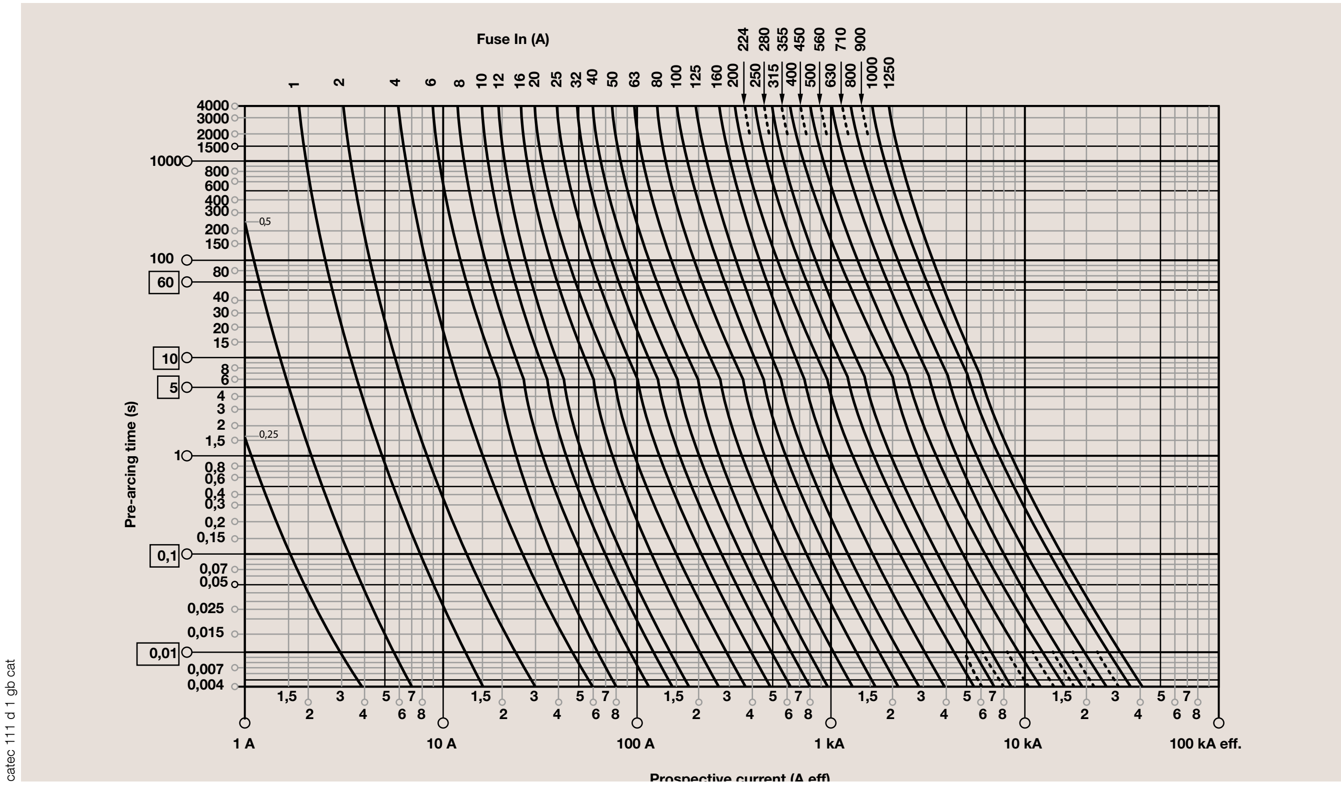
Characteristic curves of NF and NH "gG" fuses (continued)

Diagram of thermal constraint limitation



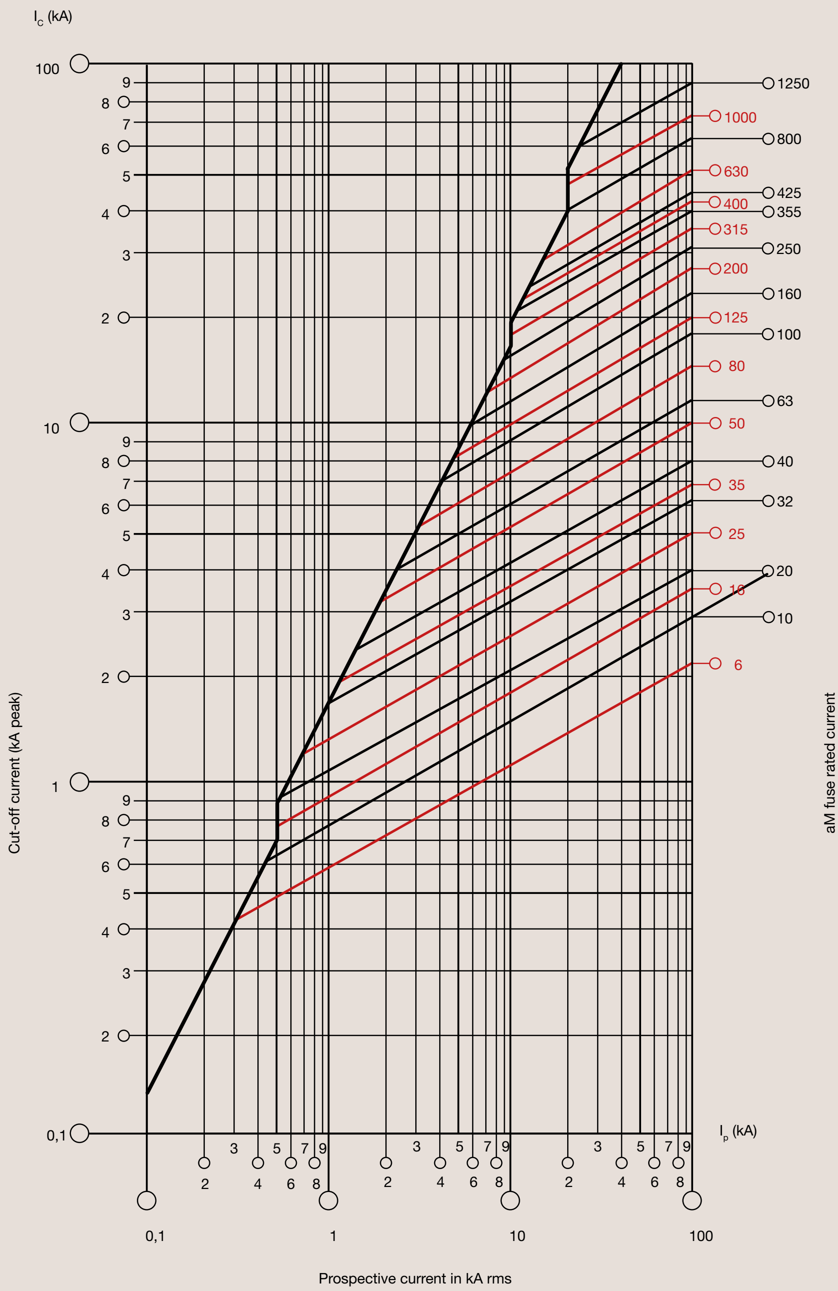


Time/current operation characteristics



Characteristic curves of NF and NH "aM" fuses

Cut-off current diagram



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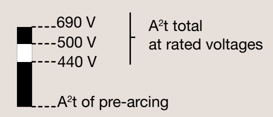
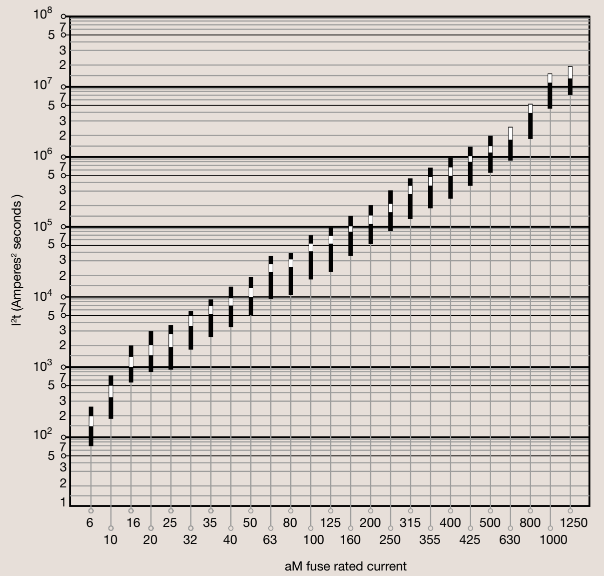
Characteristic curves of NF and NH "aM" fuses (continued)

Diagram of thermal constraint limitation



catec 227 c 1 gb cat

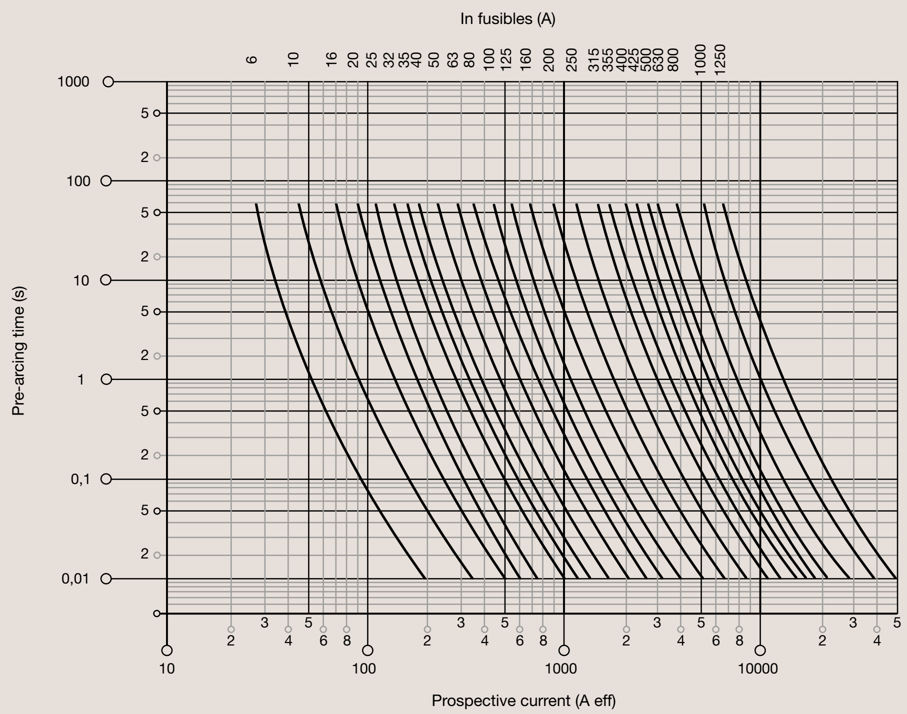


catec 226 c 1 gb cat

Power dissipation with striker (W)

Rated operational currents	Fuse size						
In (A)	000	00	0 / 0S	1	2	3	4
6	0.33		0.42				
10	0.52		0.67				
16	0.81		0.98				
20	0.92		1.04				
25	1.08		1.17				
32	1.42		1.67				
35	1.58		1.72				
40	1.68		1.91				
50		2.28	2.51				
63		2.9	3.35	3.2			
80		4.19	4.93	4.6			
100		5.09	5.72	5.7			
125		6.29	7.30	6.98	7.6		
160		7.73	9.50	9.2	9.7		
200			12.3	13.7	13.9		
224				14.0	14.0		
250				15.3	17.0		
315					26.0	20.6	18.8
355					25.2	23.9	
400					29.3	26.5	23.5
425						28.3	
500						35.8	34
630						56.9	49
800							70
1000							80
1250							108

Time/current operation characteristics



catec 113 d 1 gb cat

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Choosing “high speed” fuses

These ultra fast fuses ensure protection against short circuit currents. Due to their design, total operation time is much faster than gG and aM fuses.
They are generally used for power semiconductors (i^2t UR < i^2t of the semiconductor to be protected).
Overloading (I ~ 2 In, t ≥ 100 seconds) must be avoided. If necessary, protecting against overloads must be ensured by another device.
High speed fuse determination involves a rigorous procedure which can be complex for certain applications. The method below represents a first step.
Please consult us for any specific application.

Temperature stress

High speed fuses are designed to protect semiconductor devices. Each semiconductor device has a specified maximum I^2t, and this is the most important factor to be considered when choosing the correct fuse, rather than the thermal rating. For effective protection, the fuse I^2t must be about 20% less than the semiconductor’s rupturing I^2t.
Example: a 30A/400 V diode withstands a maximum I^2t of 610 A2s.
The associated high speed fuse's maximum I^2t will be 610 - 20 % = 488 A^2s with 400 V.

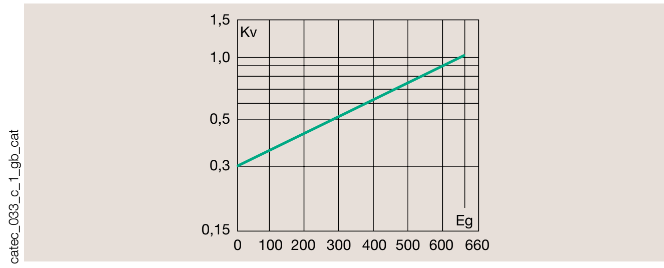
Voltage

I^2t (see general catalogue) is usually given for 660 V. Use with a different voltage requires the following correction:

$$(i^2t)\ V = Kv \times (i^2t)\ 660\ V$$

Kv: I^2t correction factor
Eg: operating voltage rms value

Example: for U = 400 V and Kv = 0.6
(i^2t) 400 V = 0.6 x (i^2t) 660 V]



Kv correction factor

Power factor

The I^2t indicated in the chapter under "LV Switchgear" is given for a power factor of 0.15 φ (cos. * of default circuit). For other power factor values, multiplying the I^2t value by Ky value is necessary.

Power factor	0.1	0.15	0.2	0.25	0.30	0.35	0.40	0.45	0.50
Ky	1.04	1.00	0.97	0.93	0.90	0.87	0.85	0.82	0.81

Nominal current

Once the fuse’s maximum I^2t has been established, the circuit’s nominal current value must then be taken into account.

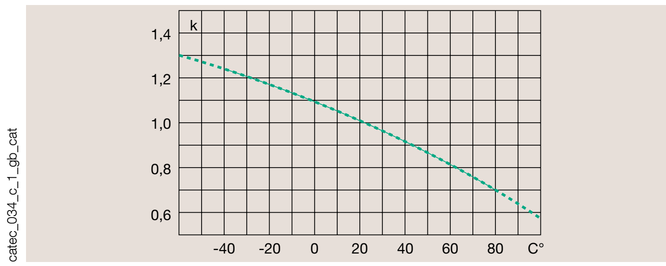
Example: in the previous example, the high speed fuse’s maximum I^2t was established thus: 488 A2s at 400 V.
At 660 V, this value is worth: 488/0.6 = 813 A2s.
The circuit current is 20 A. Note that with a 25 A high speed fuse where I^2t is at 660 V, the value is 560 A2s.

Correction according to ambient temperature

High speed fuse rating is given for an ambient temperature of 20 °C.
Maximum operating current I_b is given by:

$$I_b = K_{TUR} \times (1 + 0.05\ v) \times I_n$$

I_n: fuse’s rated current in A
v :speed of cooling air in m/s
K_{TUR} : value given by the figure below according to air temperature in fuse proximity



K_{TUR} correction factor

Fuse protection

Choosing “high speed” fuses (continued)

Series connection

This is not recommended when the fault current is insufficient to melt the fuse in less than 10 ms.

Parallel connection

Placing fuses in parallel is possible between two fuses of the same size and rating. This is usually carried out by the manufacturer.
In cases of parallel connection, care must be taken that the operating voltage does not exceed 90% of the fuse’s nominal voltage.

Cyclic overload

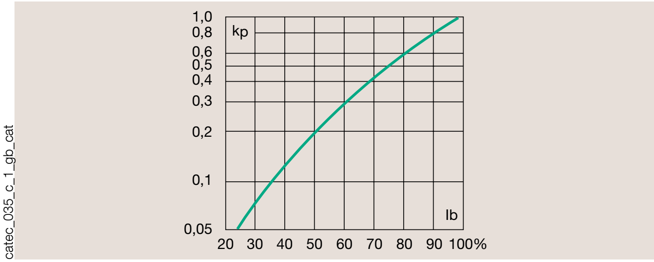
Please consult us.

Loss in Watts

- These are given in the "LV Switchgear" section and correspond to power loss with nominal current.
- To use an I_b current different from I_n, the loss in Watts must be multiplied by the K_p value given in the figure opposite.

K_p: loss correction value

- I_b: load current rms value in% of nominal current.

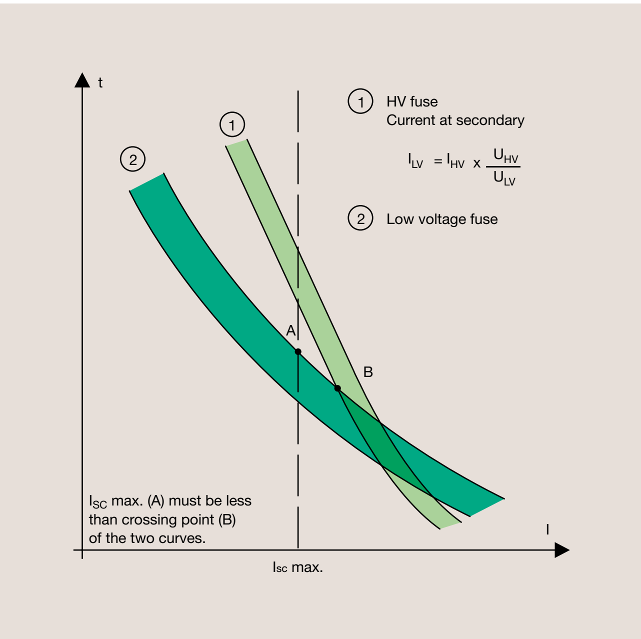


K_p correction factor

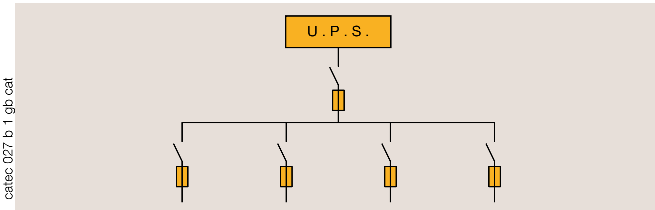
Discrimination

Discrimination between HV and LV fuses

- Operating an LV fuse must not result in melting of the HV fuse placed at the HV/LV transformer primary.
- In order to avoid this, it is necessary to check that the lower part of HV curve never crosses the upper part of the LV curve before the LV I_{sc} maximum limit *(see calculation on page 23).*



Discrimination on a network powered by UPS (Uninterruptible Power Supply)



Protection device discrimination is highly important on networks powered by UPS, where protection tripping must not cause any disturbance on the rest of the network.
Discrimination must take into account two properties of these networks:

- low fault current (approx. 2 x I_n),
- maximum fault time generally set at: 10 ms

To comply with these criteria and ensure correct discrimination, the current in each branch must not exceed the values in the table below:

Protection by	Max. starting current
gG fuse	$\frac{I_n}{6}$
High speed fuse	$\frac{I_n}{3}$
Small circuit breakers	$\frac{I_n}{8}$

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Discrimination (continued)

Discrimination between fuse and overcurrent switch

The fuse is placed upstream of the overcurrent switch. An overcurrent switch consists of a contactor and a thermal relay.
The curves of fuses linked to the overcurrent switch must pass through points A and B corresponding to:

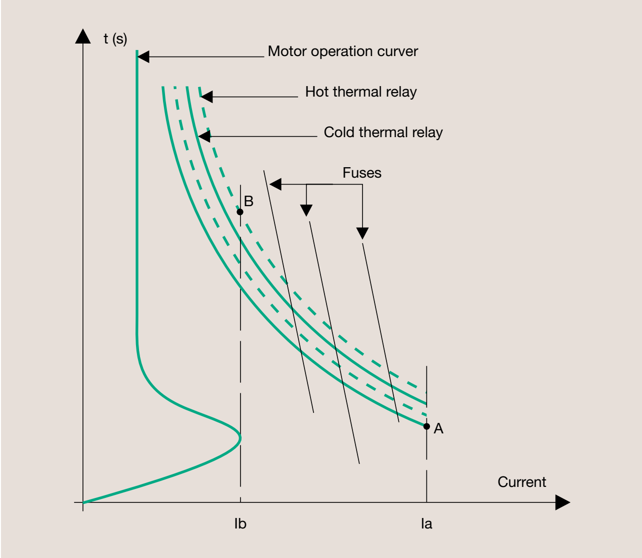
- I_a: overcurrent switch's breaking capacity
- - I_b: motor start-up current

Start-up type	I_b (1)	Start-up time(1)
direct	8 I_n	0.5 to 3 sec.
Star delta	2.5 I_n	3 to 6 sec.
Self-transformer	1.5 to 4 I_n	7 to 12 sec.
Rotor start	2.5 I_n	2.5 à 5 sec.

(1) Average values may vary considerably according to the type of motor and relECver.

The fuse's temperature stress must be less than that of the overcurrent switch.
Amongst the different fuse ratings available, choose the highest rating in order to minimise power dissipation.

catec 029 b 1 gb cat



Discrimination between circuit breaker and fuse

The judicious combination of a fuse with other devices (circuit breakers, etc.) provides perfect discrimination and offers optimum economy and safety.

Fuse upstream – circuit breaker downstream

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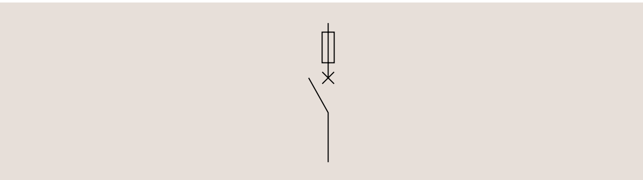

- The fuse's pre-arcing melting curve must be placed above point A (fig. 1).
- The fuse's complete blowing curve must cut the circuit breaker's curve before the circuit breaker's I_{sc} value (ultimate breaking capacity).
- After the crossover point, the fuse's I^2t must be less than that of the circuit breaker.
- The fuse's and circuit breaker's I^2t must always be less than that of the cable.

catec 024 b 1 gb cata

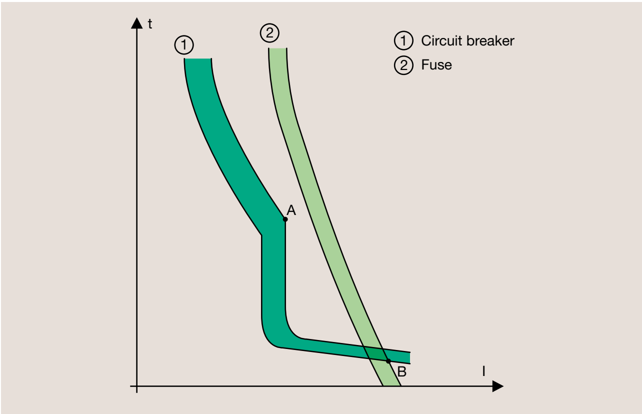

Fig. 1

gG fuse upstream – several circuit breakers downstream

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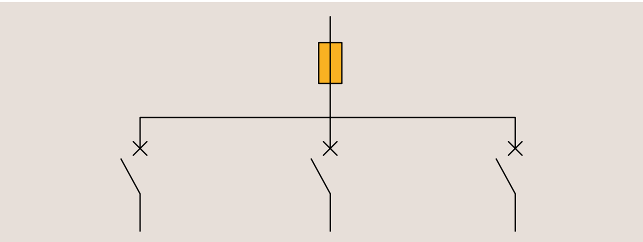
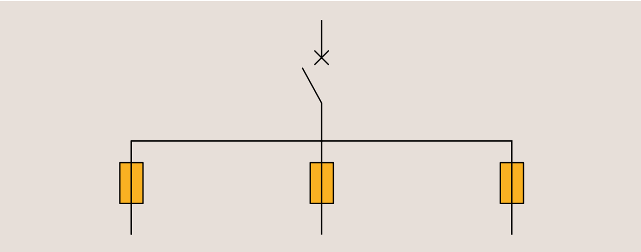


- Fuse rating must be greater than the sum of circuit breaker currents simultaneously on load.
- Fuse blowing curve must be above point A of the circuit breaker with the highest rating (see fig. 1).
- Crossover point B (see fig. 1) must be less than the circuit breakers' lowest ultimate breaking capacity.
- After point B, the fuse's total I^2t must be less than any upstream circuit breaker's I^2t.

Discrimination (continued)

Discrimination between circuit breaker and fuse (continued)

Circuit breaker upstream – several fuses downstream



- The breaking capacity of all fuses and circuit breakers must be greater than maximum short circuit current possible in the circuit.
- The thermal setting of the circuit breaker (FI_r) must be such that: $1.05\ I_r \geq I_1 + I_2 + \ldots I_n$.
  $I_1 + I_2 + \ldots I_n$: sum of currents protected by fuse in each branch.

Ir current setting must also meet the following condition:

$$I_r \geq Kd \times I_n$$

I_n: fuse rating of the circuit with the highest load.

Table A: Kd values (according to IEC 60269-2-1)

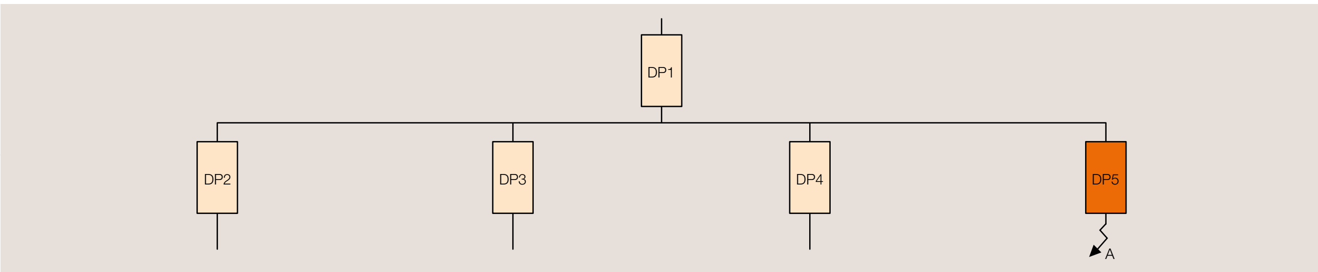
gG Fuse rating (In) (A)	Kd
4 In	2.1
4 < In < 16	1.9
16 In	1.6

Example: the circuit with the highest load is protected by a 100 A gG fuse. The upstream circuit breaker's minimum setting current enabling fuse discrimination will be: $I_r \geq 1.6 \times 100\ A = 160\ A$.

- The highest rated fuse's I^2t must be less than the I^2t limited by circuit breaker. The latter must be less than the cables' maximum <F>I^2t.
- Im (magnetic) minimum setting value: 8 Kd ≤ Im ≤ 12 Kd.
  Kd is given in table A.

General points

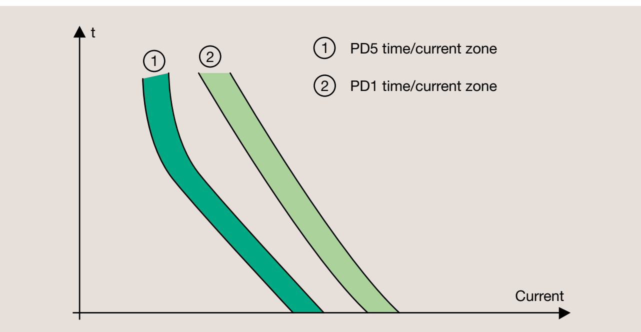
In cases of fault on any installation point, protection discrimination is ensured when the protection device (PD) opens directly upstream of the fault, without triggering the breaking of other devices in the entire installation. Discrimination permits continuous operation on the rest of the network.



a fault at point A must trigger the breaking of the protection device PD5 without breaking any other PD

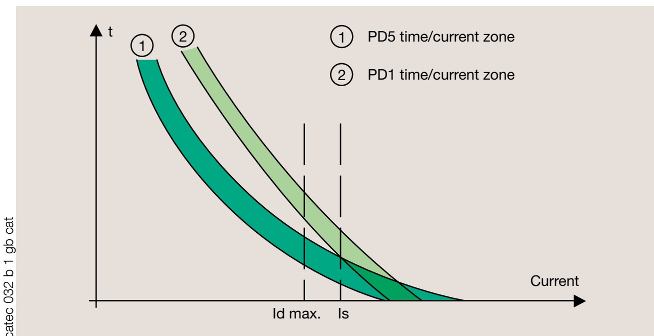
Total discrimination

Total discrimination is ensured when time/current zones characterising protection devices do not overlap.



Partial discrimination

Partial discrimination consists of limiting the PD discrimination in one part only of their time/current zone. Where the default current is less than the curves' crossover points, the result is total discrimination.



Discrimination is n the installation's maximum fault current (I_{sc} max) is limited to I_d max and I_d max < I_s.

Discrimination (continued)

Discrimination between fuses

gG and aM fuses discrimination

Total discrimination is ensured by choosing fuses in tables A and B (according to IEC 60269 -1 and 60269 -2 -1).
However, in certain uses partial discrimination may suffice.

Table A

Upstream fuse	Downstream fuse	
gG	gG	aM
Rating (A)		
4	1	1
6	2	1
8	2	2
10	4	2
12	4	2
16	6	4
20		6
25	10	8
32	16	10
40	20	12
50	25	16
63	32	20
80	40	25
100	50	32
125	63	40
160	80	63
200	100	80
250	125	125
315	160	125
400	200	160
500	315	200
630	400	250
800	500	315
1000	630	400
1250	800	500

Table B

Upstream fuse	Downstream fuse	
aM	gG	aM
Rating (A)		
4	4	2
6	6	2
8	8	4
10	10	6
12	4	2
16	16	10
20	20	12
25	25	12
32	32	20
40	32	25
50	40	25
63	50	40
80	63	50
100	80	63
125	100	80
160	125	100
200	160	125
250	160	160
315	200	200
400	250	250
500	315	315
630	400	400
800	500	500
1000	500	630
1250	630	800

gG/High speed fuses discrimination

- gG upstream - High speed downstream
  High speed fuse’s pre-arcing time must be less than half of the gG fuse's pre-arcing time, between 0.1 and 1 second.
- UR upstream - gG downstream
  High speed fuse rating must be at least equal to 3 times the rating of the gG fuse.

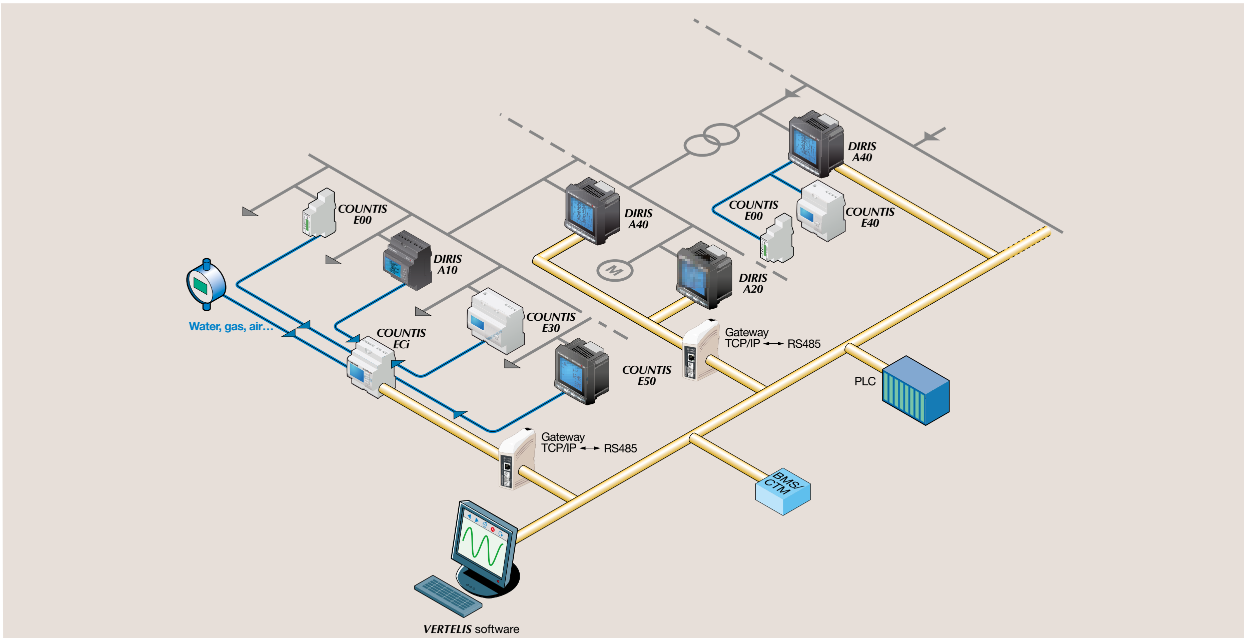
Control and energy management

Introduction

Unlike the last decade, we are entering a period where managing energy has become an obligation for both environmental and economical reasons. Energy costs have increased considerably and have a direct impact on product cost price and running costs. This new approach requires in-depth knowledge of processes, company working methods and controlling energy costs that are calculated based on a price or tariff structure. This allows for energy costs to be calculated according to periods of use, knowing that consumers will have a supply contract whose cost will be a function of the installation's power. In order to optimise price structure, the consumer will need to accurately estimate their energy requirements in order to implement the most suitable price structure. In certain cases, it will be preferable to have a few power overshoots rather than have an excessive power supply contract.

Tariff meter

To help optimise price structure and consumption, the consumer should deploy energy meters (COUNTIS type) or energy measuring units (DIRIS type) at strategic points around the electrical installation (transformer, motors etc.). Such equipment will be connected to a communication network (see § communication) to centralise and manage consumption via a supervision software package.



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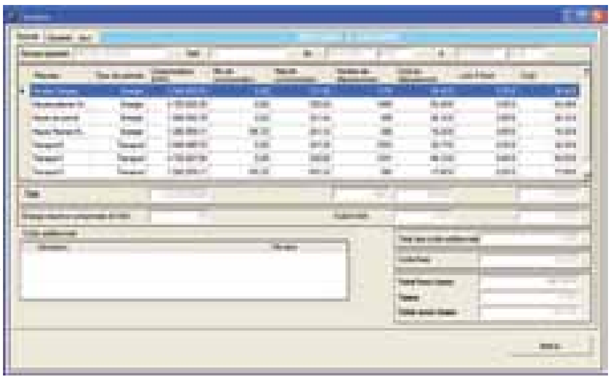
With such equipment in place, the consumer can implement actions for the following:

- load shedding on heating or lighting circuits to avoid paying excess violation penalties on subscribed power demand during peak hours,
- anticipate the start-up of certain machines in off-peak periods before the arrival of personnel,
- optimise and improve the use of PLCs, energy sources or even the operating of production resources.

In all cases, such equipment is perfectly suited to commercial applications (lighting, air conditioning, etc.) as well as industrial. They are particularly advantageous due to their accuracy in measuring currents and voltages and in calculating energy consumption.



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Measurement of electric variables

Measurement principle

Whatever the AC network (single, two and three-phase with or without neutral), it is essential to measure currents and voltages. Data concerning the current is taken from the network by current transformer (CT), taking care of the correct connecting to avoid any measurement errors. Voltage is taken directly from the network or via voltage transformer (VT), especially for MV and LV networks.

Below are the formulas used to calculate the following:

Currents

$$I1 = i1_{TRMS} \times kTC$$

(kCT being the current transformer ratio)

i1. i2. i3 are calculated directly in TRMS by integrating harmonics up to number 51.

And

$$Isyst = \frac{i1 + i2 + i3}{3}$$

Voltages

$$V1 = v1_{TRMS} \times kPT$$

(kVT being the voltage transformer ratio)

v1. v2. v3 are calculated directly in TRMS by integrating harmonics up to number 51.

And

$$Vsyst = \frac{i1 + i2 + i3}{3}$$

Active power

$$P = \frac{1}{T} \int_0^T [v1 \times i1]\, dt$$

P1. P2 and P3 are calculated directly from I and V TRMS values.

And

$$\sum P = P1 + P2 + P3$$

Apparent power

$$S1 = V1 \times I1$$

S1. P2 and P3 are calculated directly from I and V TRMS values.

And

$$\sum S = S1 + S2 + S3$$

Reactive power

$$Q1 = \sqrt{S1^2 - P1^2}$$

Q1. Q2 and Q3 are calculated directly from P and S.

And

$$\sum Q = Q1 + Q2 + Q3$$

Power factor

$$PF = \frac{P}{S}$$

PF1. PF2 and PF3 are calculated directly from P and S.

Frequency

Measuring frequency is always done on phase 1.

Energy metering

All electrical systems using AC current have two forms of power: active power (kWh) and reactive power (kvarh). In industrial processes using electricity, only the production tool's active power is converted into mechanical, heat or light energy. It can be positive or negative if the installation can produce kWh (for example, a photovoltaic installation).

Reactive energy, on the other hand, is mainly used in the magnetic circuits of electrical machines (motors, autotransformers, etc.). Moreover, certain components in transport and distribution electrical networks (transformers, lines, etc.) in certain cases also consume reactive power. To monitor these forms of power it is essential to take into account the accuracy classes in accordance with the relevant standards. The reference framework is the following:

Active energy meter (kWh):
- IEC 62053-21 class 1 or 2.
- IEC 62053-22 class 0.2S or 0.5S.

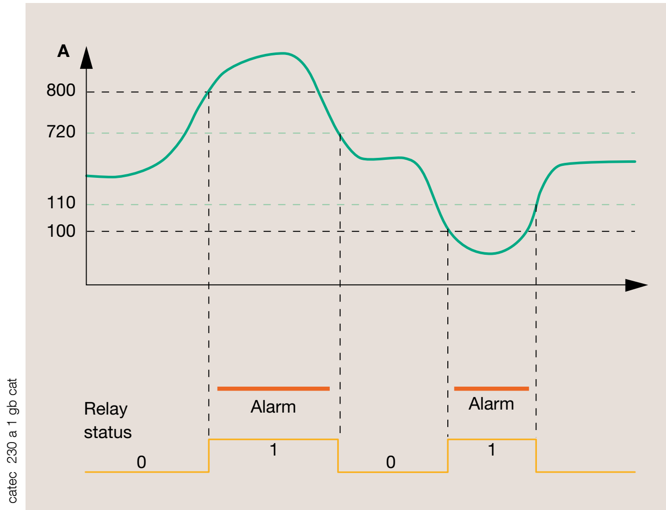
Reactive energy meter (kvarh): IEC 62053-23 class 2.

Control and energy management

Monitoring

This function ensures the monitoring of the main electric variables for:
- machine protection,
- voltage interruptions,
- abnormal transformer and feeder overloads,
- motor fractional load (belt rupturing, operating off-load, etc.).

The following must be programmed for each alarm:
- upper threshold > high trigger value,
- lower threshold > low trigger value,
- hysteresis > return to normal condition value,
- relay > break state in NO / NC,
- time delay > time delay for triggering the relay.



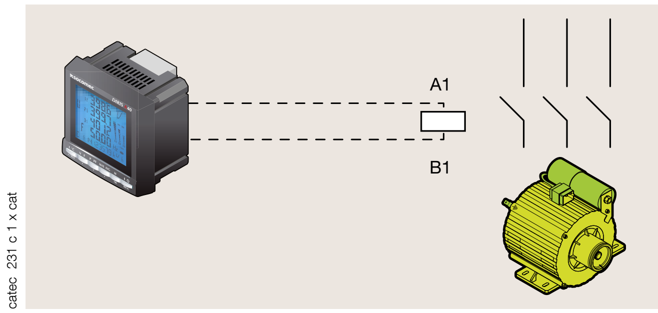
Application example:
Configuration of a relay monitoring currents with tripping if I < 100 A and I > 800 A. With a hysteresis of 10% for the relay's default status, a relay break state in NO is without time delay.

Control unit

Using a serial link directly connected to a PC or other control system (PLC, etc.), this function enables the following:

Via logical inputs:
- to count impulses from electricity, water or gas meters,
- to count the number of operations or to check the position of a protection device or changeover switch.

Via relay outputs:
- to remote control a protective tripping device's change of status,
- to remote control a motor start-up or strip light,
- to shed load on parts of an electrical distribution system.



Example:
Changing a relay's break state to control start-up of a motor.

Power quality *(see page 7)*

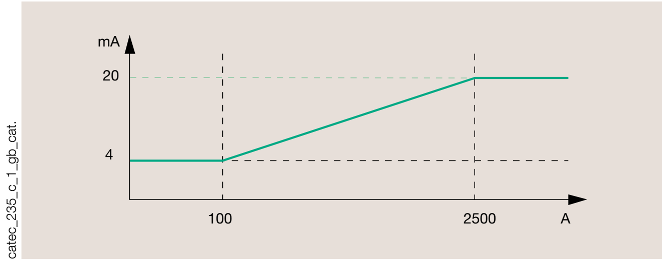
Industrial communication networks

Analogue communication

This function provides a measurement image from a PLC or other system in the form of a 0-20 mA or 4-20 mA signal.

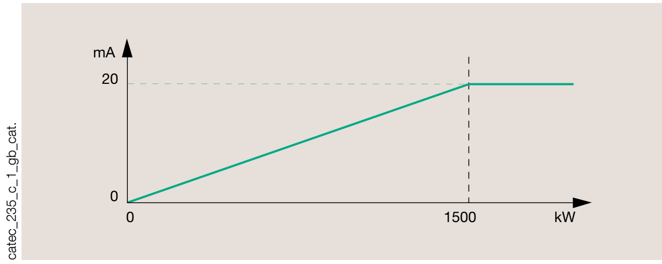
Example 1

Configuration of a current output with 100A to 4mA and 2500 A to 20mA.



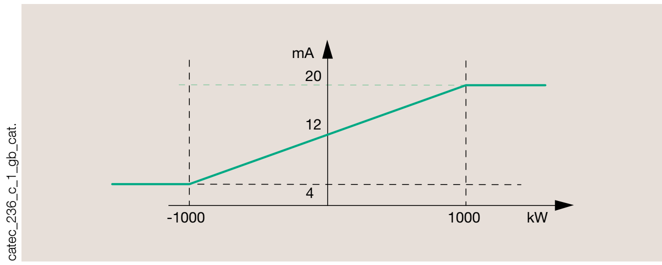
Example 2

Configuration of a total active power output SP with 0 kW to 0 mA and 1 500 kW to 20 mA.



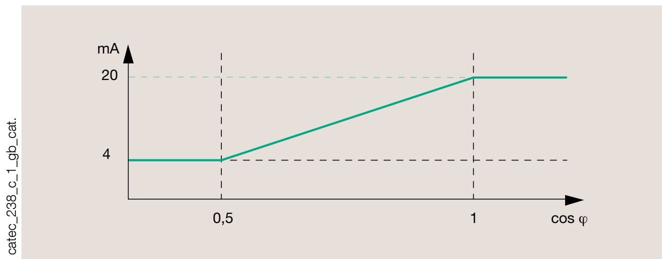
Example 3

Configuration of a total active power output SP with -1 000 kW to 4 mA and 1 000 kW to 20 mA.



Example 4

Configuration of an inductive power factor output SPFL with 0.5 to 4 mA and 1 to 20 mA.



Digital communication

Introduction

A communication network interconnects a certain number of devices in order to exchange information in terms of measurements, metering, commands or even to programme them with a PC or PLC.
Communication between several devices requires a common structure and language: this is known as the protocol.

OSI (Open Systems Interconnection) layers

Each type of link has its own protocol defined by standards. However, all the protocols are sub-divided into seven levels called OSI layers. Each layer receives elementary information from the lower layer, processes it, and then supplies more elaborated information to the upper layer.

Our products use layers 1. 2 and 7

Station 1		Station 2
7 Application Layer	⇔	Application Layer 7
6 Presentation Layer	⇔	Presentation Layer 6
5 Session Layer	⇔	Session Layer 5
4 Transport Layer	⇔	Transport Layer 4
3 Network Layer	⇔	Network Layer 3
2 Data Link Layer	⇔	Data Link Layer 2
1 Physical Layer	⇔	Physical Layer 1

Layer 1 - Physical Layer

This is the layer specific to the network's "piping". It enables a binary signal to be converted into a signal that is compatible with the chosen physical medium (copper, optical fibre, RF, etc.). The layer provides the tools for transmitting the bits to the layer above, which will use them irregardless of the medium used.

Layer 2 - Data Link Layer

This layer controls the transmission of data. A frame must be sent or received whilst correcting possible errors that may occur on the line. Control is done based on a set of bits (frame), by means of a "checksum". The layer provides the tools for transmitting the bits (frames) to the layer above. The transmissions are "guaranteed" by validity check mechanisms.

Layer 7 - Application

The role of the application layer is to provide an interface between the user and the network, therefore supporting application and end-user processes.

Transmitted information

The signal sent from one device to another is a binary element called a bit. Each type of digital link defines an analog level (voltage level) for the O and 1 logic. The information is encoded as a set of bits which form the communication frame.

Communication medium

This communication frame will pass from one point to another on the bus via a channel called the "communication medium". Depending on the technology chosen, the medium can be a pair of copper wires, an Ethernet link, coaxial cable, optical fibre, an RTC or GSM telephone link, or even radio waves. The medium depends on the chosen transmission type and the environment.

Protocols

The communication protocol defines the language rules between the various devices so that each uses the same rules for dialogue comprehension. In certain cases, it also secures the dialogue by defining how the frames are checked, such as CRC (Cyclic Redundancy Check).
CAN, PROFIBUS DP, Interbus-S, FIP, EIB, eBUS, MODBUS/JBUS, Open MODBUS or TCP-IP are numerous protocols each having their own advantages and drawbacks depending on the environment and the conditions in which they are to be used.
The SOCOMEC range of communication products mainly use the JBUS/MODBUS and PROFIBUS DP protocols. However, as will be seen later, we can also respond to other protocols such as TCP-IP, for example.

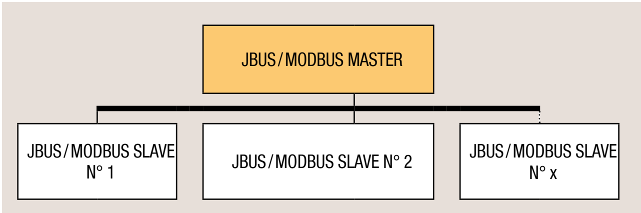
JBUS / MODBUS protocol

Presentation

JBUS (manufactured by April) and MODBUS (manufactured by Modicon) are dialogue protocols that create a hierarchical structure (a master plus several slaves).
JBUS / MODBUS can communicate in ASCII 7 bits or in RTU (Remote Terminal Unit) binary 8 bits.
The advantage of RTU mode is that to information to be transmitted takes less space and is therefore quicker. In fact, information is sent more in 8 bits than 7 bits.
The SOCOMEC products with JBUS / MODBUS protocol communicate in RTU mode (Remote Terminal Unit). This type of protocol allows the master to interrogate one or more intelligent slaves. A multipoint connection links the master to the slaves.
MODBUS / RTU is a secured protocol based on a CRC calculation (Cyclical Redundancy Check). The CRC is calculated on 16 bits and is an integral part of the message which is verified by the recipient.
The master-slave dialogue operates according to 2 principles:
- the master interrogates a slave and waits for its answer,
- the master interrogates all the slaves without waiting for their answers (general transmission principle).

The master manages all the exchanges and it alone has the initiative. The master repeats the question should there be an erroneous exchange and decrees that the slave is absent if there is no reply once the time-out period has elapsed. There can only be one emitting device at a time on the line. No slave can transmit a message without having been invited to do so by the master. All lateral communications (slave-to-slave) exist only if the master's software is designed to receive information and to send it back from one slave to the other.

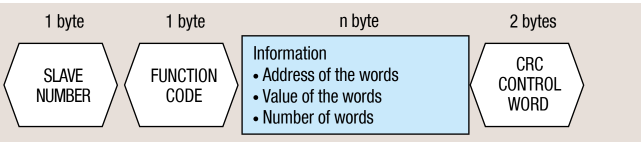
The master can address 247 slaves recognised as slave N° 1 up to slave N° 247. When the master uses the number of slave 0. this indicates a transmission to all the slaves (writing only). JBUS and MODBUS protocols enable access to the devices connected on the same cable.



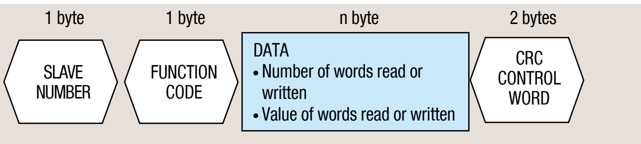
Communication frame structure

A communication frame consists of a succession of bytes that form the message, with each byte comprising 8 bits. Information can be stored in 1 byte, 1 word (2 bytes), even a double word (4 bytes).

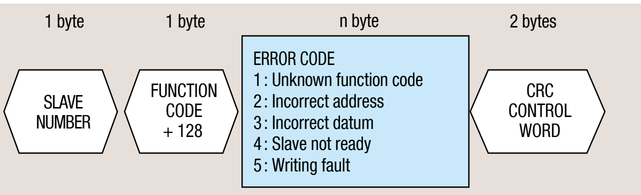
To initiate dialogue the master must send a **request frame** whose structure is the following:



The interrogated slave then responds to the request via **a response frame** whose structure is the following:



Should there be an error in the frame transmitted by the master, the slave responds by **an error frame** whose structure is the following:



JBUS / MODBUS protocol (continued)

Examples of communication frames

All SOCOMEC products are provided with instructions containing their JBUS / MODBUS tables. The tables show the address where the data is stored as well as its format (data size and signed or not type).

Information reading (function 3)

Table of values allocated current and voltage transformation ratios in 2 words

Dec. address.	Hex. address.	Number of words	Designation	Unit
50514	C552	2	Phase-phase voltage U12	V / 100
50516	**C554**	**2**	**Phase-phase voltage U23**	**V / 100**
50518	C556	2	Phase-phase voltage U31	V / 100
50520	**C558**	**2**	**Phase to neutral voltage phase 1**	**V / 100**
50522	C55A	2	Phase to neutral voltage phase 2	V / 100
50524	**C55C**	**2**	**Phase to neutral voltage phase 3**	**V / 100**
50526	C55E	2	Frequency	Hz / 100
50528	**C560**	**2**	Current phase 1	mA
50530	C562	2	**Current phase 2**	**mA**
50532	**C564**	**2**	Current phase 3	mA
50534	C566	2	**Neutral current**	**mA**
50536	**C568**	**2**	**S active power + / -**	**100 kW**
50538	C56A	2	S reactive power + / -	kvar / 100
50540	**C56C**	**2**	**S apparent power + / -**	**100kVA**
50542	C56E	2	S power factor	0.001
			- : capacitive (leading) and + : inductive (lagging)	

Table of values not allocated current and voltage transformation ratios in 1 word*

Dec. address.	Hex. address.	Number of words	Designation	Unit
51281	C851	1	Phase-phase voltage U12	V / 100
51282	**C852**	**1**	**Phase-phase voltage U23**	**V / 100**
51283	C853	1	Phase-phase voltage U31	V / 100
51284	**C854**	**1**	**Phase to neutral voltage phase 1**	**V / 100**
51285	C855	1	Phase to neutral voltage phase 2	V / 100
51286	**C856**	**1**	**Phase to neutral voltage phase 3**	**V / 100**
51287	C857	1	Frequency	Hz / 100
51288	**C858**	**1**	Current phase 1	mA
51289	C859	1	**Current phase 2**	**mA**
51290	**C85A**	**1**	Current phase 3	mA
51291	C85B	1	**Neutral current**	**mA**
51292	**C85C**	**1**	**S active power + / -**	**100 kW**
51293	C85D	1	S reactive power + / -	kvar / 100
51294	**C85E**	**1**	**S apparent power + / -**	**100kVA**
51295	C85F	1	S power factor	0.001
			- : capacitive (leading) and + : inductive (lagging)	

** Certain devices such as the DIRIS or ATyS have a table where the information is stored in 1 single word in order to be compatible with a JBUS / MODBUS master that does not accept this format.*

The table below shows the frame that the JBUS / MODBUS master sends to read a table 158 words in length (0X9E in hexadecimal).

Slave	Function	Address high-order	Address low-order	Number of words high-order	Number of words low-order	CRC 16
05	03	03	00	00	9nd	C5A2

However, if only the active power requires to be recovered, simply send the following table in hexadecimal:

Slave	Function	Address high-order	Address low-order	Number of words high-order	Number of words low-order	CRC 16
02	03	03	16	00	02	25B8

In the previous table, it is seen that the + and - signs appear for this datum. The high-order bit gives the received data sign:
- the bit is 1: the value is negative,
- the bit is 0: the value is positive.

Response of a DIRIS for a positive power:

Slave unit	Function	Number of bytes	High-order value word 1	Low-order value word 1	High-order value word 2	Low-order value word 2	WORD 16
02	03	04	00	00	8C	AC	AD8E

8CACh gives 36 012 kW / 100. or 360.12 kW

Response of a DIRIS for a negative power:

Slave unit	Function	Number of bytes	High-order value word 1	Low-order value word 1	High-order value word 2	Low-order value word 2	WORD 16
02	03	04	FF	FF	7 B	D40	AA7A

FFFF7BD3h gives -33 837 kW / 100. or -338.37 kW

To obtain this result the NOT operator 1 needs to be made (take the inverse of the value obtained in binary) and add 1 to the result, i.e.:
- NOT operator 1: FFFF7BD3 hexa gives 842C hexa,
- add 1: 842C hexa + 1 = 33 837 decimal; the value being negative this gives -33 837 kW / 100. or -338.37 kW.

JBUS / MODBUS protocol (continued)

RS485 bus for JBUS / MODBUS protocol

Transmission consists of sending and receiving. The bi-directional data transmission can be:
- separated on two distinct channels (4-cable simplex link),
- together on one channel, with sending and receiving performed alternatively in both directions (two-cable half duplex),
- together on one channel, the sending and receiving performed simultaneously (two-cable full duplex).

In all cases, the voltage level is applied in differential mode, i.e. non-earth referenced. It is the potential difference between the channel's 2 cables that creates the signal.
The RS485 field bus is very practical. It is designed to operate in difficult industrial environments with high levels of electromagnetic interference.

Even though it is robust, the bus must comply with the following rules of implementation in order to function correctly:

- maximum length: 1200 m for speeds up to 100 kbit / second. This length can be increased by adding an RS485 repeater (see Fig. 1),
- maximum number of connected JBUS / MODBUS slaves: 31. The number can be increased by adding an RS485 repeater,
- no star quad twisting,
- place a 120 W resistive load on the first and last device,
- position the security levels (pull-up and pull-down resistors) that are used to keep each bus cable at a certain level of voltage, especially when the system has reached its quiescent state, when no drivers are driving the bus
- use a cable that has impedance + capacitance characteristics that are adapted to the type of communication (shielded). The shielding should continue along the entire length of the bus and should be linked to earth at only one point, so as to avoid creating an antenna.

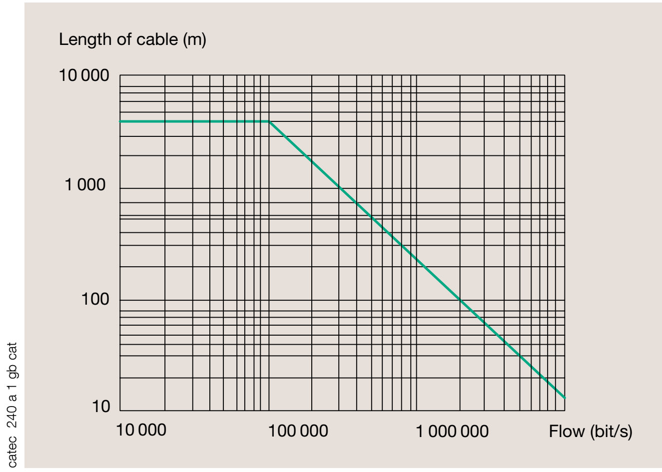
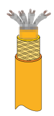


Fig. 1

Complying with all these rules will enable the RS485 bus to be used in difficult environments.

Examples of recommended cables



HELUKABEL: JE-LiYCY Bd SI Industry-Elektronic Cable according to DIN VDE 0815.
BELDEN: 9841 Paired - Low Capacitance Computer Cable for EIA RS-485 Applications.
ALPHA: 6412 Multipair, Foil / Braid shield PE / PVC, low capacitance cable.

Configuration

Certain settings for communication frame characteristics have to carried out so that the master and slaves can communicate. The settings to be adjusted are the following:
- the number of bits in each frame byte (7 or 8 bits),
- the number of stop bits (1 or 2),
- the parity (even, odd, or without),
- output (speed of communication, expressed in bauds) can be set between 1200 bauds up to 10 Mbauds. Over 100 kbds, the maximum bus length depends on the speed of communication.

Communication media for JBUS / MODBUS protocol

In general, the JBUS / MODBUS master is either a PLC linked to a coupler device or a computer linked to a communication interface. SOCOMEC offers a complete range of communication gateways in order to interface with an RS485 bus. The choice of gateway mainly depends on the environment in which it is to be used, but also certain constraints in terms of equipment and network configuration.

Various types of gateway can therefore be found:

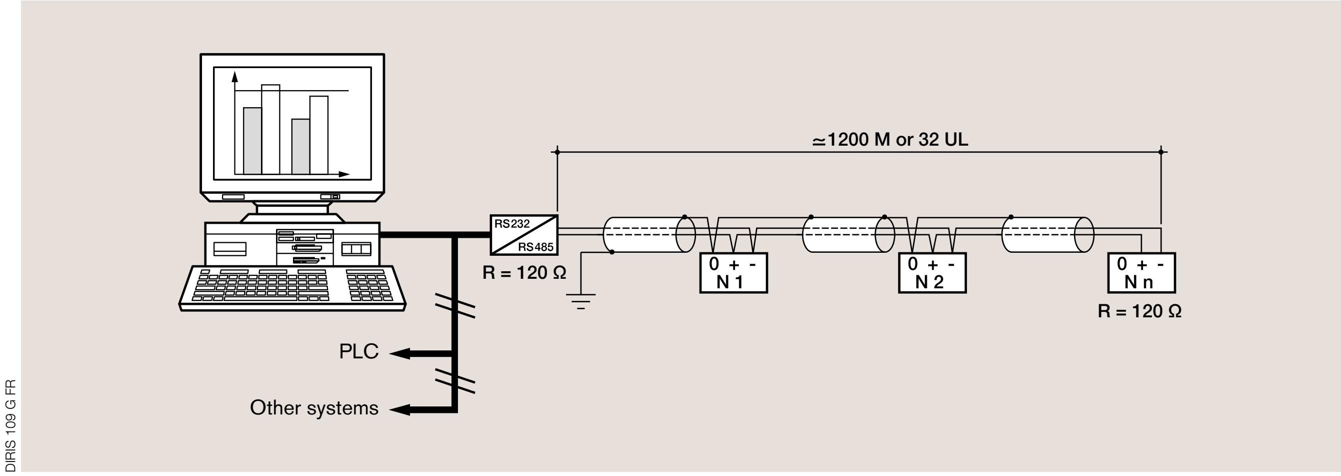
RS232	⇔	RS485		
USB	⇔	RS485		
RS232	⇔	ETHERNET	⇔	RS485
RS232	⇔	PSTN telephone link	⇔	RS485
RS232	⇔	GSM telephone link	⇔	RS485
RS232	⇔	radio link	⇔	RS485
RS232	⇔	optical link	⇔	RS485

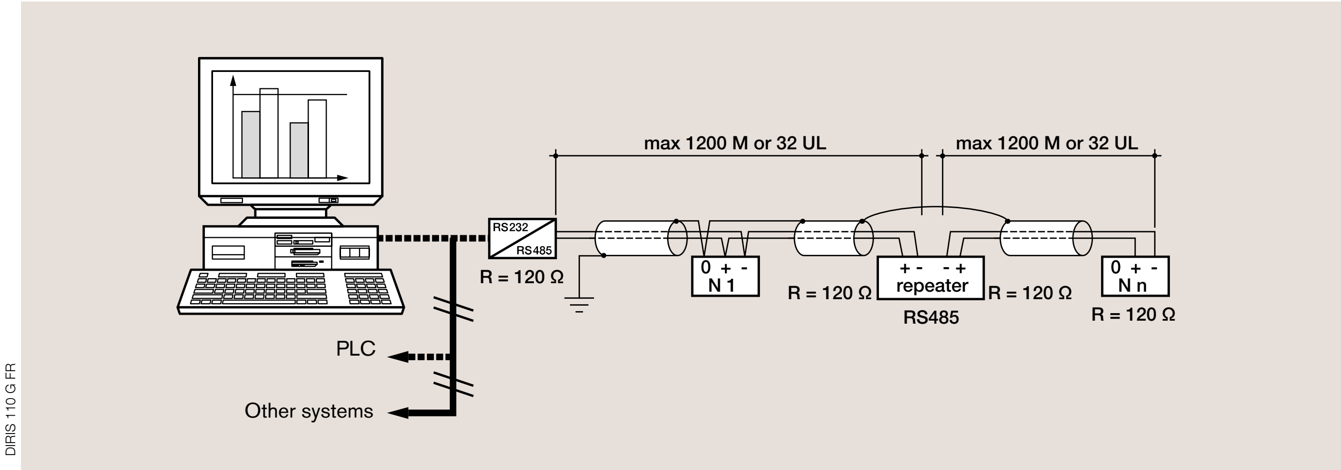
RS485 Bus

A RS485 bus is defined by the standard EIA-TIA-485-A and the application guidelines TSB-89-A

Topology

The recommended topology is a serial bus.

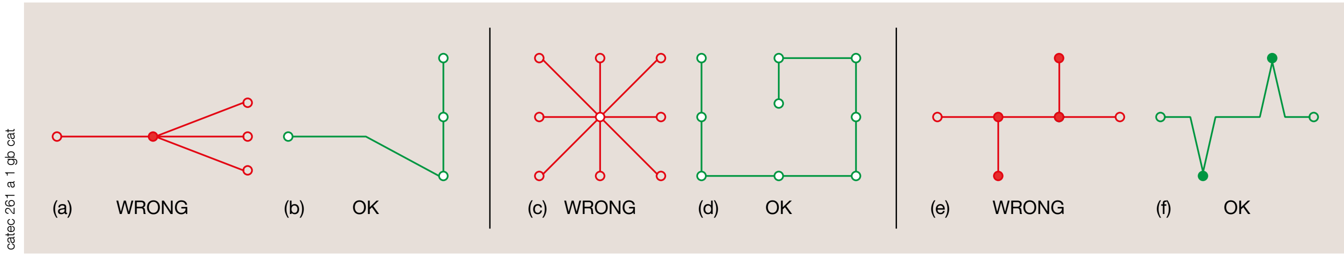




UL = unity of loads, see corresponding page below

The serial bus topology is the one that best limits signal reflection.

Example: Conversion from a non adapted topology to an adapted serial bus topology.



For the diagram (e) spurs of up to 30 cm can be tolerated (Vertical connections on the diagram (e)).

RS485 Bus (continuation)

Type of cable

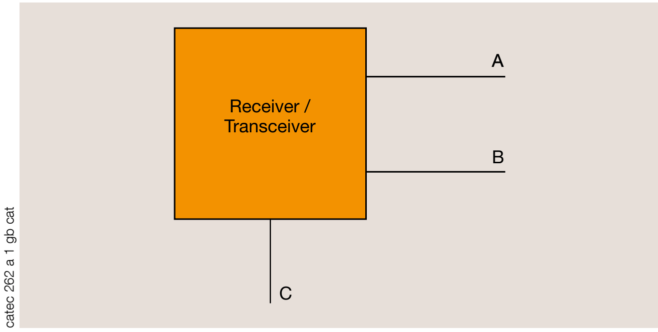
We recommend to use a shielded twisted pair (general shield) with a minimum cross-section of 0.20 mm ² (AWG 24), a 120 ohms impedance and of type L IYCY-CY.

Earthing

Only link the shield to the earth on one end to guarantee the equipotentiality of the shield.
There is no other required earthing.

Identification of SOCOMEC terminals according to RS485 standard

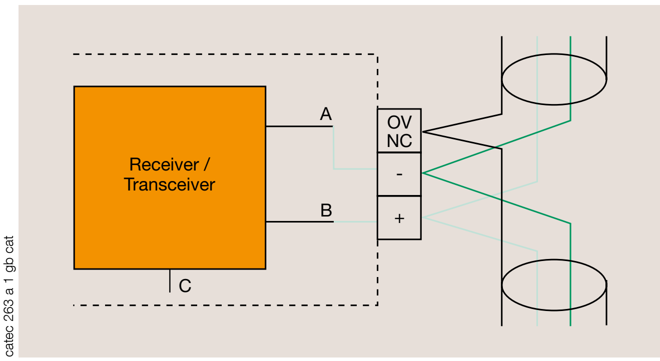
A RS485 transceiver is from a standard point of view connected through 3 points on the network.



Manufacturers may give other names to their terminals that differ from A, B or C.
Below is the correspondence with SOCOMEC terminal labelings:
- B = +
- A = -
- C = " 0V / NC "

The SOCOMEC transceivers do not need the 3rd terminal (C) to communicate correctly.
Apply the following recommendations:
- in a 3 wire network connect the 3rd terminal (C) in the terminal (OV / NC)
- in a 2 wire network use the 3rd terminal (C) to provide the shield continuity.

Principle of SOCOMEC products connections



Connection diagram of SOCOMEC products in a 2 wire network

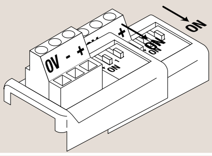
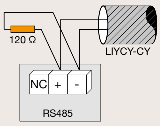
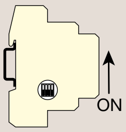
The terminal of the SOCOMEC connector (OV / NC) is not linked internally to the "C" terminal of the RS485 transceiver.
This isolated terminal can thus be used to facilitate shield continuity.

RS485 Bus (continuation)

Termination Resistor

The termination resistor, with the same value as the line impedance (120 ohms), eliminates the majority of the signal reflection.
It has to be placed at both ends of the bus. It could be directly integrated in the interface unit, depending on models.

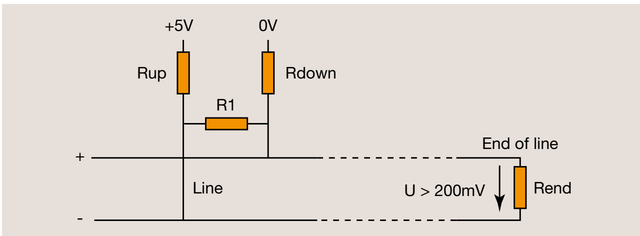
Manual activation on products

Device	Termination resistor	
DIRIS A20, A40, A60		Set: • the 2 dip switches to ON to activate the resistor • the 2 dip switches to OFF to deactivate the resistor
DIRIS A10, COUNTIS E		A 120 ohm resistor is supplied with the product (loose component). Connect between + and - terminals.
COUNTIS ECi		Set: • the 4 dip switches to ON to activate the resistor • the 4 dip switches to OFF to deactivate the resistor

the first termination (start) should be placed on the first network device which is generally an interface or PLC and not the first slave (meter)

Line fail-safe biasing

The RS485 standard imposes one differential level of 200 mV minimum to detect the signal.
If the RS485 line is not biased, this level will not be reached (without communication on the line) and successful communication will not be guaranteed.
For this, we apply a bias to only one place on the bus and it is best applied at the master. On certain models of interface unit, it is possible to activate this biasing otherwise, it would be necessary to add an external supply which guarantees a level of 250-280 mV on the whole bus when there is no active communication.
One supply of 250-280 mV is a good compromise which guarantees to be upper of 200 mV and does not lead to excessive consumption.
In order to prove this, it is best to apply the biasing at one end of the bus (on the interface side) and verify the voltage level on the other end of the bus; this ensures adequate biasing throughout the bus.
Warning, the sign of the voltage (U) must be positive.



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Fail-safe biasing principle diagram

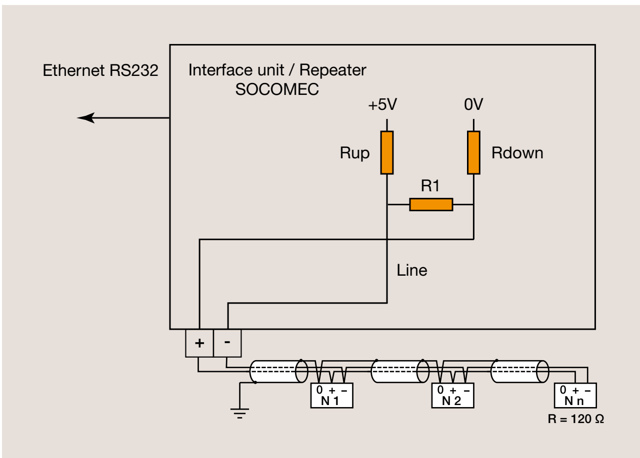

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Diagram of a bus connection with SOCOMEC interface units with integrated biasing

RS485 Bus (continuation)

Line fail-safe biasing (continuation)

Sizing

The sizing of R_{up}, R_1, R_{down} depends on the exact level of the voltage supply and the termination resistor values.
Standard values (for a voltage supply of 5V) are:
R_{up} = R_{down} = 560 ohms (+/- 5 %, ¼ W)
R_1 = 120 ohms (+/- 5 %, ¼ W)
R_{end} = 120 ohms (+/- 5 %, ¼ W)

The method of determination is achieved through a process of selection.
The approach is to check if, with these standard resistor values, the voltage level U at the end of line is in the expected range (250 - 280 mV). If not, you can adjust the Rup and Rdown resistors between 390 and 750 ohms to reach this voltage level.
Repeat these actions until obtaining a corresponding voltage.

Limitations

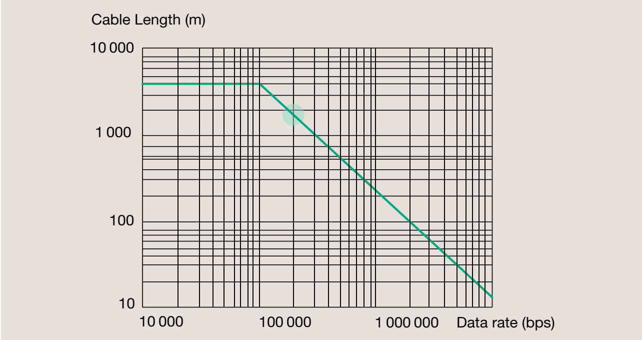
2 limitations have to be taken into account in a RS485 network

Maximum number of devices
A RS485 driver should be able to communicate on a network with a load of 32 UL (Unity of load).

Device	UL Value	Number of devices to reach 32 UL
DIRIS A10	1	32
DIRIS A20	1	32
DIRIS A40	1	32
DIRIS A60	1	32
COUNTIS Ci	1	32
COUNTIS E53	1	32
COUNTIS E33	1/2	64
COUNTIS E43	1/2	64
COUNTIS E44	1/2	64

Over a load of 32 UL, a repeater will be needed.

Maximum length of the bus
The maximum length for a speed up to 100 kbds is 1200 m.



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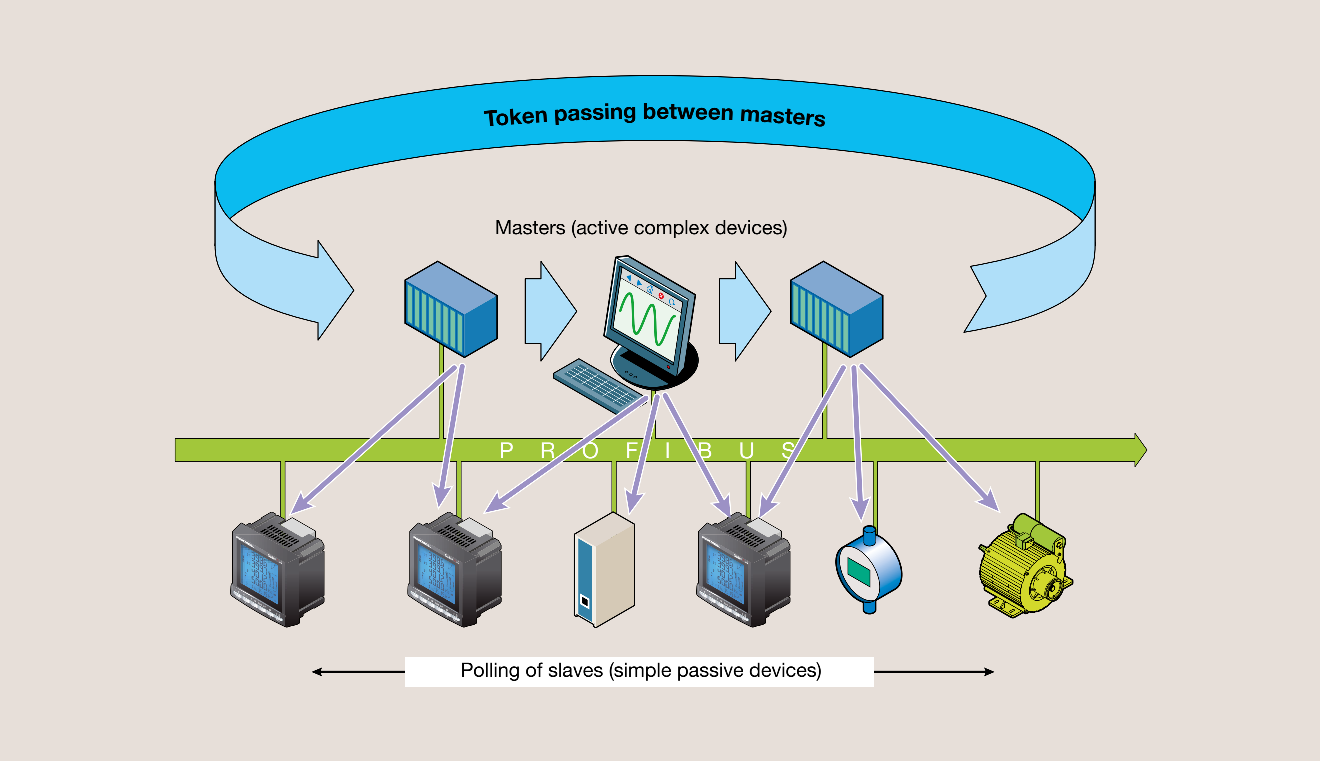
Over this distance, a repeater is needed.

PROFIBUS Protocol

Presentation

Based on cyclic exchange between masters and slaves, the PROFIBUS protocol can have several masters on the same bus. In this case the method used is token passing between master-slave: The first master holds the token, carries out exchanges with the desired number of slaves and then passes the token to the next master which does the same.



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GSD File

The protocol is based on input and output exchange tables. The description of these tables (also called modules) is done via a GSD file provided by any PROFIBUS slave. The file describes the functioning of the slave in terms of this protocol.

The different versions

PROFIBUS DP (Manufacturing) SOCOMEC products	PROFIBUS PA (Process automation)	Motion control on PROFIBUS (drives)	PROFIsafe (Universal)
Application profiles such as identification systems	Application profiles such as PA equipment	Application profiles such as PROFIdrive	Application profiles such as PROFIsafe
DP stack (DP - V0 to V2)	DP stack (DP - V1)	DP stack (DP - V1)	DP stack (DP - V0 to V2)
RS485	MBP 15	RS485	RS485 MBP 15

As for any communication protocol (especially for field buses), PROFIBUS is based on the OSI layers described above. In order to meet the requirements of different applications, four dedicated versions have been produced, each with their own specificity.

The SOCOMEC range of products has PROFIBUS DP V0 certification.

It is therefore possible to connect these products on a PROFIBUS DP bus.

PROFIBUS protocol (continued)

PROFIBUS protocol bus

OSI layer 1 assures the physical transmission of data. It defines the electrical and mechanical characteristics: type of encoding and standardised interface (RS485).

PROFIBUS specifies several versions of "physical" layers depending on the transmission modes conforming to international standards IEC61158 and IEC61784.
The different versions are as follows:

- RS485 transmission,
- MBP transmission,
- RS485-IS transmission,
- optical fibre transmission.

SOCOMEC uses the RS485 serial link with the following characteristics:
- differential digital transmission,
- rate of 9600 to 12000 kbits / second,
- two sheathed twisted cables,
- linear topology (without star network) with bus termination,
- up to 32 connectable stations with possibility to add repeaters.

It is highly recommended to use a standardised PROFIBUS cable to secure transmissions.
Please consult the following website for a selection of references: http://www.procentec.com/products/cable/index.php.

Electrical measurement

Ferro-magnetic equipment

This consists of two repelling magnets (one fixed, the other moving and attached to the needle), placed inside a coil supplied by the current to be measured.

Ferro-magnetic equipment reads the rms alternating signal; wave-form influence is negligible. It can also be used on a DC signal, but is detrimental to its accuracy class.

Its simplicity makes it a particularly suitable instrument for measuring alternating currents on LV switchboards.

Magneto-electric equipment

Measuring current flows through a moving coil placed in a permanent magnet's magnetic field. Under electro-magnetic forces, the coil pivots in proportion to the current value.

With its low consumption, it is an excellent measuring device for low value DC signals.

Magneto-electric equipment with rectifier

As the moving-coil galvanometer is a DC polarised device, it can measure high AC values by the addition of a diode rectifier.

Operating position

ROTEX and DIN indicators are calibrated with dials in a vertical position.

Use in other positions is possible without noticeable loss of accuracy. Indicators can be calibrated to work in different positions on demand (to be specified when ordering).

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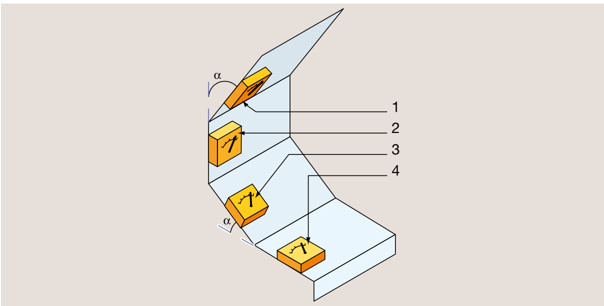

1 : α > 90°
2 : α = 90°
3 : α < 90°
4 : α = 0°

Use of voltage transformers

3 VT circuit:
63 kV mains - VT 63 kV/100 V/√3

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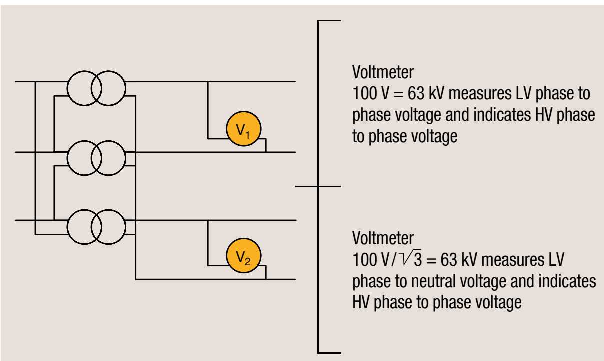

2 VTs in "V" circuit: 63 kV mains - VT: 63 kV/100 V
(use: measuring 3 voltages with 2 VTs)

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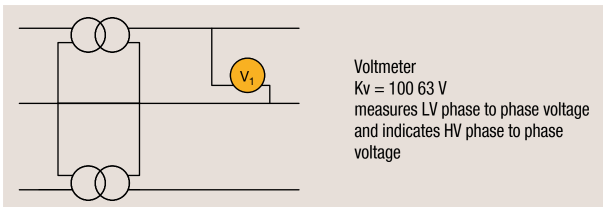


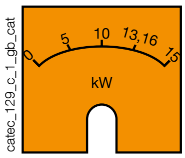
Power converter

Example
Calibrating an active power converter: CT 20 / 5 A, U = 380 V, three-phase mains, cos j = 1. Standard calibration:
P' (converter) = UI cos j √3 = 380 V x 5 A x 1 x 1.732 = 3290 W, therefore with a 20 A CT: P = 3290 W x 20 / 5 = 13.16 kW
converter output: 0 mA = 0% ; 20 mA = 100% load.

- Calibrating for numeric display, threshold relay or BMS (Building Management System: a numeric display can be calibrated to display 13.16 kW at 20 mA, therefore converter calibration is unnecessary.
- Calibrating for needle indicator (scales from 0 to 15 kW) calibrated at 20 mA at scale lower limit: the associated device is not adjustable, therefore converter calibration will be performed as follows:

$$P' \text{ (converter)} = \frac{15 \text{ kW}}{13.16 \text{ kW}} \times 3290 \text{ W} = 3750 \text{ W for 20 mA}$$

$$I' \text{ (converter output)} = \frac{13.16 \text{ kW}}{15 \text{ kW}} \times 20 \text{ mA} = 17.55 \text{ mA}$$



3290 W = > 13.16 kW => 17.55 mA
3750 W = > 15 kW => 20 mA

Accuracy class

- **Analogue measuring devices** are characterised by a class index (or accuracy class). This represents the maximum error expressed in hundredths of the device's highest value.

Example: for an ammeter with 50 divisions, class 1.5
The error will be $\frac{1.5}{100}$ x 50 therefore giving: 0.75 division
- therefore for a 20 A ammeter: 20/50 x 0.75 = 0.3 A
- therefore for a 400 A ammeter: 400/50 x 0.75 = 6 A

- **Numeric (or digital) devices** can indicate a value of ±1 unit of the last displayed digit in addition to the true accuracy of the devices components.

Example: a 3-digit indicator (999 points), with 0.5% accuracy, connected to a CT 400/5 A, 400 A display.
- (a) intrinsic error 400 x $\frac{0.5}{100}$ therefore ± 2 A
- (b) 1 digit display error, therefore ± 1 A
- maximum reading values: (a) + (b) = ± 3 A (at nominal load).

- **Current transformers** (CT) are characterised by their accuracy class.
The error varies according to loads as follows:

Error (± % of In)								
Load level		$0.1 I_n$	$0.2 I_n$	$0.5 I_n$	I_n:	$1.2 I_n$	$5 I_n$	$10 I_n$
Class	0.5	1.0	0.75		0.5			
	1	2.0	1.50		1.0			
	3			3	3	3		
	5			5	5	5		
	5P5				5		5	
	5P5				5			5

Example: 5P5 CTs are used to measure motor circuit current and guarantee a ± 5% accuracy at 5 I_n.

Copper cable losses

Cable losses must be taken into account to define the CT or converter power to be chosen, so as to ensure correct measuring chain functioning (L: between CT and indicator).

$$\text{Loss in VA} = \frac{I^2 \text{ (in A)} \times 2}{S \text{ (in mm}^2) \times 56} \times L \text{ (in m)}$$

Cable loss in VA(1) - For 5 A CT

L (in m) / S (mm^2)	1	2	5	10	20	50	100
1.0	0.89	1.79	4.46	8.93	17.9	44.6	89.3
2.5	0.36	0.71	1.79	3.57	7.14	17.9	35.7
4.0	0.22	0.45	1.12	2.23	4.46	11.2	22.3
6.0	0.15	0.30	0.74	1.49	2.98	7.44	14.9
10	0.09	0.18	0.45	0.89	1.79	4.46	8.93

Cable loss in VA(1) - For 1 A CT

L (in m) / S (mm^2)	1	2	5	10	20	50	100
1.0	0.04	0.07	0.18	0.36	0.71	1.79	3.57
2.5	0.01	0.03	0.07	0.14	0.29	0.71	1.43
4.0	-	0.02	0.04	0.09	0.18	0.45	0.89
6.0	-	-	0.03	0.06	0.12	0.30	0.60
10	-	-	0.02	0.04	0.07	0.18	0.36

(1) Only the active component of losses is taken into account.

Summation transformer

Summation CTs enable rms addition of several AC currents of the same phase. These currents can have different j.
Summation CTs are defined by:
- the number of CTs to be connected (CTs with the same winding ratio),
- operating nominal power.

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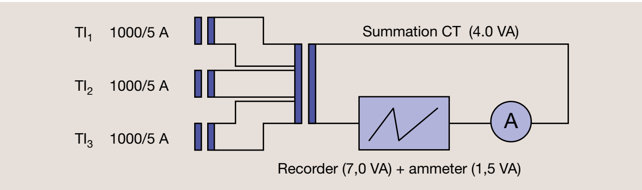

Example: 3 circuits to be measured for output onto recorder and indicator:
- (a) Power balance to be supplied by summation CT:
  (ammeter + recorder + measuring circuit loss)
  P' = 1.5 VA + 7.0 VA + 1.5 VA = 10.0 VA,
- (b) Power balance to be supplied by CTs:
  P = P' + summation CTs own consumption
  P' = 10.0 VA + 4.0 VA = 14.0 VA; therefore P/3 per CT.

Saturable CT

Saturable CTs ensure power supply to low power thermal relays by protecting them against overcurrent due to frequent motor start-up (saturable CTs are only available with 1 A output).

SOCOMEC distinguishes between two types of saturable CTs:
- CTs with saturation starting at 4 I_n for normal start-up (e.g. pumps),
- CTs with saturation starting at 1.5 I_n for abrupt start-up (e.g. flapless fans).

Adapting winding ratios

With nominal currents of less than 50 A it is possible to use CTs with higher primary current, by passing the primary line through the CT several times. Apart from savings, this method enables the different winding ratios to be adapted (constant efficiency and measuring accuracy).

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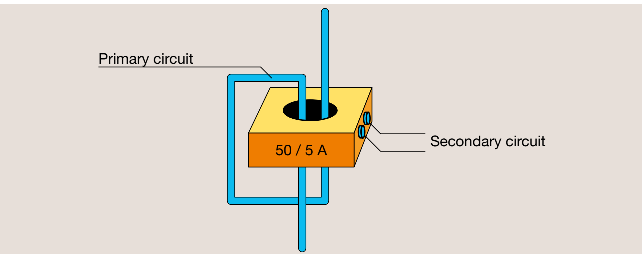


Example: 50 A CT primary circuit.

Primary current to be measured	Number of passes
50 A	1
25 A	2
10 A	5
5 A	10

Digital protection of networks

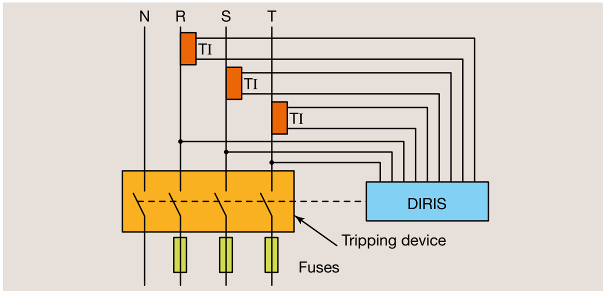
General points

In addition to measuring, metering, alarms monitoring and communication functions, the DIRIS protection device also provides protection against overcurrent. This function is provided by the DIRIS module that allows for tripping curves to be set.
The I_0 current is calculated by the vector sum of the phase's three currents I_1, I_2, I_3 or measured directly on the fourth input current. The fourth input can be connected to the neutral by a current transformer or connected to a homopolar TOROID for measuring earth leakage current.
The device's tripping threshold depends on the choice of a time-dependent curve (SIT, VIT, EIT or UIT), or a DT (definite time) time-independent curve.
All the current measurements are given in TRMS values.
Protection against fault current is assured by comparing measured current against predefined tripping curves.

Protection functions

Magnetic protection on I1. I2. I3. In:	I >>	ANSI code: 50
Protection against thermal overload on I1. I2. I3. In:	I >	ANSI code: 51
Magnetic protection on homopolar component I0:	I0 >>	ANSI code: N 50
Protection against thermal overload on homopolar component I0:	I0 >	ANSI code: N 51
Protection at maximum of directional current:	Idir	ANSI code: 67
Logic discrimination		ANSI code: 68
Protection against active power inversion	> rP	ANSI code: 37

The DIRIS protection device assures the protection of electrical circuits. It must be associated with a breaking device assuring circuit breaking within the standard breaking times (see page 30).



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Breaking system block diagram.

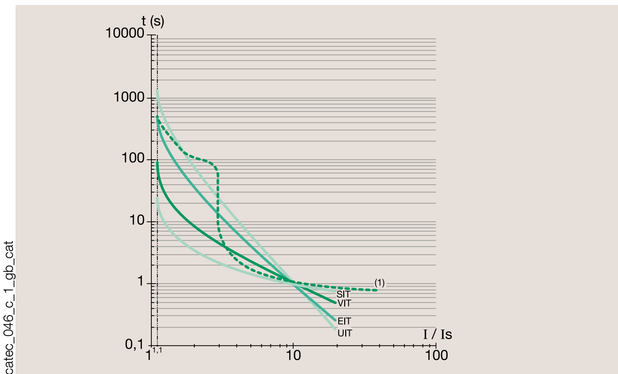
Time-dependent tripping curves

ANSI code 50 (phase protection) or 50 N (neutral or earth fault protection) - according to IEC 60255-3 and BS 142. These tripping curves are generally used for setting the **lower threshold** (overload).
To set the lower threshold, it is necessary to choose a curve, define a I_s threshold (in percentage) and a T_s time value that corresponds to the tripping time for a fault equal to 10 I_s.
The I_s threshold is the value of current for which there is no tripping. Tripping occurs once there is an overshoot of current higher than 1.1 I_s and after the T_s time delay.
The protective curves, thresholds and time delays are identical for the phase currents and the homopolar I_0 or neutral I_n current.

Protection relays

In case of threshold overshoot in terms of time delay, an RT relay trips for the phase fault. This relay tripping command can be locked in cases where the protective breaking device is a fuse combination switch, so as to respect its breaking capacity. This limit is fixed at 7 I_n.
The RT relay is reset by pressing the "R" key on the keyboard.

Representation of curve types



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Programmable curves.

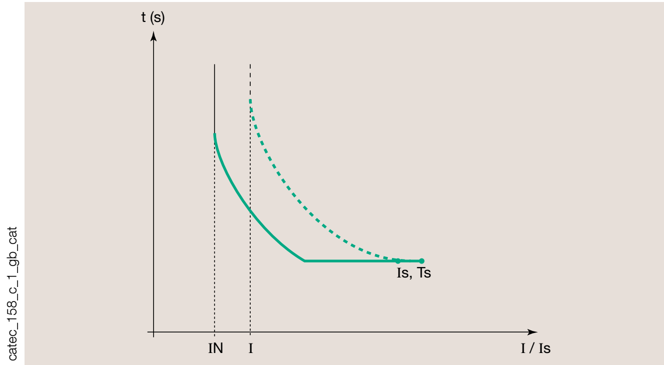
Curve equations

Inverse time curve (SIT):	$t = T_s \times \dfrac{47{,}13 \times 10^{-3}}{(I/I_s)^{0.02} - 1}$
Very inverse time curve (VIT):	$t = T_s \times \dfrac{9}{(I/I_s) - 1}$
Extremely inverse time curve (EIT):	$t = T_s \times \dfrac{99}{(I/I_s)^{2} - 1}$
Ultra inverse time curve (UIT):	$t = T_s \times \dfrac{315{,}23}{(I/I_s)^{2.5} - 1}$

The "UIT" curve can be reset point by point by the operator, using an RS485 serial link.

Neutral protection

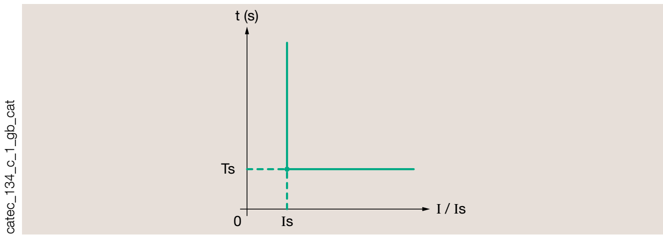
Protection of the neutral is achieved by transposing the phases' protection curve:
- ts times are identical,
- currents are divided using a KN coefficient.



" Earth fault " protection

This protection is configured as for the phases' currents.
" Earth fault " protection is protection against high earth fault currents. It does not provide protection against direct or indirect contact, but rather fire prevention or drainage of the earth connections.

Time-independent protection curves



ANSI code 50 (phase protection) or 50 N (neutral or earth fault protection) - according to IEC 60255-3 and BS 142. This curve is used to set the upper threshold (short circuit). It can also be used to set the lower threshold if the time-dependent curve has not been retained. To set the independent threshold(s), it is necessary to choose the time-independent curve (DT), define a threshold and a time delay.

Independent time (DT) with:

$0.1\ I_n < I_s < 15\ I_n$

$0.02s < T_s < 30$ s

$0.02s < T_s < 300$ s

with I_n = nominal current.

Current inversion protection

ANSI code 37

This is the detection of a negative active power threshold on the three phases associated with a time delay.
For this it is necessary to set an absolute value of between 5% and 110% of Sn, together with a time delay of between 1 and 60 s.
Current inversion is detected as soon as the following conditions are met:
- P < 0 and IPI > 10% of Q, therefore an angle of between 96° and 264°,
- U > 70% of Un (nominal voltage) on the 3 phases,
- I > I_n/20 on the 3 phases (therefore 250 mA si I_n = 5 A and 50 mA si I_n = 1 A),
- P > rP (threshold set with absolute value).

Choosing a CT

The minimal recommended class of the protective CT is 5P 10 (5% accuracy at 10 In).

Choosing CT power in VA

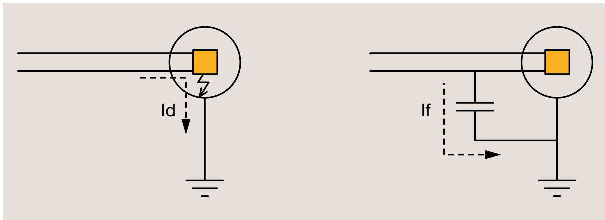
- The CT class (5P 10. 10P 10. etc.)is guaranteed for a given maximal load in VA.
- The DIRIS represents a load of 1.5 VA to which must be added the losses due to connecting cables.

Example:
Nominal current: 275 A
A CT 300 A/1 A P is chosen.
The maximum load of this CT is 4 VA, for example.
The CT is connected by 2 x 2.5 mm^2 cable with a length of 10 m.
Cable losses in VA (see page 77): 3.57 VA.
Total load: 1.5 VA (DIRIS) + 3.57 VA = 5.07 VA.
The CT is not suitable: It is necessary to either reduce the length of cable or increase its cross-section or choose a CT whose admissible load is higher than 5.07 VA.

Differential protection

General points

An earth fault current is a current which flows to earth when there is an insulation fault (Id). An earth leakage current is a current which flows from the live parts of the installation to earth, in the absence of any insulation fault (If).



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A Residual Current Device (RCD) as defined by IEC 60755 is designed to detect earth leakage or fault currents occurring generally downstream of their installation point.
The main types of differential device are:
- differential circuit breakers
- differential switches
- differential relays which are not integrated in the breaking device.

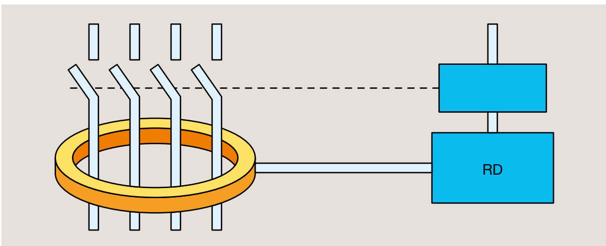
SOCOMEC, a specialised manufacturer, offers a complete range of differential relays able to meet the requirements of every case appropriately.
Differential relays have two purposes:
- to cut off the installation when it is associated with a breaking device with automatic tripping,
- to signal a leakage or fault current when it is used as a signalling relay.

Signalling

Signalling when an earth leakage or fault current is detected and remains at a level nevertheless allowing preventive maintenance work.
Differential signalling consists of:
- a toroid surrounding the live conductors to be monitored which detects the residual current when the sum of the currents on line is no longer zero,
- a differential current analysis and measuring device which, using its alarm LEDs, its output relays or its digital output will alert operators.

Certain applications may require both functions (breaking and signalling) at the same time.

Cutting off the installation



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Differential protection in this case consists of:
- a toroid surrounding the live conductors of the circuit to be protected which detects the residual current when the sum of the currents on line is no longer zero,
- a differential current analysis and measuring device which issues the alarm signal,
- a power supply breaking device which is tripped by the alarm relay.

When a danger appears (electric shock, fire, explosion, malfunctioning of a machine, etc.), an automatic supply breaking device performs one or more of the following functions:
- protection against indirect contacts,
- limitation of leakage currents,
- complementary protection against direct contact,
- protection of the equipment or of the production,
- etc.

Differential relays may be combined, in certain conditions, with contactors, circuit breakers or with the switches and fuse switches with tripping in the SOCOMEC SIDERMAT, FUSOMAT and INOSYS LBS range.

Differential protection

Definitions

Rated residual differential current IΔn

The rated residual differential current, written as IΔn, is the differential residual current's maximum value which must trigger the device's operation. Its value generally expresses the RCD's sensibility or the setting of its rating (example: RCD 30 mA). An RCD can, from the point of view of the differential product standards, trip with half its rated residual differential current.

SOCOMEC devices, thanks to RMS measurement, can bear currents up to 80% (in class A) of the rated residual current. This level of accuracy allows bigger leakage currents for the same level of protection and thus allows better discrimination.

IΔn current values are classified according to three classes of sensitivity:

Sensitivity	IΔn settings
Low sensitivity	30 A
	10 A
	5 A
	3 A
Average sensitivity	1 A
	500 mA
	300 mA
	100 mA
High sensitivity	30 mA

Cut-off time

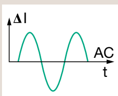
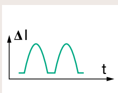
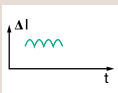
The IEC 60755 technical report suggests the following preferential values for maximum cut-off time expressed in seconds for differential devices intended to protect against electric shocks in the event of indirect contact type faults:

		Cut-off time values		
Class	In (A)	IΔn S	2 IΔn S	5 IΔn S
TA	any value	2	0,2	0,04
TB	≥ 40 A only	5	0,3	0,15

Class TB takes into account combinations of a differential relay with a separate breaking device. For protection against indirect contacts, the installation standard NFC 15100 allows a cut-off time at the most equal to 1s for a distribution circuit, without taking into account the contact voltage if discrimination is judged necessary. In an end distribution, the differential devices used for the protection of people must be of the instantaneous type.

Classes of differential relays

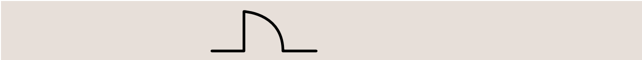
The IEC 60755 technical report defines three utilisation classes for RCDs depending on the type of network:

Differential relay class	Symbol	Example of a fault current	
AC type			The device provides tripping with residual differential sinusoidal currents.
A type			The device provides tripping with residual differential sinusoidal currents, or pulsed DC residual differential currents whose DC component remains lower than 6 mA during an interval of at least 150° at the rated frequency.
B type			The device provides tripping with differential currents identical to the devices in class A, but also differential currents coming from rectifier circuits: - single alternation with capacitive load producing a smooth direct current, - three-phase simple or double alternation, - single phase double alternation between phases, - any that charges an accumulator bank.

Definitions (continued)

Electromagnetic compatibility (EMC)

The RCDs sometimes trip for reasons other than the presence of an insulation fault. The causes are varied: storms, operation of high voltage devices, short circuit currents, motors starting, fluorescent tubes coming on, closing on capacitive loads, electromagnetic fields, electrostatic discharges.



RCDs with sufficient immunity to these disturbances are identified with the symbol opposite.

According to standard NF C 15100 § 531.2.1.4. the RCDs should be chosen in such a way as to limit the risk of spurious tripping due to EMC disturbance. To this end, the products of the SOCOMEC RESYS range provide a reinforced immunity to ECM disturbance, especially for their TRMS measurement system.

The auxiliary power supplies of SOCOMEC differential relays, strongly immunised, avoid spurious tripping or the destruction of components in the event of overvoltage due to lightning or a HV operation (see opposite).

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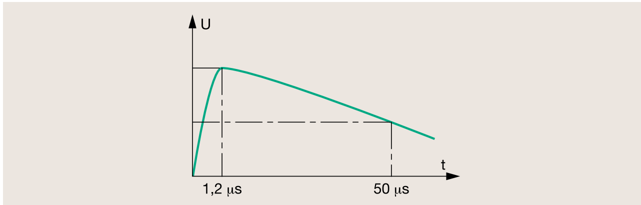

The principle of measurement by digital sampling of the differential signal and the choice of the toroid materials guarantee good resistance of the differential relays in the event of a wave of transient current occurring on closure of highly capacitive circuits (Fig. a), or on a disruptive discharge in the event of a dielectric rupture due to an overvoltage (Fig. b).

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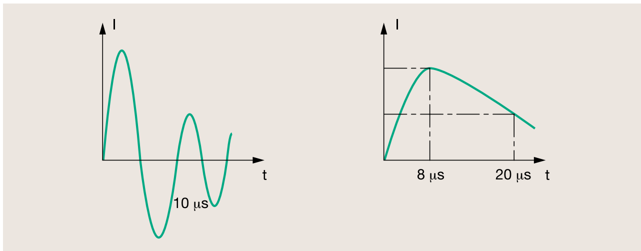

Fig. a. *Fig.b.*

Applications

Protection of an installation

Total discrimination (vertical discrimination)

This is intended to suppress the fault current only in the part of the installation where the fault is to be found. To do this, two conditions must be met:

1. The operating time of the downstream RCD (t_{fB} fig. 2) must be smaller than the non-operating time of the upstream device (tnf A). A simple solution to meet this condition consists of using class S RCDs (adjustable delay). The upstream RCD delay must be greater than the downstream RCD delay (fig. 1).

2. The sensitivity of the downstream RCD (IΔn B) must be smaller than half of the IΔn A of the upstream RCD's sensitivity see fig. 1 and 2).

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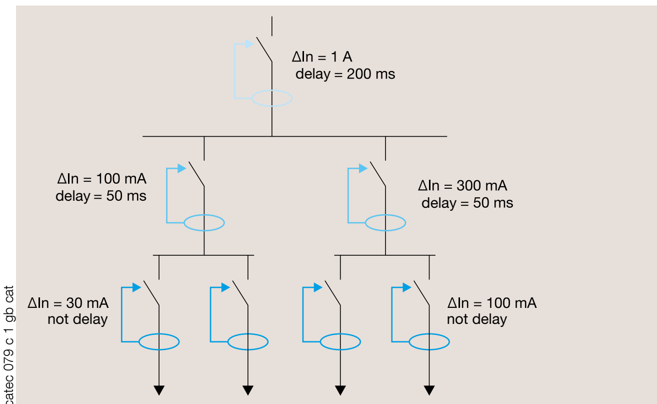

Fig. 1

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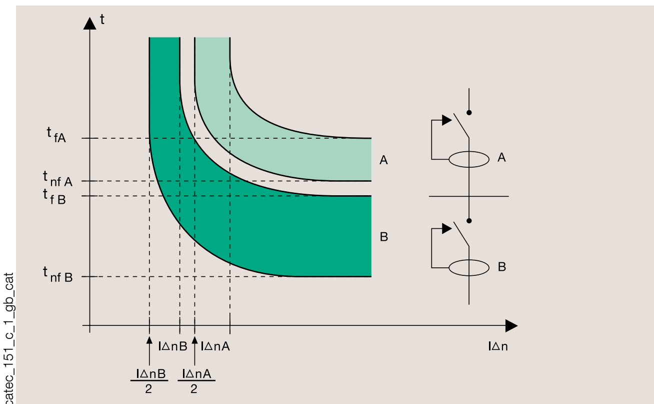

Fig. 2

Differential protection

Applications (continued)

Protection of an installation (continued)

Horizontal discrimination

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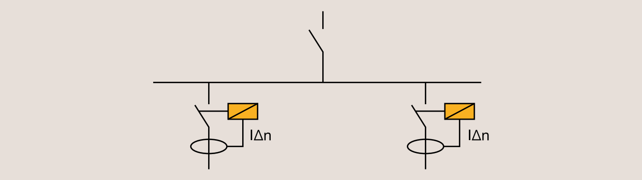

With a TT type arrangement, a general differential device (IΔn) is not obligatory upstream of the differential section feeders insofar as all the installation up to the upstream terminals of the latter, complies with the provisions relating to class II or by extra insulation during the installation.

Protection of motors

An insulation fault that affects the motor coil will have effects that can be classified at two levels:

- destruction of the coil, the motor can be repaired,
- destruction of the magnetic circuit, the motor is destroyed.

The installation of a differential device which limits the fault current to less than 5% of I_n guarantees the non-perforation of the magnetic circuits and saves the motor. As certain large motors may show imbalance between the currents or leakage currents during the start-up phase, it is acceptable to neutralise the differential relay during this phase in certain conditions.

Leakage current of equipment

Information processing equipment, according to standards EN and IEC 60950. may be a source of leakage current due to the particular filtering devices that are associated with them.

Capacitive leakage currents of 3.5 mA are accepted for power connector circuits and 5% (in certain conditions) for fixed installation circuits.

Standard EN 50178 for Electronic Equipment (EE) used in power installations accepts maximum leakage currents of 3.5 mA AC and 10 mA DC for EE.

In case of these values being exceeded, it is necessary to take supplementary measures such as doubling the protective conductor, cutting off the power supply if the PE is broken off, installing a transformer which provides galvanic insulation, etc.

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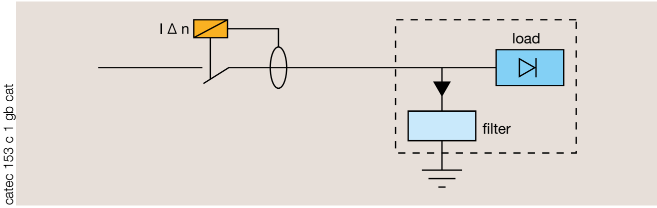

Connection of IMD (general case).

" Sympathy " effect

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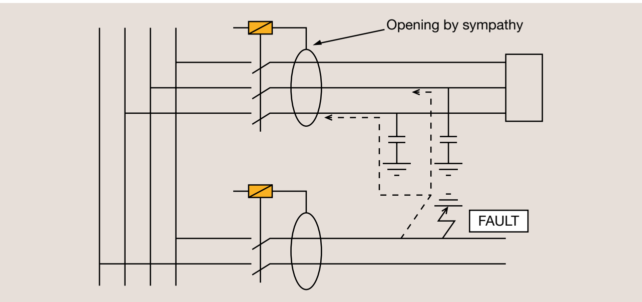

One solution to limit this effect is to delay the differential devices.

An important insulation fault affecting a feeder can loop back by the earth leakage capacities of another feeder and cause the latter to trip without there having been any reduction in the insulation of the circuit concerned.

This phenomenon will be particularly frequent on feeders with potentially high earth leakage capacities or when the fault appears in a very long wiring system.

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Applications (continued)

Protection against fire

Paragraph 422.1.7 of standards NF C 15100 and IEC 60364 stipulates the use of RCDs at $I\Delta n \leq 300$ mA to protect premises where there is a risk of fire (BE2 premises).

Sites with risk of explosion

In TT or TN arrangements, standard NF C 15100 § 424.10 stipulates protection of wiring systems by a 300 mA RCD in BE3-type sites where there is a risk of explosion.

Radiant heating floors

Heating elements for radiant floors must be protected by an RCD with Idn < or = 500 mA, so as to avoid damage to metal coatings (NF C 15100 § 753.4.1.1).

Monitoring of differential currents

Residual fault location systems

Insulation resistance is an important - if not decisive - factor in the availability and safe operating of an electrical installation. Indeed, it represents an absolute priority in electrical safety measures. Numerous studies have shown that about 90% of insulation faults are of a long-standing nature, with only 10% of such faults occurring suddenly. However, the safety devices generally used, such as differential circuit breakers, only take into account this 10% , whereas no preventive measure is taken for faults that evolve over a longer period.

The causes of degradation in the level of insulation are in fact quite common factors such as: humidity, ageing, contact contamination, climatic reasons.
The list of potential incidences of insulation faults is as long as their gravity is varied: such faults can simply be constraining, unfortunate, or even dangerous:

- spurious cut-off of the installation, lengthy (and therefore costly) interruption of production processes,
- erroneous commands after several insulation faults. The simultaneous appearance of two insulation faults can in certain cases simulate the alarm signal of a command device. Programmable PLCs or miniature relays, for example, are very sensitive and respond to even very low currents,
- risk of fire due to power loss following highly resistant insulation faults: a power loss value of 60 W at the site of fault is already considered dangerous, and that furthermore can lead to fire hazards ,
- long and tedious insulation fault detection, especially when the latter comprises several minor faults,
- weak differential currents, because of high impedance insulation faults, are not detected. As a result, there is a progressive drop in the insulation resistance.

In all cases, insulation faults generate costs of one sort or the other. Research has shown that the frequency of faults increases between the power source, the main distribution network and secondary distribution circuits, as far as connected applications.
The above explains why the standards in force demand regular checking of insulation resistance. Nevertheles, such repetitive checks remain limited and specific, and do not therefore exclude the possible occurrence of faults.
More recent device design however, integrates the idea of planned and preventive maintenance. This requires an intelligent and permanent monitoring of the insulation level, and constitutes the only preventive protection measure against insulation faults.

The DLRD 460 differential currents location system has been designed for such purposes as outlined above. As a signalling (and not a breaking) device for TNS and TT arrangements (earthed networks), it complements the traditional protection devices against differential currents.
The DLRD 460 system selectively monitors the various feeders of a network. The differential current detection threshold is individually programmable for each feeder. In addition, operators can also set an alarm threshold (pre-alarm). The system immediately signals any exceeding of the preset value. Such devices provide the following:

- preventive maintenance by the rapid detection (simultaneously on 12 feeders per device) of any fault (measurement of AC, A and B-type currents),
- signalling without cut-off: no interruption of processes,
- costs reduction by a rapid detection of faults,
- centralised information and operation via Profibus DP, Modbus or TCP/IP communication (via dedicated gateway),
- easy upgradability depending on changes in your installation (up to 1080 feeders).

Differential protection

Implementation

All installations have an earth leakage current that is mainly due to the conductor's capacitive leakage and to anti-parasitic or EMI filtering capacitors, for example class I equipment.
The sum of these leakage currents may cause highly sensitive RCDs to trip. Tripping becomes possible from IΔn/2 (IΔn x 0.80 for the SOCOMEC RESYS M and P devices) without it endangering safety to personnel.
Leakage currents can be limited by:

- using class II equipment,
- isolating transformers,
- limiting the number of receptors protected by the same RCD.

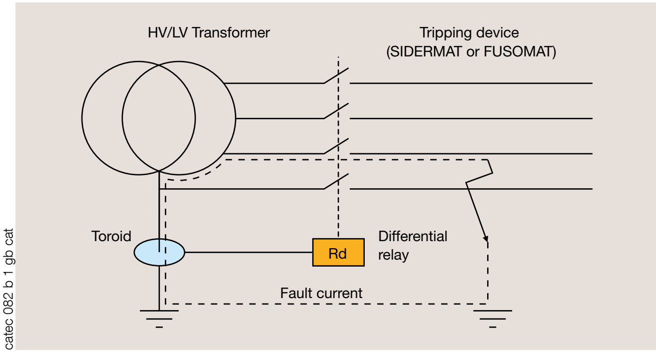
Improving RCD performance

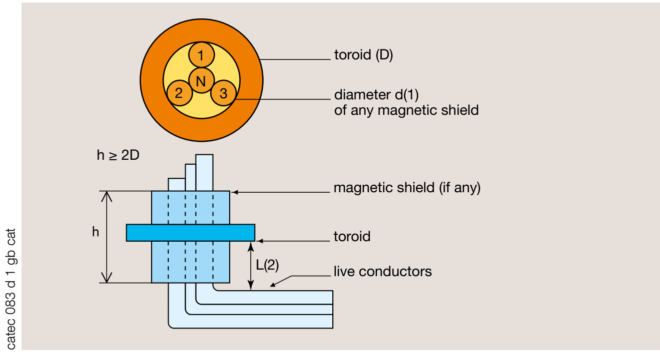
Implementing at the origin of a TT installation

At the origin of a TT installation (and only in this case), it is possible to replace the detection toroid placed around live conductors by a single toroid linking the HV/LV transformer neutral to the earth. This arrangement improves immunity to disturbances and has the advantage of being more economical.

Increasing immunity to disturbances of a toroid by:

- symmetrical arrangement of the phase conductors around the neutral conductor,
- using a toroid with a diameter of at least equal to twice that of the circle formed by conductors: D ≥ 2d,
- possible addition of a magnetic shield, with a height at least equal to 2D.





(1) d = the centring of the cables in a toroid guarantees the local non-saturation of the toroid. A saturated toroid causes spurious trippings.
(2) L = distance between the toroid and the bend in the cables.

Indication of test conditions of differential devices

Complementary marking should be provided to indicate to the user that the test must be activated regularly (every 3 to 6 months is recommended).

Choosing a differential device according to the protection to be provided

Standard NF C 15100 § 531.2.3 stipulates a choice depending on the type of protection to be provided:

- protection against indirect contacts (sensitivity to be chosen depending on admissible contact voltage),
- complementary protection against direct contacts (IΔn 30 mA),
- protection against fire risk IΔn (300 mA).

Choosing a differential device in IT load

Standard NF C 151 00 § 531.2.4.3

To avoid spurious tripping of RCDs protecting against indirect contacts, for average sensitivity RCDs the device's rated residual differential current (IΔn) must be higher than double the value of the leakage current (If) that flows during a first fault **IΔn > 2 x If.**

Implementation (continued)

Choosing a differential device according to auxiliary power supply principles

The level of operator skill and the operational purpose of the installation will, according to standard IEC 60364. determine the choice of the differential protection devices depending on the type of operation linked to the power supply principle.

Type of differential device	Possible choice depending on type of installation	
	Uninformed personnel (BA1)	Tried and checked by personnel at least informed (BA4)
With auxiliary source independent of the network	NO	YES
Operating independently of the network voltage	YES	YES
With operation dependent on the network voltage or on any fail-safe auxiliary source	NO	YES
With operation dependent on the network voltage without a fail-safe	NO	YES except PC 16 A circuits
With operation dependent on the voltage of an auxiliary source without a fail-safe	NO	YES except PC 16 A circuits and signalling of an aux. source fault.

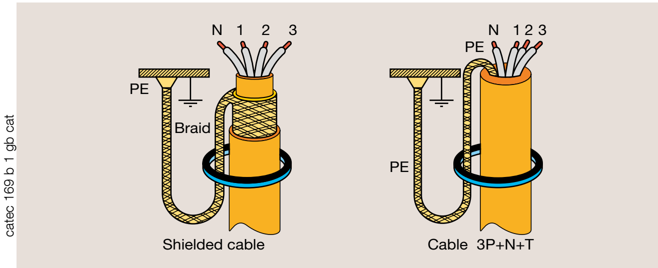
Note: a transformer connected to the network does not constitute an auxiliary source independent of the network.

Characteristics of a differential device with auxiliary source

- Monitoring independent of the monitored circuit voltage.
- Suited to networks with high and rapid fluctuation.
- Monitoring independent of the load current (surge of non-balanced currents, coupling of inductive loads).
- Better immunity to tripping in cases of transient faults
  (integration time in the region of 30 ns, whereas a device with its own current risks tripping in a few ms).

Precautions when installing toroids on armoured cables

Armoured cable: insulate electrically from the connection box, and connect it to earth.



Choosing class of differential devices according to loads

Equipment is increasingly fitted with rectifying devices (diodes, thyristors, etc.). Earth fault currents downstream of these devices have a DC component capable of desensitising the RCD.

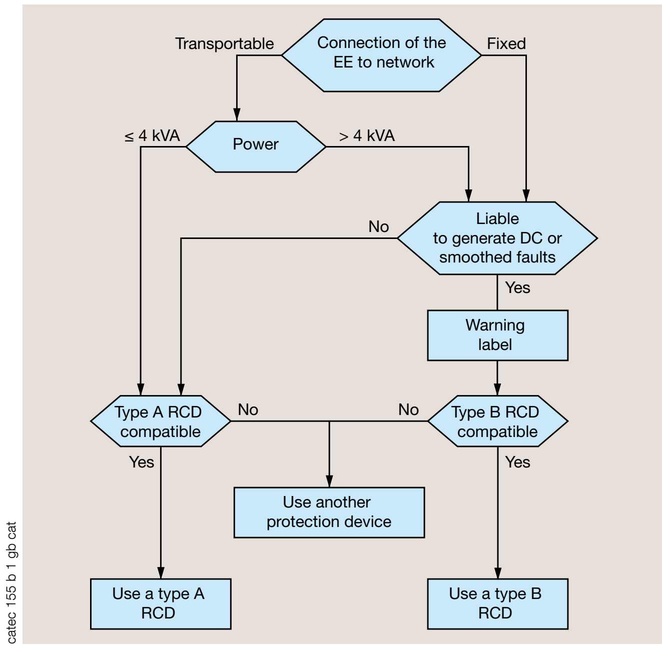
Differential devices must be of the class suited to the loads (see chapter on definition of classes).

Standard EN 50178 stipulates the following organisation diagram which defines requirements when using EE behind a differential device (EE: electronic equipment).

Transportable EE whose rated apparent input power does not exceed 4 kVA, must be designed to be compatible with type A RCDs (protection against direct and indirect contact).

Any EE which risks generating DC component fault current that risks interfering with the operation of the differential protective devices must be accompanied by a warning label which says so.

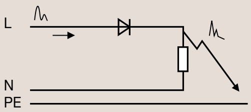
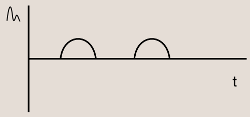
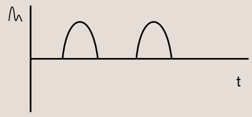
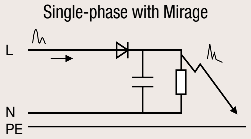
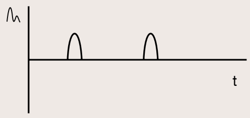
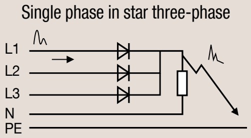
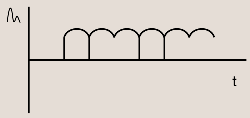
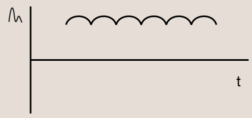
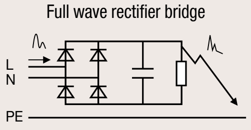
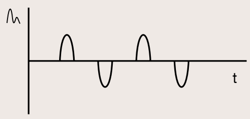
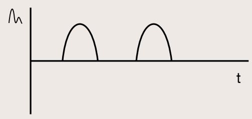
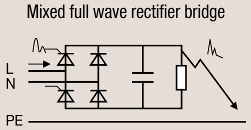
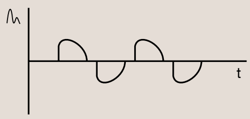
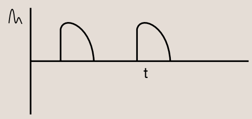
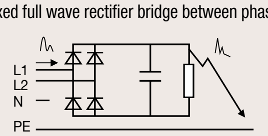
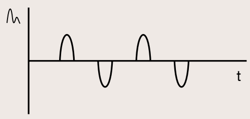
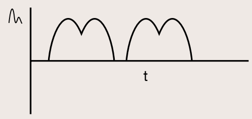
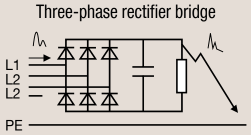
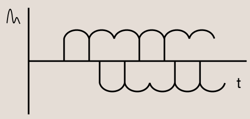
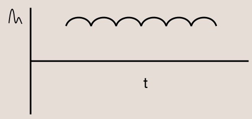
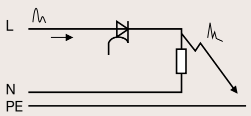
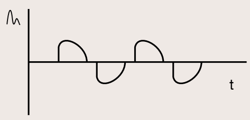
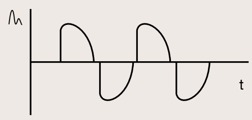
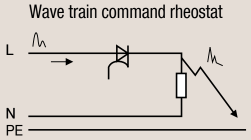
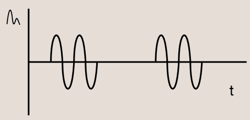
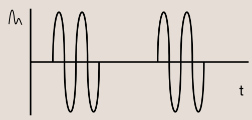
When the RCDs cannot be compatible with the EE to be protected, other protection measures must be adapted, such as: isolating the EE from its environment by double or reinforced insulation, or insulating the EE from the network by using a transformer, etc.



Implementation (continued)

Choosing class of differential devices according to loads (continued)

Standard EN 61800-5-1 offers a choice of RCD class according to the internal electronics of the receptors.

	Class required	Installation	Normal supply current	Earth leakage fault current
1	≥ A	Single-phase 		
2	B	Single-phase with Mirage 		
3	B	Single phase in star three-phase 		
4	≥ A	Full wave rectifier bridge 		
5	≥ A	Mixed full wave rectifier bridge 		
6	B	Mixed full wave rectifier bridge between phases 		
7	B	Three-phase rectifier bridge 		
8	≥ AC	Phase command rheostat 		
9	≥ AC	Wave train command rheostat 		

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Implementation (continued)

" Industrial " loads

The most common devices are of AC class, but the real situation of industrial installations justifies the use of at least A class devices.

Speed variator type loads

As this type of load fluctuates considerably, class B relays, independent of the voltage and current, will be even more particularly suited to prevent risks of non-tripping.

Grouping of uses according to load type

Installations must group together the types of devices which cause identical faults.
If loads are liable to generate DC components, they must not be connected downstream of devices intended to protect loads that generate, in fault, only AC or pulsed rectified components.

Signalling or pre-alarm of a leakage or fault

In installations where continuity of operation is imperative and where the safety of property and people is particularly at risk, insulation faults constitute a major risk that it is particularly important to take into account.

The signalling function may be performed in two ways:

1. the automatic breaking of the power supply for imperative reasons of protection (protection against direct and indirect contact, or limiting the leakage current) is provided by differential devices, the signalling function may be provided by the pre-alarm relays which are incorporated in certain differential relays. These products with pre-alarm that meet the recommendation in § 531.2.1.3 requiring that the sum of prospective leakage currents be limited to a third of the rated operating current.

2. the automatic breaking of the power supply for imperative reasons of protection (protection against direct and indirect contacts, or limiting the leakage current) is provided by other devices, such as for example, protection devices against overcurrents. The relay contact alarm may therefore be used only for signalling a differential current.

Preventive signalling of insulation faults provides optimisation of an electrical installation by:

- anticipating a machine repair before the process is stopped or on fault,
- locating insulation faults in TNS neutral loads,
- preventing risks of fire, explosion, etc.,
- anticipating the operation of an overcurrent protection device and thus avoiding the replacement of the fuse or the ageing of the circuit breaker,
- controlling the leakage currents and thus reducing the homopolar currents in protection circuits, and reducing the generating of particularly disturbing electromagnetic fields,
- etc.

Insulation Monitoring

General points

Introduction

Standards NF C 15100 (§ 411.6.3) and IEC 60364 impose the use of a permanent Insulation Monitoring Device (IMD) in IT arrangements IT: "A permanent insulation monitoring device must be designed to indicate the first occurrence of a live mass or earth fault; It must trigger an audible or visual signal."

IMDs must meet the requirements set out in standard NF EN 61557-8.

SOCOMEC offers a wide range if IMDs from the ISOM range.

IMDs must have the measuring principles chosen according to the nature of the circuits to be monitored:

- those which apply a DC measuring current only in AC current installations (i.e. with no rectifiers that risk generating a DC component in case of downstream fault),
- those which apply an AC measuring current in AC and DC installations (i.e. with rectifiers without upstream galvanic isolation).

Certain SOCOMEC IMDs are fitted with an AMP measuring device (called pulse-code) that provide monitoring in all measuring cases and particularly where installations could generate components that will inhibit the IMDs measuring signals. These loads are, for example, variable speed drives, or any other power electronics equipment.

Operating principle

The majority of IMDs inject a measuring current in the loops formed by the live conductors and the earth (fig. 1). An increase in measuring current signifies a circuit insulation decrease.
Measuring current is compared with the IMD alarm threshold.

Correct IMD operating in the ISOM range does not require a high measuring current.

The 1 kW impedance normally added between the circuit to be monitored and the earth (impeding neutral) is unnecessary for the SOCOMEC IMDs.

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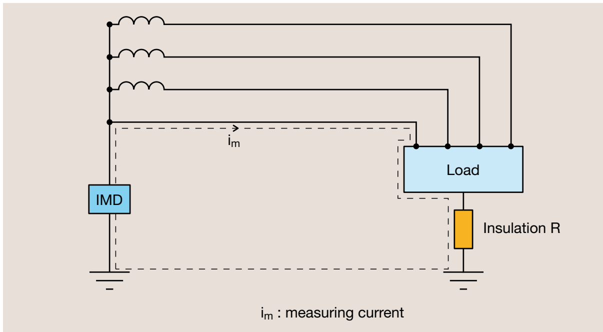

Fig. 1 measurement of an installation's insulation resistance by an IMD.

Settings

Standard NF C 15100 § 537.1.3 proposes a preventive threshold set to 50% of the installation's insulation and an alarm threshold under 1 kW.

The choice of higher insulation thresholds guarantees better control of service continuity.

This choice of more suitable settings allows for:

- anticipating the fault location from several dozen kW and and to guarantee better preventive control of faults,
- limiting the flow of leakage currents that can trigger tripping of high-sensitivity differential devices.

When integrating an IMD in an installation, account must be taken of the fact that this device will measure the overall insulation of the installation, i.e. the sum of the individual leakage resistances of each feeder.

$$\frac{1}{Re} = \frac{1}{R1} + \frac{1}{R1} + \frac{1}{Rn} \quad (R1.\ R2.\ Rn \geq 0.5\ M\Omega)$$

Note: the IMD can indicate a decrease of insulation resistance without there being a dead short (presence of humidity after prolonged switching off, for example). Installation start-up will restore the level of insulation.

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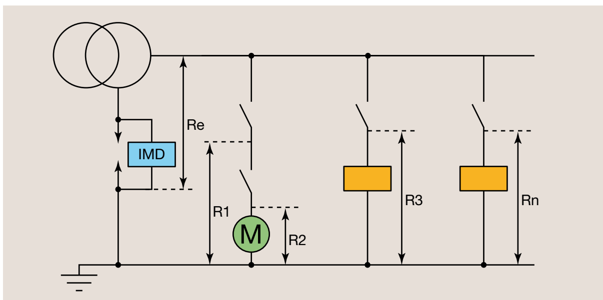

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Definitions

Split network

A split network is characterised by:

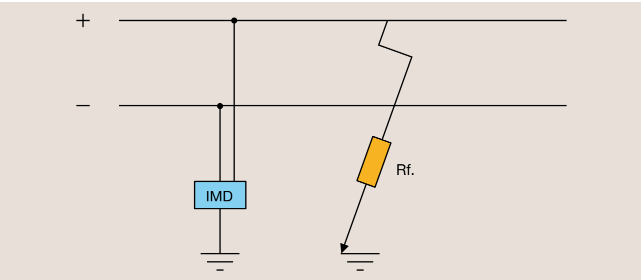
- a single receptor or receptors of the same type (motors, safety lighting, etc.),
- a moderately extended circuit (low earth leakage capacitance) and clearly located circuit (workshop, operating theatre, etc.),
- a well-defined circuit (only AC or DC loads).

Global network

The opposite, a global network, has various receptors and rectifiers (with AC and DC currents). The network is often an extended one (high earth leakage capacitance).

Asymmetrical fault (DC network)

An asymmetrical fault only affects one of the network's polarities.



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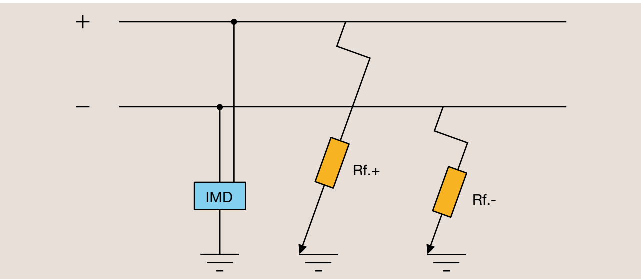
Symmetrical fault (DC network)

A symmetrical fault affects both polarities of the network. This type of fault often develops in circuits where the respective lengths of the + and - conductors are comparable.
Since the end of 1997 standards IEC 61557-8 and EN 61557-8 have required that DC circuits be monitored by IMDs capable of detecting symmetrical faults.



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Insulation resistance of the electrical installation

This is the installation's insulation level with regard to the earth. It must be greater than the values given in standard NF C 15100.

Table A: minimum insulation resistance values (NF C 15100 - § 612.3) with power off

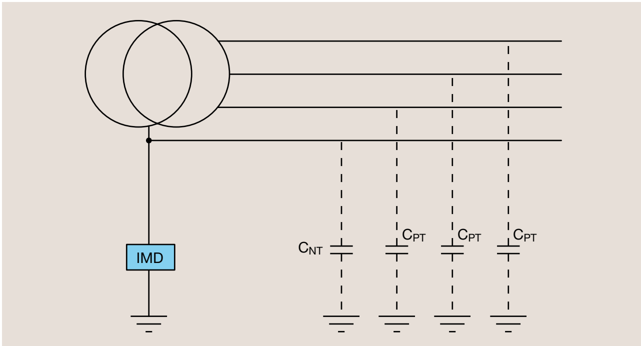
Circuit nominal voltage (V)	DC test voltage (V)	Insulation resistance (mΩ)
SELV and PELV	250	≥ 0.25
500 V	500	≥ 0.5
> 500	1 000	≥ 1.0

Receptor insulation

- Rf Motor > 0.5 MW
- Rf > x MW according to product standard.

Conductor earth leakage capacitance

When two conductors have a potential difference (voltage), there is a capacitive effect between them according to their geometric shape (length, shape), to the insulation (air, PVC etc.) and to the distance between them.
This physical characteristic can trigger a capacitive leakage current between network conductors and the earth. The more extended the network, the higher the current will be.



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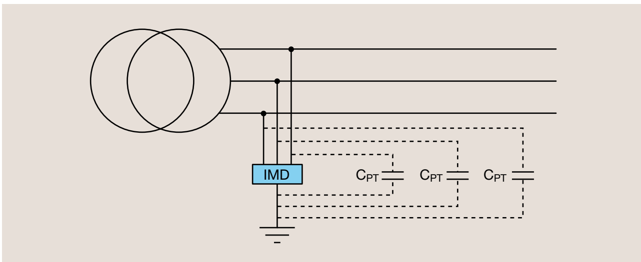
Earth leakage capacitance in an AC network.

Maximum earth leakage capacitance

This is the sum of the network's earth leakage capacitance and the capacitance of the capacitors installed in the electronic equipment, computer equipment, etc.
Maximum earth leakage capacitance is an important parameter when choosing an IMD. It should be noted that the overall leakage capacitance has considerably increased due to ECM filters (in the region of several hundred nF for a filter).



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Uses

Premises used for medical purposes IMD HL

Such premises require particularly strict measures linked to the continuity of electrical network service and the protection of patients and users of the medical equipment.

Standard NF C 15211

This standard describes the specifications intended to assure the electrical safety of people in premises used for medical purposes, taking into account the particular risks due to the treatments performed in these premises and the specifications relating to the electrical supply of the premises.

Applicability
The measures of this standard are applicable for works whose planning permission dates from 31st January 2007.

Medical IT arrangement

The standard defines the implementation of "levels of criticality" for certain medical activities, with - as a consequence - the classification of dedicated premises into group 0. 1 and 2. Should the medical or healthcare manager choose to classify certain premises in group 2. the electrical distribution will therefore be done according to the rules of IT arrangement.

Directly concerned premises

- Operating theatre,
- Intensive care unit,
- Interventional radiology.

Consequences of the medical IT arrangement

- Implementation of an isolating transformer conforming to standard NF EN 61558-2-15 with power limited to 10 kVA maximum. Generally of 230 VAC single phase type, its phase to phase voltage must not exceed 250 V in case of three-phase secondary.
- The ISOM TRM transformers perform this isolation between the hospital building's general distribution network and the electrical distribution intended for premises where patient safety must not be jeopardized in case of insulation fault.
- Implementation of an IMD specially provided with the following characteristics:
  - AC internal resistance ≥ 100 kW,
  - measuring voltage ≤ 25 VDC,
  - measuring current ≤ 1 mA,
  - adaptation of the measuring principle to the nature of the receptors, especially in the presence of DC components (electronic loads),
  - IMD set to 150 kW.

It is particularly important to choose IMDs that function according to the pulse-code measuring principle. These guarantee optimum measurement, especially in operating theatres that use equipment supplied with wave-cutting technology without galvanic isolating transformer.

- Mandatory monitoring of overloads and transformer temperature rise.
  the ISOM HL IMDs integrate current and temperature inputs that can centralise - in the same way as the alarm linked to a decrease in insulation - an overload or overheating of the isolation transformer. The information is available on the IMD's output RS485 bus .
- Obligation to alert medical personnel with audible or visual alarm and to send it to a place that is permanently monitored. The ISOM RA alarm transfers enable the retrieval of information provided by the IMD CPI HL (insulation fault, transformer overload and overheating) and to forward the data in a clear and legible way to the operating theatre. It can also be sent to the technical monitoring premises (communication by bus RS485).

Other associated solutions

For IT arrangement, standard NF C 15100 § 537.3 strongly recommends associating a fault location system to the IMD. This logic also applies in medical IT arrangement, especially bearing in mind the urgency and critical context of premises used for medical purposes and the interventions that are carried out in such places.
The ISOM DLD insulation monitoring device associated with the insulation fault test device dedicated to medical IT arrangement ISOM INJ with detection current limited to 1 mA guarantees a rapid location of the feeder in fault.
SOCOMEC also offers the supply of electrical distribution enclosures in premises used for medical purposes. The offer includes full design, manufacture, supply of main components (transformers, UPS, mains supply changeover systems, measuring and protection devices, enclosures) as well as commissioning and associated training.

Uses (continued)

Monitoring the insulation of dead motors (e.g. IMD SP 003)

Monitoring the insulation of dead motors is a preventive measure when equipment safety and availability requirements are obligatory:
- critical cycles in industrial processes,
- strategic or large motors.

In a security installation an IMD must (according to NF C 15100 § 561.2) assure the monitoring of equipment insulation:
- safety equipment: fire fighting motors,
- smoke extractor installations.

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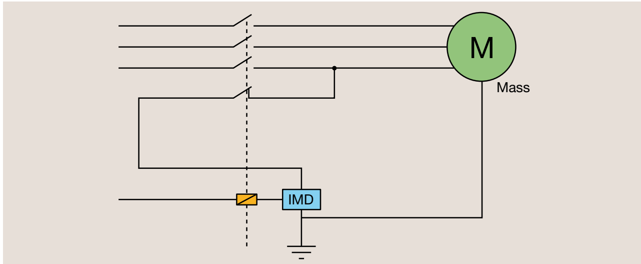

Assembly principle: the IMD is off circuit when the motor is supplied.

Adjustment of the IMD monitoring a dead motor

The alarm threshold will generally have a value higher than 1 MW, which may be given by the first threshold of the IMD.

The motor must not be used when insulation resistance is less than 300 kW; in this case the SP-type IMD's second threshold can provide the preventive cut-off to prevent start-up of a motor in fault.

Type SP IMDs are specially designed for the monitoring of the insulation with the power off, and are also a means of rapidly locating transient faults thanks to their memory function (examples: points motors, rapid process port cranes).

Monitoring special installations and sites

- In sites with risk of explosion (BE3), according to standard NF C 15100 § 424.8. it is acceptable to use an IMD to monitor the insulation of security circuits supplied by CR1 type cable. This monitoring can be done with the power on or off.
- On building sites whose electrical installation is in IT arrangement according to § 704.312.2. the monitoring of insulation by IMD is mandatory.
- To assure protection against fault currents on heating devices, the impedance of the IMD as well as the characteristics of the RCD must be chosen in such a way as to assure breaking at first fault according to § 753.4.1.

Monitoring speed variators

The monitoring of speed variators must take into account the low frequencies that they generate.

Only IMDs and search devices with measuring principles using coded signals different to those generated by the variators, can, over time, correctly perform their function.

Mobile generator sets

Protecting circuits supplied by mobile generator sets is often difficult to organise because earthing is not possible (portable sets, emergency rescue, etc), or because earthing is not considered valid (resistance impossible to measure, etc.).

This sort of protection is often provided by 30 mA RCDs which has the disadvantage of spurious tripping *(see page 39)*. In cases where continuous operation is imperative for safety reasons, an IMD may be used (see fig. 1).

The set mass is not linked to the generator mid-point, but to the network consisting of the interconnected masses of the equipment. The IMD is inserted between this mass and a phase. This measure meets the requirements of article 39 of the French decree of 14.11.88 on the separation of circuits and chapter 413.2.3. of standard NF C 15100. Traditional devices can also be perfectly suitable if their implementation integrates environmental stress (vibration, tropicalisation, hydrocarbon resistance, etc.).

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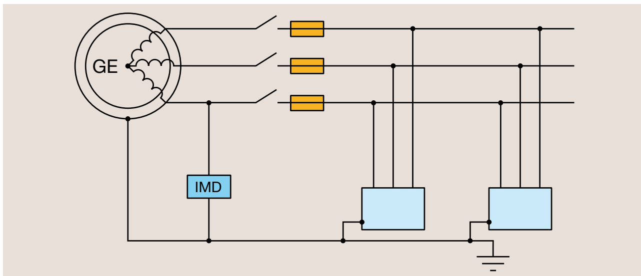

Fig. 1 use of an IMD for a circuit supplied by generator sets

Monitoring feeders with high disturbance by DLD

Low frequencies

Chapter 537.3 of standard NF C 15100 recommends the use of a DLD to locate the fault and thereby minimise the time spent in searching. The standard to be taken into consideration is NF EN 61557-9. SOCOMEC DLDs (DLD 460-12) are compatible with this standard. They have a synchronisation device by RS485 bus that enables quick fault location, even in networks with high disturbance. Fault location in this type of circuit is controlled by the synchronisation of the search current injections and the analyses by the locators.

High frequencies

The central locator has measurement validation function by renewing analysis cycles on request.

High homopolar currents

DLD toroids are equipped with clipping diodes controlling potential overvoltages on the secondary.

Uses (continued)

Networks supplied by UPS

Static Uninterruptible Power Supply systems comprise a DC component. It is required (UTE C 15402) that the installation supplied by DC current be grouped together in the same area so as to ensure protection of masses by equipotentiality. When it is not possible to apply this requirement, an IMD must be installed to monitor the installation's correct insulation when supplied by DC current.

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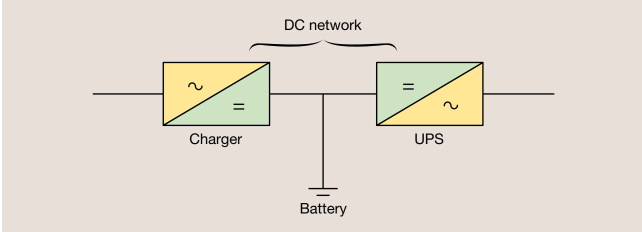

Other general criteria for UPS installation

- Not having, at the same time, two IMDs monitoring networks that are galvanically interconnected (particularly in the BY-PASS phases).
- Providing for the installation of an IMD adapted to the network being monitored..

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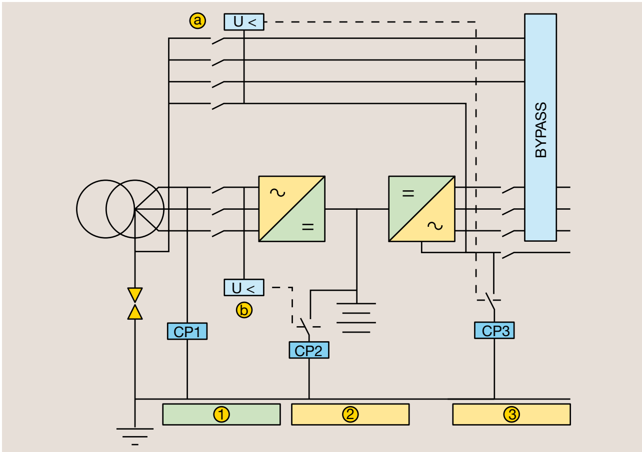

1. IMD which can monitor circuits with DC components and high leakage capacitances.

2. IMD which can monitor DC circuits with symmetrical faults.

3. IMD which can monitor AC circuits, note (a) and (b), control system avoiding the use of IMDs in parallel on networks not galvanically insulated.

Monitoring of control and signalling circuits

These circuits, generally supplied by isolating transformers, must ensure non-spurious tripping of power circuits. A common solution, proposed by standards and regulations is to have a wiring system with a TN arrangement (common point coil linked to earth). Another possibility meets these requirements by integrating the secondary's non-connection to earth combined with an IMD.

This solution presents shunting risks on actuators due to an insulation fault. This fault may be both sufficient for controlling actuators and too weak to trip an overcurrent protection.

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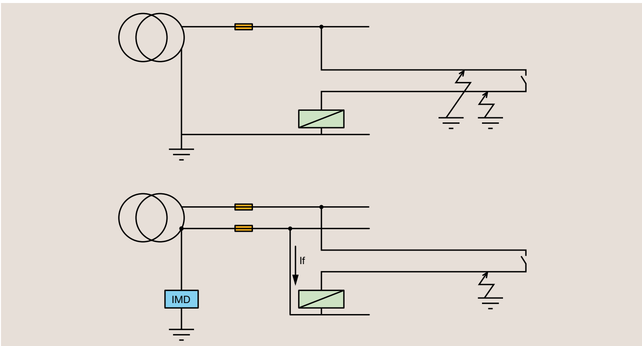


These risks are greater on new equipment for two main reasons:

- operating voltages are low and do not facilitate fault detection,
- control auxiliaries' operating thresholds are increasingly sensitive, to a few tens of mA (micro-relay, PLCs, optocouplers, etc).

Compared to an earthed solution, using an insulated network linked to an IMD offers the double advantage of not tripping at the first fault, and providing preventive monitoring of equipment ageing.

IMD adjustment

$$Zm = \frac{U}{ir}$$

U: control circuit maximum supply voltage.
ir: smallest relay dropout current.
Zm: IMD adjustment impedance.

Fault search systems such as DLD 260 and the portable DLD3204 system allow preventive location of insulation faults, without changing the status of the actuators or operating controls thanks to a search current limited to 1mA.

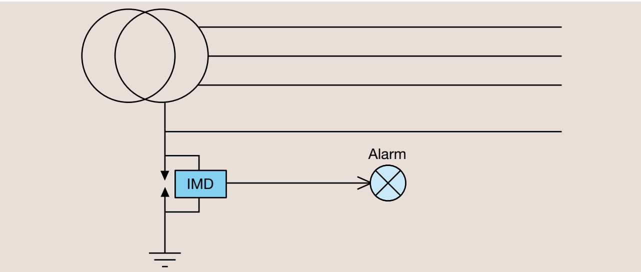
IMD connections

General case

Connecting an IMD is normally done between the transformer neutral point located at the IT installation origin and the earth.

The installation must have an alarm device and an overvoltage protection (if HV/LV transformer).

Using ISOM IMDs does not require and impedance of 1 kW in parallel *(see operating principle on p. XXX)*.



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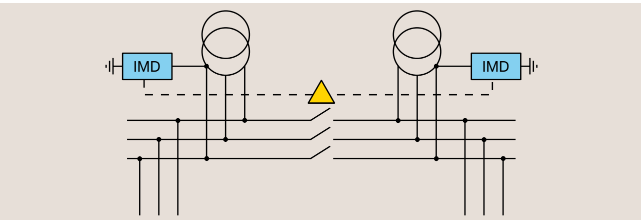
Power supply by several transformers in parallel

The use of an IMD common to two power sources is no longer accepted by standard NF C 15100 § 537.1.2.

It is necessary to connect an IMD per power source and to make sure they are electrically "interlocked".

The SOCOMEC IMDs for this purpose have inputs/outputs and/or bus (depending on model) so as to inhibit one or the other IMD in this operating mode.



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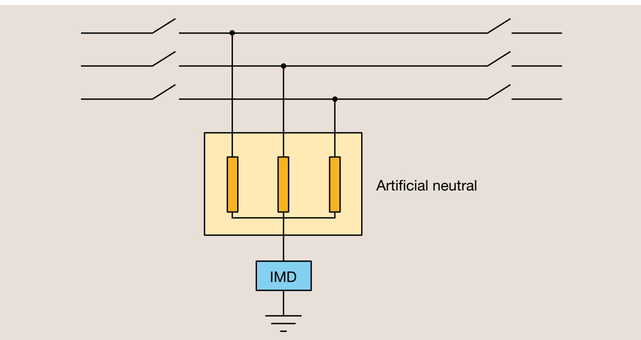
Monitoring a dead network

Using an artificial neutral



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Connection and protection of IMD measuring circuits

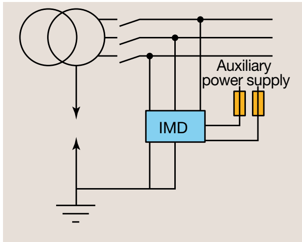

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Fig. 1 IMD connection downstream of main switch.

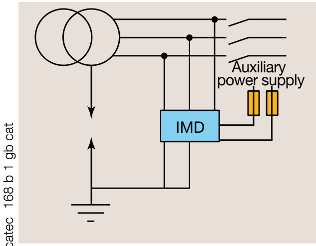

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Fig. 2 IMD connection upstream of main switch.

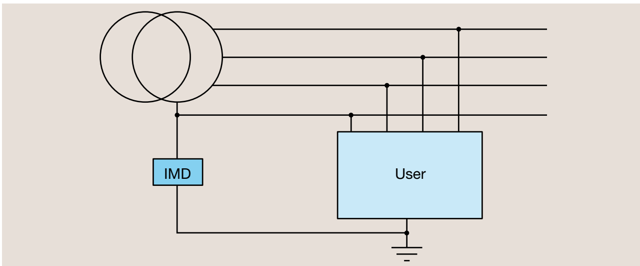
Protection against short circuits is currently not permitted by NF C 15100 in order to avoid a risk of non-measurement, but supposes an appropriate installation to avoid short circuit risks (no passing of conductors over sharp busbar edges and over insulated conductors).

Self-monitoring of the network connection of most SOCOMEC IMDs makes the above provision unnecessary:

- Connection of the IMD before the transformer coupling switch, avoids control systems between IMDs where the networks are coupled (fig. 2).
- Connection of the IMD after the transformer coupling switch, allows preventive measurement on the dead network (measuring signal present on the phases and not requiring looping via the transformer windings) (fig. 1).

Neutral accessibility

In this case, the IMD is inserted between the transformer neutral and the nearest mass earth connection or if not, the neutral earth connection.



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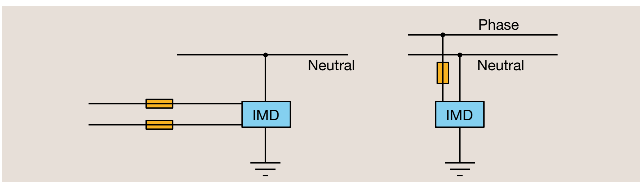
IMD connections: inaccessible earth

This type of connection also avoids the installation of protection on the measuring conductor in IMD (short circuit-type overcurrents being improbable).

Auxiliary power supply connection

Certain IMDs have an auxiliary power supply. This makes them insensitive to voltage variations. The auxiliary power supply inputs must be protected:



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Overvoltage limitor

General points

The Overvoltage Limitor (OL) meets the requirements of articles 5 and 34 of the French decree of 14.11.88. It is designed to make overvoltage and fault currents flow to the earth.

Protection against overvoltage

The OL ensures the flow to earth of overvoltages coming from HV networks.

Accidental flashover between HV and LV circuits risks taking the potential of an LV installation and earth to a dangerous level.

In cases of detecting this type of fault, the OL permanently short circuits the neutral and earth, thus allowing protection of the LV network. After operating as an overcurrent limitor, the OL must be changed, particularly for an IT arrangement, to enable the insulation regulator to correctly resume monitoring.

Current limiting inductors

Although limitors can withstand fault currents of 40 kA / 0.2 sec., in high power installations it is always preferable to limit the current to 10 or 15 kA in order to take into account the possibility of a 2nd fault on the busbars, in which case the neutral phase short circuit current can exceed 20 kA. Such limitation is done using specific inductors.

Effective protective level ensured by an overvoltage limitor

		Limitor connected between neutral and earth		Limitor connected between phase and earth	
Installation nominal voltage (V)	Admissible voltage limitation U_0 + 1200 (V)	Limitor nominal voltage (V)	Effective protective level (V)	Limitor nominal voltage (V)	Effective protective level (V)
127/220	1330	250	880	250	970
230/400	1430	440	1330	(*)	(*)
400/690	1600	440	1500	(*)	(*)
580/1000	1780	440	1680	(*)	(*)

(*) Standardised voltage limitors do not allow voltage protection.

Power frequency nominal sparkover voltage

Limitor nominal voltage (V)	Non-primer nominal voltage (V)	Primer nominal voltage at 100 % (V)
250	400	750
440	700	1100

The primer nominal voltages of overvoltage limitors conform to standard NF C 63-150.

OL connection and inductance

The earth terminal must be linked:

- either to all the installation's interconnected masses and conductors,
- or to a remote earth outlet of appropriate value.

If there are several transformers in parallel, an OL must be fitted for each transformer. For installations with non-accessible neutral, ensure that all OLs are connected to the same phase.

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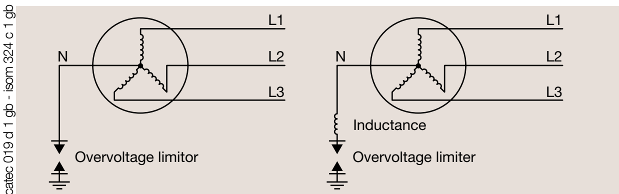
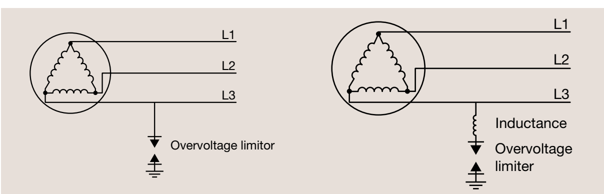


One single transformer - accessible neutral.

catec 021 d 1 gb - isom 325 b 1 gb



One single transformer - non-accessible neutral.

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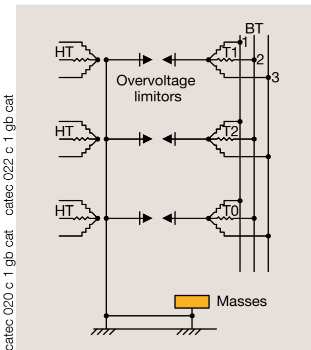

"n" transformers in parallel - accessible neutral.

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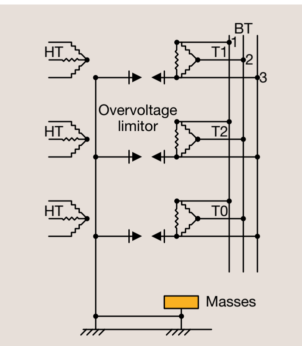

"n" transformers in parallel - non-accessible neutral.

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Innovative Power Solutions

Protection against transient overvoltages

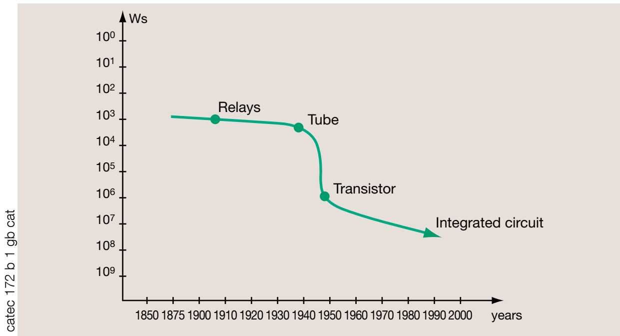
Good quality low voltage power supply is indispensable for a service or industrial site, as all the equipment shares it.
A global approach to disruptive phenomena is therefore extremely important for the overall reliability of the electrical installation.
Among the phenomena that can disrupt the operation of equipment connected to the mains network are the aggressive overvoltages that should be taken into account, as they are at the origin of particularly disruptive, even destructive, secondary effects.
Apart from overvoltage caused by lightning, industrial overvoltage is also a reality.
Systematic protection against overvoltage is therefore recommended for any type of electrical installation, as shown in the high amount of damage or unexplained recurrent breakdowns of operating equipment.

Operating constraints and equipment susceptibility

The necessity of providing systematic protection is explained by the following factors:
- increasing equipment susceptibility,
- proliferation of sensitive equipment,
- minimum tolerance to service interruptions,
- prohibitive downtime costs,
- increased awareness on the part of insurance companies to overvoltage phenomena.

Effects on electronic components

The graph below shows the growing decrease in equipment robustness as the technology evolves: as a consequence, problems of reliability when exposed to transient disturbance will only increase.



Admissible power according to technology

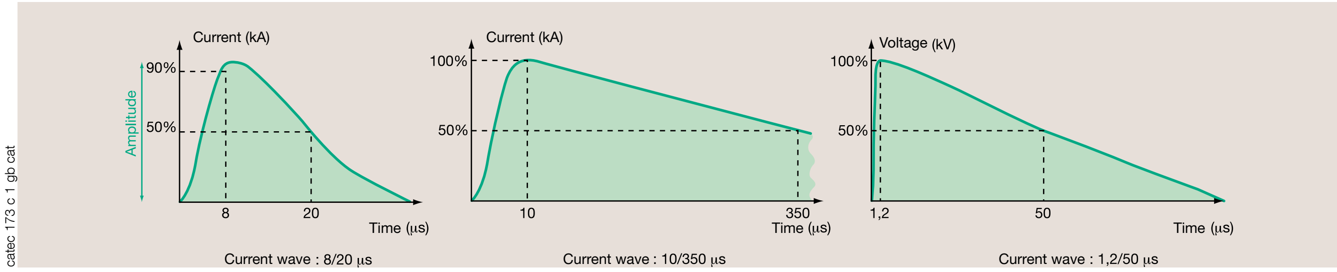
- Destruction (partial or total) of:
- component electroplating,
- triacs/thyristors,
- sensitive integrated circuits (MOSFET).
- Operating disruptions: jammed programmes, transmission errors, operating stoppage.
- Accelerated ageing or deferred destruction: significant reduction in component lifetime.

Transient overvoltages

SURGYS® surge protective devices (SPD'S) are devices designed to provide protection for equipment and electrical installations by limiting “transient-type” overvoltages.
A transient overvoltage is a sudden increase in voltage, generally of high frequency (several hundred kV) and of short duration (several microseconds to several milliseconds) compared to the network or electrical circuit’s rated voltage.

Protection against transient overvoltages (continued)

Standard waves



Definition of transient voltage or current waveforms.

Transient overvoltages in LV networks and low current circuits (communication networks, current loops, telephone lines) are due to different events and can be mainly classified into two categories:

- industrial overvoltages (or similar and linked to human activity),
- overvoltage due to lightning.

Transient industrial overvoltages

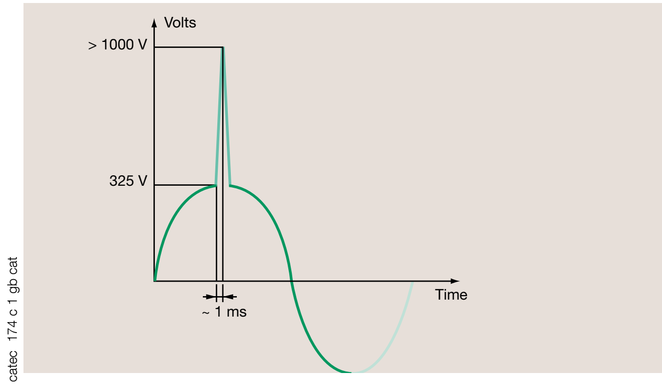
These are becoming more and more numerous in networks today, and can be divided into:
- switching and changeover overvoltage,
- interaction overvoltages between networks.

Origins of switching overvoltages

Certain overvoltages are due to intentional actions on the power network (e.g. switching a load or a capacitance) or linked to automatic functions such as:

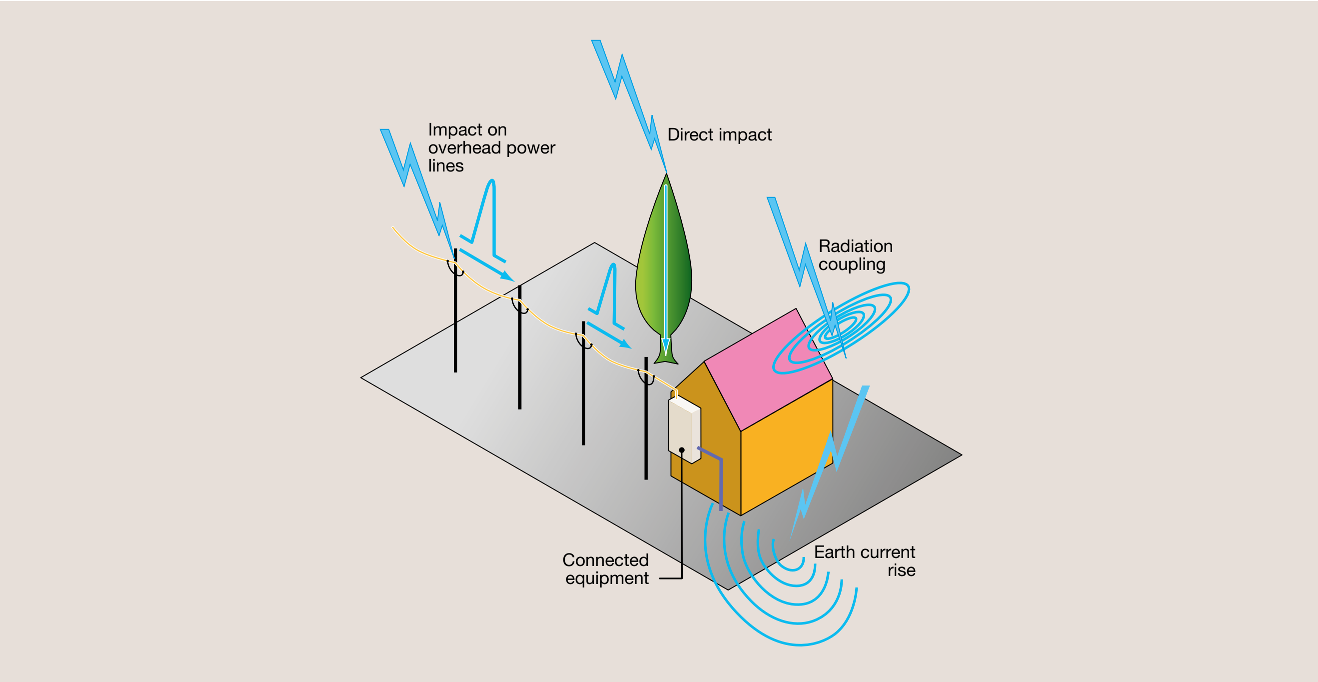
- opening/closing of the circuit by switching devices,
- operating phases (start-up, hard stop, switching on lighting devices, etc.),
- electronic switching overvoltage (power electronics).

Other overvoltages are due to unintentional events such as faults in the electrical installation and their elimination via the unexpected opening of protective devices (differential devices, fuses, and other protective devices against overcurrents).



Overvoltage after a fuse melting.

Overvoltages caused by lightning



Overvoltages of atmospheric origin arise from uncontrollable sources and their severity for the load depends on many parameters that are determined according to where the lightning strikes and the structure of the electrical network.

The impact of lightning on a structure produces spectacular results, but nevertheless is very localised. Protection against the effects of a direct lightning strike is provided by lightning conductors and is not covered in this document.
A lightning strike creates overvoltages that propagate along any type of electrical cabling (electrical distribution mains, telephone connections, communication bus, etc.), metallic wiring systems or conducting elements of significant length.
The consequences of lightning, i.e. the overvoltages created on the installations and equipment, can be appreciable over a radius of 10km.
Such overvoltages can be classified according to their point of impact: direct, near or distant lightning strikes. For direct lightning strikes, the overvoltages are caused by the flow of lightning current in the structure concerned and its earth connections. For near lightning strikes, overvoltages are created in the loops and are in part linked to rises in earth potential due to the flow of lightning current.
For distant lightning strikes, the overvoltages are limited to those created in the loops. The occurrence of overvoltages due to lightning and their characteristics are statistical in nature and much data remains uncertain.

All regions are not equally exposed and for each country there generally exists a map that indicates the density of lightning strikes (Ng = annual number of lightning strikes on earth per km2. NK = isokeraunic level, Ng = Nk / 10).
In France, the number of lightning strikes on earth is between 1 and 2 million. Half of these lightning strikes that reach earth have amplitude of under 30 kA, and less than 5% exceed 100 kA.

Protection against the effects of direct lightning strikes

The protective principle is to attempt control of the point of impact by attracting the lightning on to one or several specified points (the lightning conductors) that are placed away from the places to be protected and by letting the pulse current flow to earth.
Several lightning conductor technologies exist and can be of the following types: stem, meshed cage, taut wire or even priming device. The presence of lightning conductors on a facility increases the risk and amplitude of pulse currents in the earthing network. The use of SPD'S is therefore necessary to avoid increasing damage to the installation and equipment.

Protection against indirect effects by SPD

The SURGYS® range of SPD provides protection against transient overvoltages as well as protection against the effects of indirect lightning strikes.

Conclusion

Irrespective of statistical considerations for lightning and the corresponding recommendations set out in ever-changing installation standards, protection against overvoltages by SPD is today systematically demanded for any type of industrial or service activity. For the latter, the electrical and electronic equipment is strategic and expensive, and not ponderable as certain domestic appliances might be.

Main regulations and standards (non-exhaustive list)

Foreword

This Application Guide is not a substitute for the regulations and standards currently in force. Please refer in all cases to the official documents.

Regulations or recommendations requiring the implementation of protection against the effects of lightning

Strict obligation

- Classified facilities for the protection of the environment (ICPE) subject to authorisation (French decree of 15 January 2008 and its scope of application dated 24 April 2008 relative to protection against lightning for certain classified installations)*
- New, simple and solid depots storing nitrate-based fertiliser (French decree of 10 January 1994)
- Pre-sorted household, assimilated industrial and commercial refuse sorting centres (DPPR 95-007 circular of 5 January 1995)
- Facilities specialised in incineration and co-incineration of certain special industrial waste (French decree of 10 October 1996)
- Refrigeration facilities using ammonia as refrigerating agent French decree of 16 July 1997)
- Nuclear facilities (French decree of 31 December 1999)
- Silos and facilities used for storing cereals, grain, foodstuff or other organic substances releasing flammable dust (French decree of 15 June 2000)
- Places of worship: steeples, church towers, minarets (French decree of 16 September 1959)
- High-rise buildings (French decree of 24 November 1967 and 18 October 1977)
- Firework factories (French decree of 28 September 1979)
- High-altitude hotels and restaurants (French decree of 23 October 1987)

** This decree clearly mentions the obligations to be respected and the actions to be carried out:*
- carry out a lightning-risk analysis to identify the equipment and facilities that need to be protected,
- conduct the necessary engineering design,
- protect the facility in accordance with the engineering design,
- carry out checks of the lightning protection measures that have been implemented,
- assure that all measures carried out have been approved by a relevant inspection body.

Places where protective measures are recommended

- Multiplex-type theatres
- Open metallic structures receiving public in tourist areas
- Open-air assemblies of whatever nature, receiving high numbers of public and lasting over several days
- Old people's homes (French decree circulars of 29 January 1965 and 1 July 1965)
- Various military facilities (e.g. standards MIL / STD / 1 957A)
- Warehouses covered with combustible, toxic or explosive materials (French decree circular of 4 February 1987 and Decree type N° 183 ter)
- Oil extraction workshops (directive of 22 June 1988)
- Oil industries (guide GESIP 94 / 02)
- Chemical industries (UIC document of June 1991)

Main regulations and standards (non-exhaustive list) (continued)

Standards for surge arresters

Implementation standards

Until 2002. the use of surge arresters to protect equipment connected to LV networks was not mandatory, and only certain recommendations were set out.

Standard NF C 15100 (December 2002)

- Section 4-443: “Overvoltages of atmospheric origin or due to switching operations”. This section defines the level of obligation and use for surge arresters.
- Section 7-771.443: “Protection against overvoltages of atmospheric origin (surge arresters)”. Similar to section 4-443. but applicable to residential premises.
- Section 5-534: “Protective devices against voltage disturbances”: contains the general rules for choosing and implementing LV surge arresters.

UTE C 15443 user’s guide

This guide gives more complete information for the choice and implementation of SPD'S, and also provides a method for evaluating risks to help determine a recommendation level for the SPD'S. It also contains a section on SPD'S for communication networks.

UTE C 15712 guide for solar cell facilities

This guide sets out, in addition to NF C 15100. the protective and installation conditions for solar cell arrays.
It also provides, among other points, practical advice in choosing and implementing SPD products.

Obligations and recommendations for using SDPs

Sections 4-443 and 7-771.443 of standard NF C 15100 define the situations that determine the mandatory use of SPD:

1 - The facility is equipped with a lightning conductor: SPD mandatory, at origin of the electrical installation. It shall be type 1 with minimum I_{imp} current of 12.5 kA.

2 - The facility is supplied by overhead LV distribution network and the local isokeraunic level (Nk) is higher than 25 (or with Ng higher than 2.5): SPD mandatory, at origin of the electrical installation. It shall be type 2 with minimum I_n current of 5 kA.

3 - The facility is supplied by overhead LV distribution network and the local isokeraunic level is under 25 (or with Ng under 2.5): SPD not mandatory.*

4 - The facility is supplied by underground LV distribution network: SPD not mandatory.*

(*) However, the standard states that: “… protection against overvoltages may be necessary in situations where a higher level of availability or a higher level of risk is expected.”

Sections 443 and 534 of standard NF C 15100

These sections are based on the following concepts:

- SPD'S shall be installed according to industry standards. They shall be coordinated both between themselves and the facility’s protective devices,
- SPD'S shall conform to NF EN 61643-11 in order to guarantee in particular that their end of life cycle is without risk to facilities and persons.

Additional measures may be stipulated for complex industrial installations or installations that are particularly exposed to risk of lightning.
Classified installations subject to authorisation (ICPE) pertaining to the decree of 15 January 2008 and scope of application circulars of 24 April 2008. must undergo a preliminary study of lightning risks.

Extracts of guide UTE C 15443

The UTE C 15443 guide sets out the rules for the choice and installation of SPD'S.

Foreword

“Electrical devices comprising electronic components are today widely used in industrial, service and household facilities. In addition, a high number of these devices remain in a constant standby state and provide control or safety functions. The reduced withstand to overvoltages of these devices has given increased importance to the protection of LV electrical installations, and especially to the use of SPD'S for their protection against overvoltages caused by lightning and transmitted throughout the electrical network.”

Surge Protective Devices

Technology

Surge Protective Devices: terminology

The term “Surge Protective Device (SPD)” defines the set of protective devices that protect equipment against transient overvoltages, whether due to lightning or coming from the electrical network (switching surges).
SPD'S are adapted to the different types of wired networks entering into facilities:

- electrical distribution mains,
- telecommunications network lines,
- computer networks,
- radio communications.

Some definitions

Follow current

This is the current supplied by the electrical distribution mains that flows in the SPD after the passage of discharge current. It only concerns surge arresters having a follow current (e.g. air-gap or gas discharge arresters).

Leakage current

This is electrical current that, in normal operating conditions, flows to earth or in conductive elements.

Temporary overvoltage (U_T)

This is the RMS peak value acceptable by the SPD and corresponding to the oscillatory overvoltage at power frequency due to faults on the LV network.

Protection level (U_P)

This is the peak voltage at the SPD terminals in normal operating conditions. The level of SPD protection must be less than the protected equipment’s impulse withstand voltage.

Peak voltage in open circuit (U_{oc})

This is the acceptable peak voltage of the combined wave (peak = 20 kV / only for type 3 SPD).

Short circuit withstand (generally I_{cc})

This is the maximum short circuit current that the SPD can withstand

Nominal discharge current (I_n)

This is the peak value of an 8 / 20 current wave form flowing in the SPD. The current may flow through it several times without damaging it. This characteristic is one of the criteria when choosing a type 2 SPD.

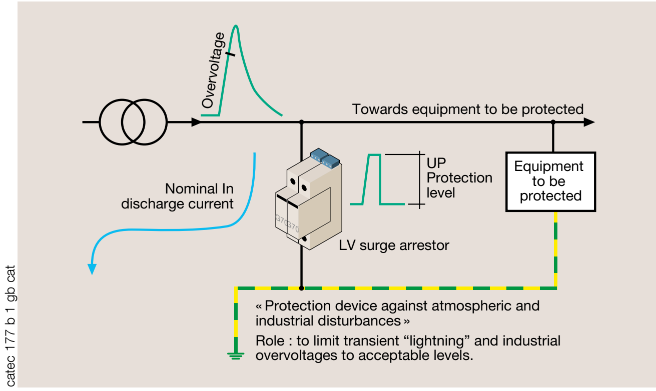
Surge current (I_{imp})

This is generally a 10 / 350 wave form, for which type 1 SPD are tested.

Maximum discharge current (I_{max})

This is the peak value of a 8 / 20 current wave form that may flow through the type 2 SPD without modification of its characteristics and without necessarily providing the level of protection U_p and therefore the protection of the equipment to be protected. This value is a consequence of the choice of I_n and is given in the manufacturer’s technical data sheet.

Operating principle and function of SPD'S

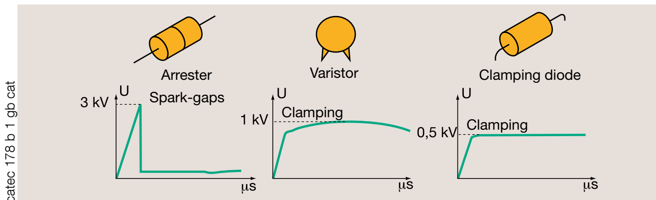


SPD technology

Several types of SPD technology are available to meet the requirements of different electrical networks.
SPD'S can therefore have different internal components:

- arresters,
- varistors,
- peak limiting diodes (also called "clipping diodes").

The purpose of such components is to quickly limit the voltages that appear at their terminals: the function is achieved by sudden modification of their impedance to a defined voltage threshold.



Operation of SPD components.

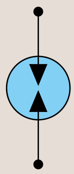
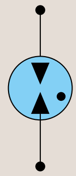
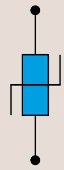
There are two possible properties:

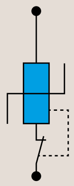
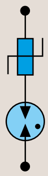
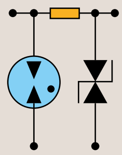
- **Tripping:** the component passes from a very high state of impedance to quasi short circuit; this is the case for arresters.
- **Clipping:** after a defined voltage threshold, the component, passing to low impedance, limits the voltage at its terminals (varistors and clipping diodes).

Technology (continued)

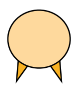
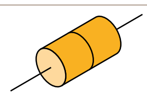
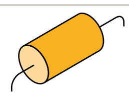
Main technologies

These series of technologies comprise several versions and may need to be inter-connected in order to achieve optimum performance.
Hereunder is a description of the main technologies (or combination of technologies) used.

Air-gap arrester	Encapsulated air-gap arrester	Gas discharge arrester	Varistor
			
A device generally comprising two electrodes placed facing each other and between which a disruptive discharge is produced (followed by a follow current) as soon as an overvoltage reaches a certain value. On electrical distribution mains, in order to quickly interrupt the follow current, an arc extinction is used, the final consequence of which is the expulsion of hot gases toward the exterior: this property requires careful implementation.	Spark-gap arrester where the quenching of the follow current is done without gas expulsion: this is generally done to the detriment of the breaking capacity of the follow current.	An arrester in an airtight enclosure filled with a mixture of rare gas under controlled pressure. This component is generally used for and well-suited to the protection of telecommunications networks. It is characterised by its very low leakage current.	Non-linear component (variable resistance according to voltage) containing zinc oxide (ZnO) that limits the terminal voltage: this clipping method enables follow current to be avoided, which makes this component particularly suited to protecting HV and LV electrical distribution mains.

Varistor with high temperature conductor	Arrester / Varistor	Clipping diode	Arrester / Clipping diode
			
Varistor fitted with auxiliary device designed to disconnect the component from the network in case of excessive temperature rise: this component is essential to guarantee a controlled end of life cycle for the varistors connected to the electrical network.	Serial assembly of components, designed to benefit from both technologies: no leakage current and low Up (arrester) and no follow current (varistor).	Zener-type diode (voltage limitation) equipped with a special structure to optimise its clipping characteristic on transient overvoltages. This component is characterised by very rapid response time.	Parallel assembly of gas discharge arrester(s) and clipping diode(s); provides the advantages of the arrester's flow capacity and the rapid response time of the diode. Such an association requires a decoupling element in series so that operating coordination of the protective components is assured.

Technologies used in the SURGYS® range

Type	 Varistor	 Gas discharge arrester	 Clipping diode
G140-F	•		
G40-FE	•	•	
G70	•		
D40	•		
E10	•		
RS-2		•	•
mA-2		•	•
TEL-2		•	•
COAX		•	

Internal structure

Disconnection devices

In accordance with "LV SPD" standards, the SURGYS® SPD'S are equipped with internal thermal devices that disconnect the network's protection function in case of abnormal operating (excessive temperature rise due to an exceeding of the product's characteristics). In this case, the user is alerted to the fault by the tripped red indicator on the front side of the defective module, which should then be replaced. In addition, to withstand fault currents such as short circuits or temporary overvoltages, SPD'S must be connected to the LV network by external disconnection devices specific to such surge protective devices.

This external disconnection is to be carried out using suitable Socomec fuses.

The mounting of fuses in Socomec fuse combination switches improves safety and facilitates under operating conditions certain procedures such as insulation measurements, for example.

Remote signalling

Most of the SURGYS® SPD'S are fitted with a "remote signalling" contact. This function, that enables remote checking of the SPD operating status, is particularly advantageous in cases where the products are difficult to access or without monitoring.

The system comprises a changeover-type auxiliary contact that is activated if the protection module's status is modified.

The user can therefore continuously check:

- the correct operating of the SPD,
- the presence of plug-in modules,
- end of life (disconnection) of SPD'S.

The "remote signalling" function therefore allows the choice of a signalling system (operating or defect indicator) that is adapted to its installation via different means such as visual indicator, buzzer, automatic control and transmissions.

Main characteristics of SPD'S

Definition of characteristics

The main parameters defined by the "SPD" standards will allow the user of the product to determine the technical performance and use of the SPD:

- steady state peak voltage (U_c): peak voltage accepted by the SPD,
- Nominal discharge current (I_n): 8/20 µs pulse current that can be tolerated 15 times, without damage, by the SPD during operating tests,
- maximum discharge current (I_{max}): 8/20 µs pulse current that can be tolerated once, without damage, by type 2 SPD,
- surge current (I_{imp}): 10/350 µs impulse current that can be tolerated once, without damage, by type 1 SPD,
- protection level (U_p): voltage that defines the efficiency of the SPD. This value is higher than the residual voltage (U_{res}) occurring at the SPD terminals during the flow of nominal discharge current (I_n),
- prospective short-circuit current (I_{cc}): maximum value of 50 Hz current that can pass in the SPD during arrester fault.

These different parameters will enable the SPD to be correctly rated according to the network to which it is to be connected (U_c and I_{cc}), according to risk (I_n and I_{max}) and finally, compared to the required level of efficiency and/or the type of equipment to be protected (U_p).

Verification of U_c

According to standard NF C 15100 section 534. the maximum operating voltage U_c of the SPD in common mode of protection shall be selected as follows:

- in TT or TN loads: $U_c > 1.1 \times U_n$,
- in IT loads: $U_c > \times U_n$,

As the SURGYS® SPD'S are compatible with all neutral systems, their U_c voltage in common mode is 400 VAC.

Verification of U_p, I_n, I_{max} and I_{imp}

The U_p protection level to be chosen must be as low as possible, whilst keeping to the imposed U_c voltage.

The I_n, I_{max} and I_{imp} discharge currents are chosen according to risk: please refer to the "guide to choosing" in the SURGYS® SPD catalogue.

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Choosing and installing primary SPD'S

Types of Low Voltage SPD'S

SPD'S are categorised by standard NF EN 61643-11 in 2 types of products, corresponding to testing index. These specific constraints depend essentially on the location of the SPD in an installation and on external conditions.

Type 1 SPD

These devices are designed to be used in installations where the risk of "lightning" is very high, especially where lightning rods are present on site. Standard NF EN 61643-11 stipulates that such SPD be subject to Class 1 tests, characterised by current wave injections of type 10/350 µs (I_{imp}), these being representative of lightning current generated during a direct strike. Such SPD'S must therefore be especially powerful to carry this high energy wave.

Type 2 SPD

As these are intended to be installed upstream of the installation, normally at the level of the LV distribution panel on sites where the risk of direct lightning strike is considered to be practically inexistent, Type 2 primary SPD'S are therefore considered to protect the entire installation. These SPD'S are subject to (I_{max} and I_n) 8/20µs current wave tests. If the equipment to be protected is distant from the origin of the electrical installation, type 2 SPD'S should be used in proximity to it *(see paragraph "Coordination between primary SPD and distribution", on page 108).*

LV primary SPD'S

The SURGYS® range of SPD is available in two versions: primary and distribution arresters.

Primary SPD'S protect an entire LV installation by shunting most of the currents that generate overvoltages to the earth.

Distribution SPD'S ensure protection of equipment by carrying the remaining energy to the earth.

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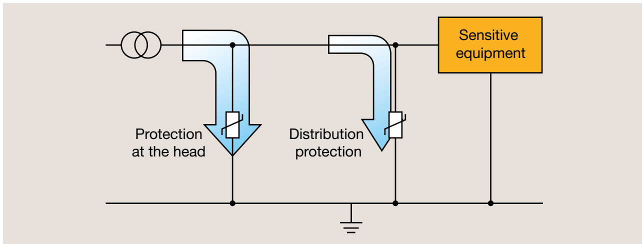

Choosing a primary SPD

In all cases, the primary SPD'S are to be installed immediately downstream of the master control device.

The discharge currents that such SPD'S must be able to carry in case of overvoltage may be very high and their choice is generally made by checking that the (I_n, I_{max}, I_{imp}) discharge currents are correctly adapted to theoretical risk evaluations practiced, for example, by certain specialised electrical design consultancies.

The following selection table gives practical information for choosing the primary SPD directly, taking into consideration the technical performance of the SURGYS® products.

Type of installation		SURGYS® primary SPD
• With lightning conductor • Exposed sites (altitude, etc.) • Water body • High voltage electricity pylon • Building with extended metallic structures, or close to chimney stacks or with protruding elements	Type 1	SURGYS G140F
• With lightning conductor and LV switchboard panel of < 2 m length and equipped with sensitive equipment	Type 1	SURGYS G40-FE
• Buried input • Unexposed site • Switching surges	Type 2	SURGYS G70

Installing primary SPD'S

Primary SPD'S are placed:
- at the level of a LV switchboard panel (fig. 1),
- at the level of a building's main electrical panel, in case of overhead power cable exposed to lightning.

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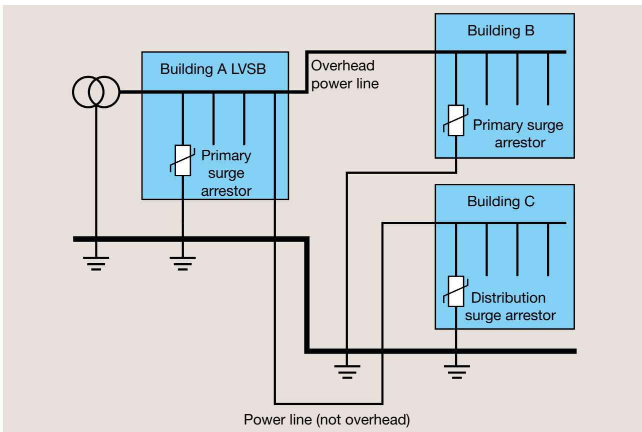

Fig. 1 choosing primary or distribution SPD'S.

Surge Protective Devices

Choosing and installing primary SPD'S (continued)

Presence of lightning conductor(s) and primary SPD'S

The presence of a lightning conductor (a structure designed to capture the lightning and to let its current flow through a special path to earth) on or close to an installation will contribute to increasing the amplitude of impulse currents: In case of direct strike on the lightning conductor, there will be a sharp rise in earth potential and part of the lightning current will be shunted into the LV network, passing in transit through the SPD.

For this reason, the simultaneous use of type 1 SPD'S with lightning conductors is mandatory within the framework of standard NF C 15100. Connecting to the earthing network is to be done via a conductor with a minimum section of 10 mm².

Coordination with the Master Control Device

The Master Control Device of the installation (supply circuit breaker) is always placed upstream of the SPD. It must be coordinated with the SPD to limit spurious tripping during operation of the arrester. In TT arrangements, improvement measures are essentially guided by the choice of a type S (selective) general differential device that allows the flow of over 3 kA in 8/20 µs wave without tripping.

Should the SPD reach its end of life, the installation's service continuity should be favoured, i.e. to try to assure discrimination between the Master Control Device and the disconnector associated with the SPD.

NB: possible protection of the "neutral" point should be planned. The detection of a neutral's blown fuse need not cause the breaking of the corresponding phases because in the particular case of an SPD, the "load" is balanced and there is no risk of generating a functional overvoltage should the neutral disappear.

Quality of SPD connections

The quality of an SPD connection to the network is essential to guarantee effective protection.

During the flow of discharge current, the entire parallel branch to which the SPD is connected is under load: The residual voltage (U) at the terminals of the equipment to be protected will be equal to the sum of residual voltage of the SPD (U_p) + the voltage drop (U1 + U2 + U3) in the connecting conductors + the voltage drop (U_D) in the associated disconnection device.

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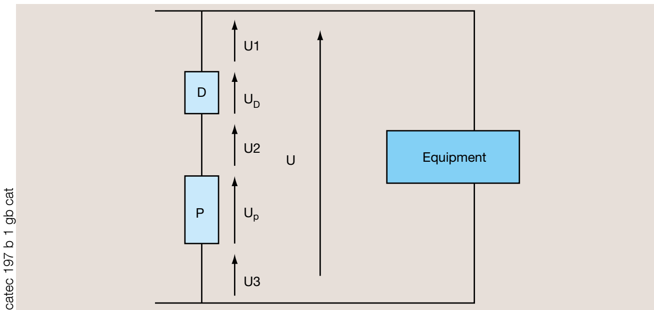

Terminal voltage of the equipment.

Connection sections

SPD earthing conductors must have a minimal section of 4 mm² according to section 534.1.3.4 of standard NF C 15100. In practice, the same section is retained for the network connection conductors.

50 cm rule

In order to reduce the voltage (U), it will be advisable to reduce to a minimum the lengths of connection conductors, the recommended value of (L1 + L2 + L3) being 0.50 m maximum.

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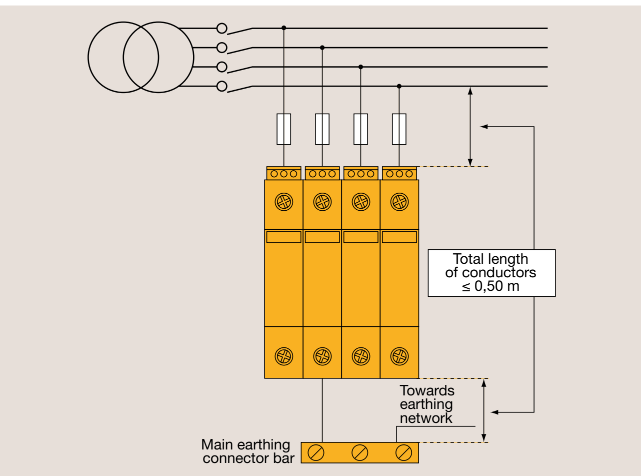

Distance SURGYS®/LV switchboard panel.

Installing primary SPD'S

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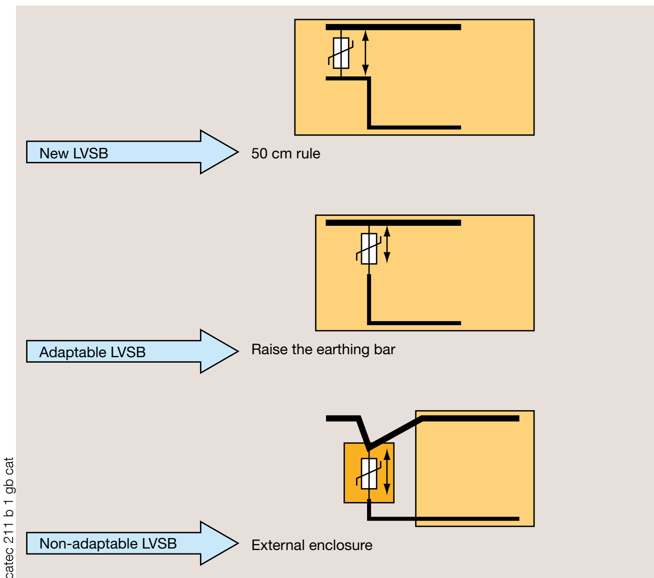

Implementation according to conditions of the installation.

Protection of equipment and distribution SPD'S

Protection of equipment and choice of SPD

To ensure effective protection of equipment against overvoltages, a SURGYS® distribution SPD should be installed as close as possible to the equipment to be protected.
The distribution SPD'S installed as close as possible to the equipment to be protected should have a level of protection coordinated to the impulse withstand of the equipment to be protected:
SPD U_p < rated impulse withstand voltage of the equipment to be protected*.

** Subject to a correct implementation (see previous page).*

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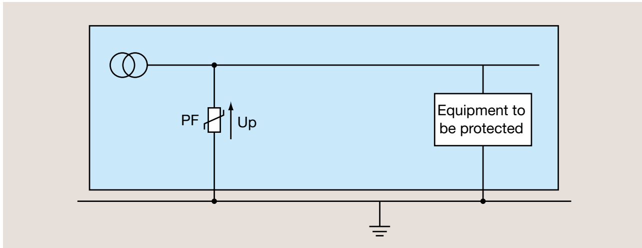

Dielectric withstand of equipment

The different types of equipment are classified into four categories. They correspond to four levels of acceptable overvoltage impulse withstand for the equipment.

	Examples of equipment with			
	very high IW	high IW	normal IW	reduced IW
Three-phase networks	• pulse meters • remote measuring devices	• distribution devices: circuit breakers, switches • industrial equipment	• household electric appliances • portable tools	• equipment with electronic circuits
Installation nominal voltage (V)	Rated impulse withstand voltage (kV)			
230/440	6	4	2.5	1.5
400/690/1000	8	6	4	2.5

Common mode and differential mode

Common mode

The overvoltages occur between each active conductor and the mass. The currents flow in the same direction in both lines and return to the earth via the earthing connection (Ph/T, N/T).
Overvoltages in common mode are dangerous because of the risk of dielectric rupture.

Differential mode

The overvoltages occur between active conductors (Ph/N, Ph/Ph). The current, via the phase, crosses the receptor and loops back on itself by the neutral.
These overvoltages are particularly dangerous for electronic equipment.

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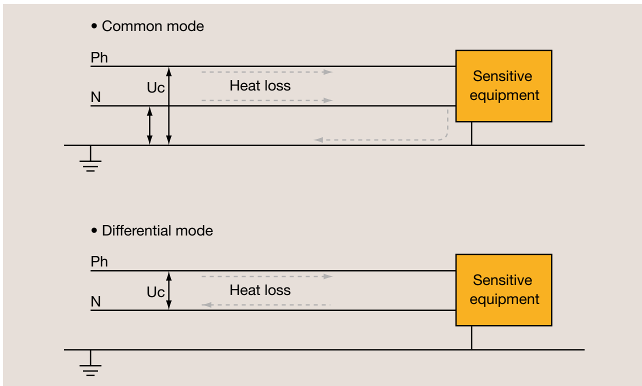


Protection in common mode

Generally, the SPD'S are connected between active conductors (phases and neutral) and the general earthing link of the electrical panel, or the appropriate general protection conductor (PE).
SURGYS® D40 and E10 distribution SPD'S ensure the protection of equipment in common mode.
This mode of protection is generally suited to the following earthing arrangements:

- TNC network,
- IT network.

Protection of equipment and distribution SPD'S (continued)

Protection in differential mode

To protect against differential mode overvoltages (i.e. those liable to occur between phases and neutral), two solutions are possible:

- use additional single-pole SPD'S to those used for the common mode and connect them between each phase and the neutral,
- use SPD'S that have an integrated differential protection mode such as the SURGYS® type D40 MC / MD or E10 MC / MD.

This mode of protection is especially recommended in the following cases:

TT network

Overvoltages in differential mode may occur as a result of the possible dissymmetry between the neutral's earth connection and the LV measurements; this is particularly so in cases where the resistance of the user's earth connection might be high (> 100 ohms) compared to the earth connection of the neutral point.

TNS network

Overvoltages in differential mode may occur as a result of the cable length between the transformer and the LV origin of installation.

Coordination between primary and distribution SPD'S

In order that each SPD assures its respective function, the primary surge arrester drains off most of the energy, whereas the distribution SPD will ensure voltage clipping close to the load to be protected.
This coordination is only possible if the distribution of energy between both SPD'S is controlled via an impedance. This impedance may be assured either by a 10 m wiring system or by a L1 coupling inductor for shorter distances.

Distance between SPD and equipment

The length of conductor between the SPD and the equipment to be protected has an influence on the effectiveness of protection. Too great a length will generate oscillations (reflections of incident overvoltage wave), the consequence of which (in the worst case) will be the doubling of the U_p protection level at the protected equipment's terminals.
It is therefore recommended to keep to a length under 30 m between the SPD and the equipment, or to resort to the coordination of SPD'S (see paragraph "Coordination between surge arresters").

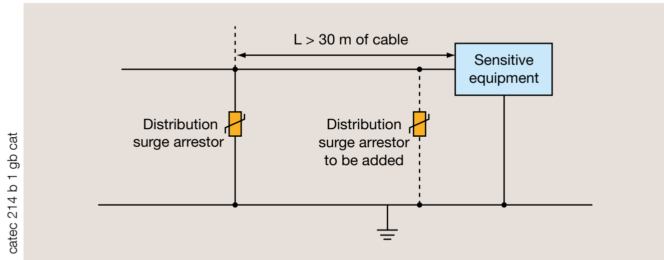


Illustration of equipment placed at distance.

Rules and choice of SPD'S

As with low voltage incomers, the "low current" inputs of equipment (Telecom, modem lines, data transmissions, computer networks, current loops, etc.) are extremely sensitive to transient overvoltages. The high sensitivity of equipment connected to a "low current" line is due to the conjunction of two factors:

- much weaker "breakdown" strength of circuits than those in low voltage circuits,
- additional overvoltage occurring between low current circuits and low voltage circuits, especially by coupling.

In order to guarantee reliable systems operation, it is therefore essential to protect this type of connection, in addition to power feeders.

Low current SPD standards

Product standard

Standard NF EN 61643-21: this document defines the tests to be applied to low current SPD'S.
The parameters tested are similar to those for LV SPD'S, with the exception of typical tests of LV 50 Hz networks (short circuit currents, temporary overvoltages, etc.). Additional tests for quality of transmission (attenuation), on the other hand, are required.

Selection and Installation standard

Standard IEC 61643-22: information about SPD technology for low currents, selection methods and installation recommendations.

SURGYS® SPD for low currents

SOCOMEC offers a range of modular SPD'S for low current connection, with easy installation in standardised enclosures. The "surge arrester" function is pull-out to optimise maintenance and control.
The design of the SURGYS® SPD for low current lines is based on the association of three-pole gas discharge arresters and rapid clipping diodes, providing the following characteristics:

- nominal discharge current (without destruction) in 8/20 µs wave > 5 kA,
- protection response time < 1 ns,
- residual voltage adapted to equipment withstand,
- service continuity,
- security of operation by short-circuiting in case of permanent fault.

The systematic use of three-pole gas discharge arresters provides optimum protection thanks to simultaneous tripping of the three electrodes.
All of these characteristics are essential for optimum reliability of the protected equipment, whatever the incident disturbance.

Risk assessment

There is no obligation to install SPD'S on low current connections, even though the risk is growing. It is necessary therefore to assess the risk by analysing some simple parameters:

	Use of SURGYS® SPD'S	
	recommended*	optional
Telecom connections		
Power systems	overhead	underground
"Incident" history log	> 1	0
Equipment	50 Hz supply	not supplied
Equipment importance	essential	secondary
Data transmission		
Power systems	external	Internal
"Incident" history log	> 1	0
Line length	> 30	30 m
Electromagnetic environment	dense	weak
Equipment importance	essential	secondary

** Recommended if the installation meets at least one of these criteria.*

Implementation and maintenance

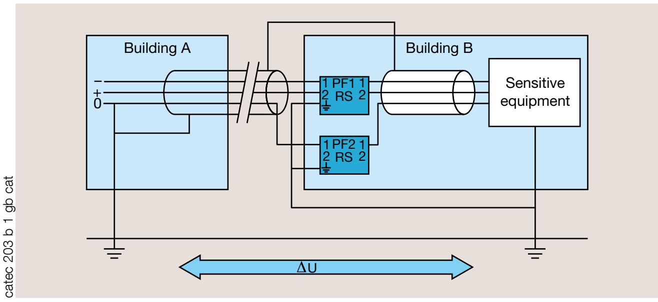
Installation

Location

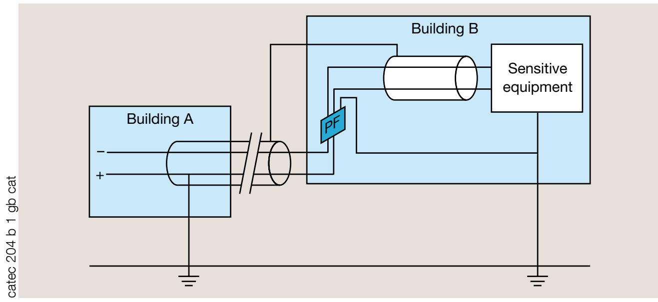
To optimise effective protection, the SPD'S should be correctly positioned; they are placed therefore:

- for external lines: at the entry to the installation, i.e. at the level of the main distribution frame or input cable terminal box, in order to shunt the impulse currents as quickly as possible,
- for internal lines: in immediate proximity to the equipment to be protected (example: in the mains box of the equipment).

In all cases, the protected equipment should be close to the SPD (length of "surge arrester / equipment" conductor under 30 m). If this rule cannot be respected, a "secondary" protection should be installed close to the equipment (coordination of SPD'S).



3-wire RS link (with wire 0 V).



2-wire RS link.

Connection to earthing network

The length of the SPD connection to the installation's earthing network should be as short as possible (under 50 cm) in order to limit additional voltage drops that would penalise the effectiveness of the protection. The section of this conductor should be 2.5 mm^2 minimum.

Cabling

Cables that are protected against overvoltages (downstream of the SPD) and those that are not protected (upstream of the SPD) should be physically separated (example: no circulation in parallel in the same chute), in order to limit coupling.

Maintenance

The SURGYS® SPD'S for low current networks do not require any systematic maintenance or replacement; they are designed to withstand high shock waves repetitively without destruction.

End of life

Nevertheless, destruction can occur should the characteristics of the SPD be exceeded. Security deactivation occurs in the following cases:

- prolonged contact with a power line,
- exceptionally violent "lightning" shock.

In such cases, the SPD is permanently short-circuited, thereby protecting the equipment (by earthing) and indicating its functional destruction (line interruption): The user should therefore now replace the pull-out module of the SURGYS® SPD.
In practice, the end of life of a TEL SDP on a telephone line is indicated to the user by the constantly occupied tone.
The operator (France Télécom) will see the earthing of the line and will inform the subscriber accordingly.

Reactive energy compensation

Principle of compensation

Improving an installation's power factor involves the implementation of a capacitor bank, which is a source of reactive energy.
The power capacitor bank reduces the amount of reactive energy supplied by the source.
The power of the capacitor bank to be installed is calculated from the load's active power and phase shift (voltage/current) before and after compensation.

Nature of powers operating in an installation without harmonics

Traditional electrical receptors use two types of power to function:
- active power (P) which is transformed into mechanical, thermal or light energy,
- reactive power (Q) which is inherent to the internal functioning of an electrical machine (magnetisation of a motor or a transformer, etc.).

The vector sum of these powers is called apparent power (S). This is provided by the installation's power supply sources.

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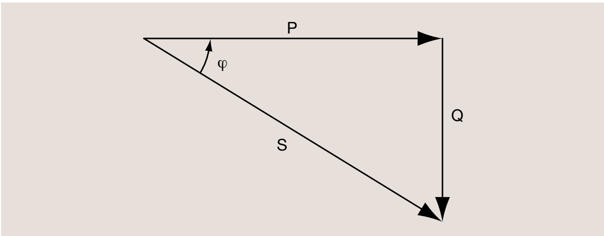

The apparent current (I) consumed by an electrical installation is broken down therefore into two components:
- a component (I_a) in phase with the active power,
- a component (I_r) phase shifted by 90° in relation to the active component; phase shifted by 90° lagging for an inductive load and phase shifted by 90° leading for a capacitive load.

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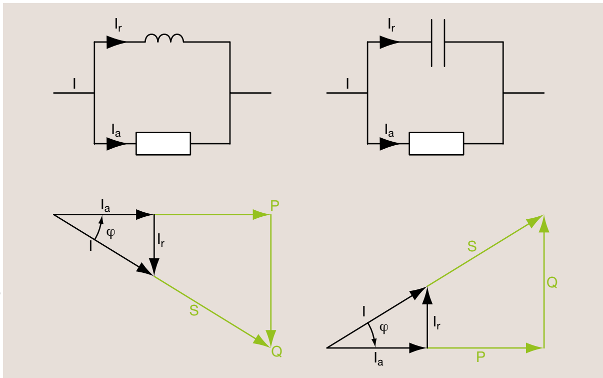

The power factor

This is the relation between the active power and the apparent power:

$$Fp = \frac{P}{S}$$

If the installation has no or few harmonics this relation is close to cos φ.
This concept can also be expressed in Tan form φ.

$$\tan\varphi = \frac{Q}{P}$$

This relation gives the proportion of the reactive power that must supply the transformer for a given active power.

Reactive energy compensation

Reactive power can be supplied directly:
- to the entire installation,
- to each receptor.

Reactive power can be supplied by the capacitor banks connected directly to the subscriber's installation.

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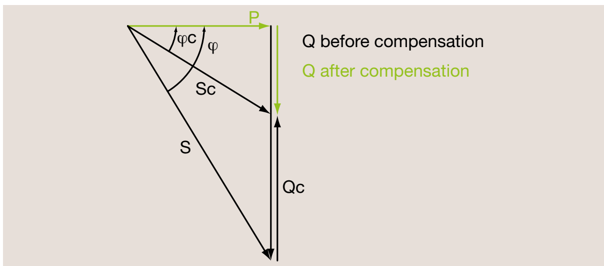


Technical and economic advantages of reactive energy compensation

Optimising the power factor provides the following advantages:
- avoidance of paying tariff penalties to the utility,
- increasing the available power of the transformer,
- reduction of cable sections,
- reduction of line losses,
- reduction of voltage drops.

Reactive energy compensation

Principle of compensation (continued)

Low voltage compensation technology

Compensation is generally done with capacitor banks.

Fixed-value capacitor banks

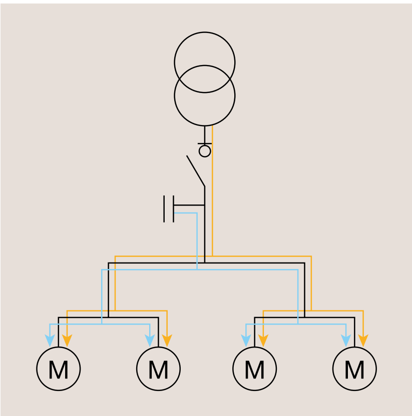
This type of capacitor bank is used when the reactive power to be compensated is constant. It is particularly suited to individual compensation.

Automatically-controlled capacitor banks

This type of capacitor bank allows compensation to be adjusted depending on variations in installation consumption.
This type of compensation avoids supplying reactive power in excess of the installation demand, when the installation is running on low load. In fact an overcompensation is not recommended because it increases the operating voltage of an installation.

Where to compensate?

Global compensation



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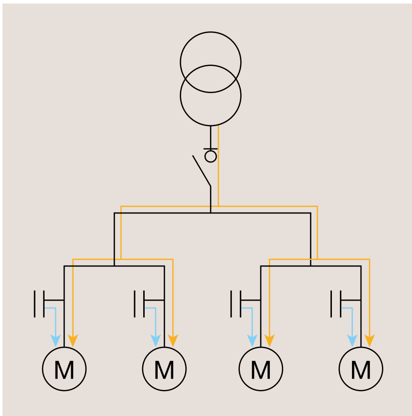
Individual compensation



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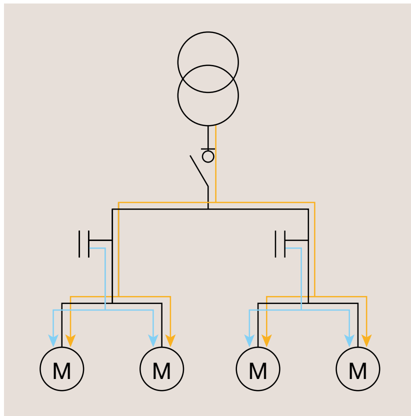
Compensation by sector



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Active energy   Reactive energy

Notes
- Global compensation or by sector is often more economical and avoids problems linked to harmonics.
- Individual compensation is the solution that overall most reduces line losses.

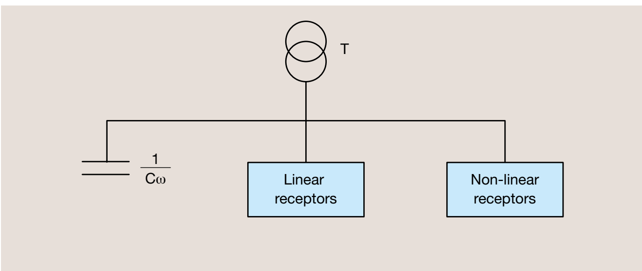
Compensation and harmonics

The power of a capacitor bank is always calculated to compensate the fundamental current of the installation, i.e. the current that is the same frequency as the distribution network.
However, most electrical installations circulate harmonic currents.
These harmonic currents can be high for frequencies generally between 150 Hz and 450 Hz.
The capacitor banks connected to such networks are sensitive to these types of current.

Resonance phenomena

Let us consider an electrical installation comprising:

- a transformer T,
- a fixed capacitor bank ($Z = 1 / X\omega$),
- linear receptors not generating harmonic currents,
- linear receptors generating harmonic currents.



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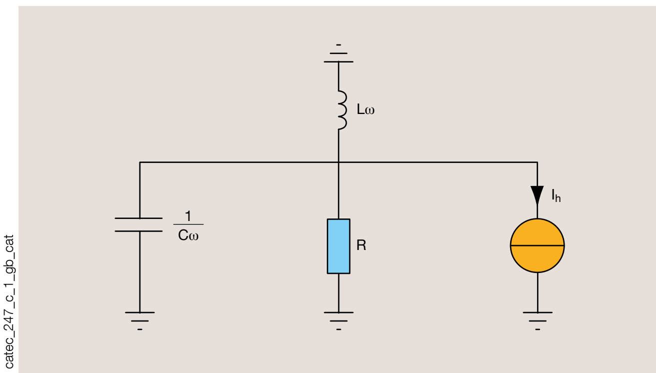
With harmonic currents present, the simplified modelling of the installation is the following:



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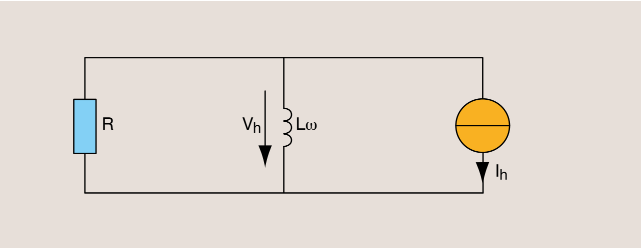
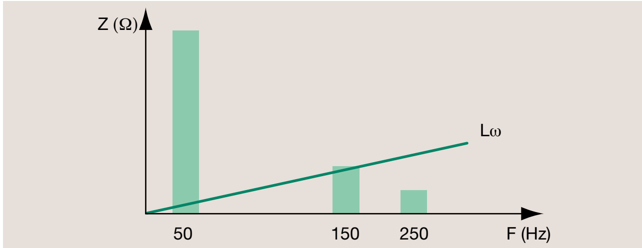
Principle of compensation (continued)

Resonance phenomena (continued)

Installation modelling without capacitor bank



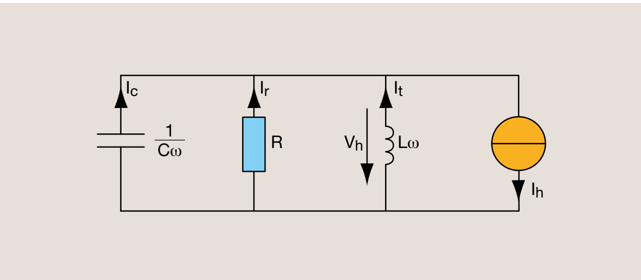
Equivalent single-phase arrangement.



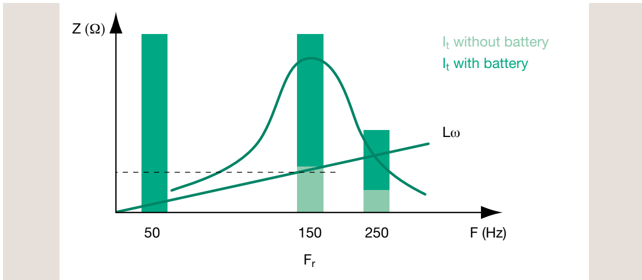
Equivalent impedance of the electrical installation without capacitor bank.

NB: The harmonic currents conveyed by non-linear loads generate Vh voltage drops in the transformer's impedance. These harmonic voltages in turn cause a distortion of the receptors' supply voltage, which explains the propagation mechanism of harmonic pollution on networks.

Installation modelling with capacitor bank



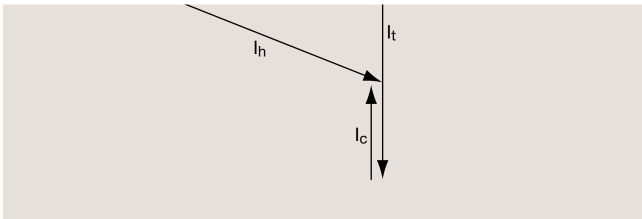
Equivalent single-phase arrangement with capacitor bank.



Equivalent impedance of the electrical installation with capacitor bank.

Equivalent impedance of the installation

It has an impedance peak. The frequency corresponding to this peak is called the resonance frequency.
At resonance frequency, the impedance of the installation can become high. It is shown therefore that if the harmonic currents imposed by the non-linear loads exist and have a frequency close to the installation's resonance, such currents are amplified and circulate in the capacitors and the transformer.



Vector representation of currents through the various elements of the electrical installation.

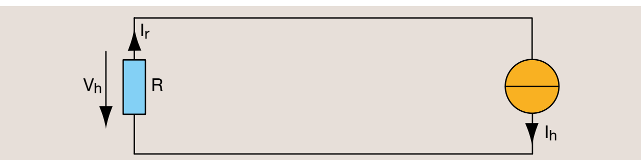
Amplification of a harmonic current

Example of a harmonic current number N whose frequency corresponds to the resonance frequency of the installation (calculation of the total impedance of the equivalent arrangement of an RLC circuit in parallel).

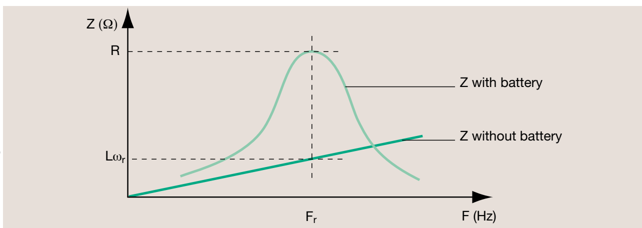
$$Z = \sqrt{\frac{1}{\frac{1}{R^2} + (C \; \frac{1}{L})^2}}$$

At resonance frequency (r): $C = \frac{1}{L\omega}$

With Z = R



$V_h = R \, I_h$



Reactive energy compensation

Principle of compensation (continued)

Amplification of a harmonic current (continued)

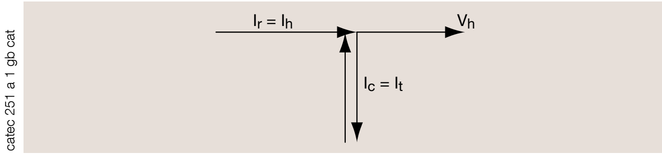
However, as the transformer and capacitor bank are always present, let us calculate the currents that circulate in these elements.

Calculation of currents circulating in the transformer and capacitor bank

$$I_t = \frac{V_h}{L\omega_r} = \frac{I_h R}{L\omega_r} = K I_h$$

Resonance amplification factor: $K = R/L\omega r$.

Harmonic currents at frequency Fr



$$I_c = C\omega_r V_h = RC\omega_r I_h = K I_h$$

We notice therefore an amplification of harmonic current number N in the transformer and the capacitors.
According to the amplification factor K, the resonance phenomena can cause:

- a current circulating in the capacitors that may greatly exceed the nominal current capacity and lead to downgrading of capacities due to overheating,
- an abnormal overload of the transformer and cables that supply the installation,
- a degradation of the voltage sine wave which may in turn cause abnormal operation of the receptors.

The resonance number can be calculated in the following way (simplified formula):

$$N = \frac{F_r}{F_0} = \sqrt{\frac{S_{cc}}{Q_c}}$$

S_{cc}: transformer short circuit power
Q_c: capacitor power in service
F_r: resonance frequency
F_0: electrical network frequency

$$N = \frac{F_r}{F_0} = \sqrt{\frac{S_n \times 100}{U_{cc}}}$$

$S_{cc} = S_n \times 100/U_{cc}$
S_n: transformer power
U_{cc}: transformer short circuit voltage

The harmonic current of frequency F_r present in the installation will be amplified in the capacitors and in the transformer:

$$K = \frac{\sqrt{S_{cc} Q_c}}{P}$$

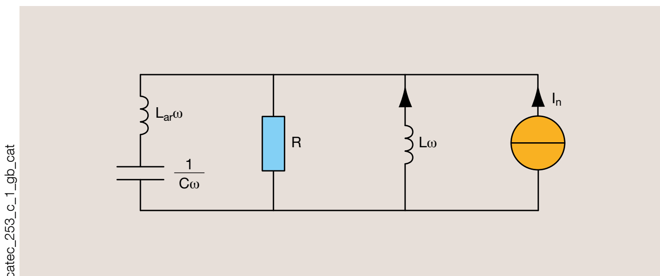
S_{cc}: transformer short circuit power
Q_c: capacitor power in service
P : linear receptor active power

In practice, N does not exceed 10 on account of cable impedances that are not taken into account in this modelling. It is vital to remember that the capacitors connected on an installation can amplify existing harmonic currents, but they do not generate them.

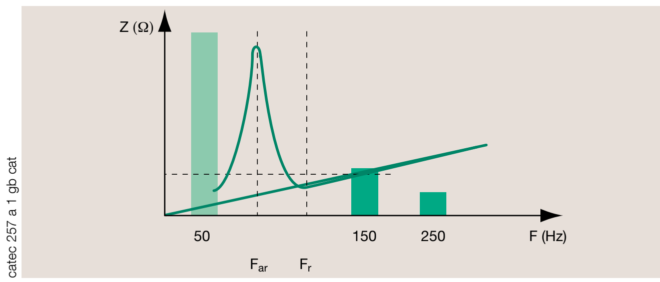
NB: The amplification of a harmonic current with frequency equal to resonance frequency is maximum.
The other harmonic currents will be amplified to lesser proportions.
During full evaluation of resonance phenomena, it is advisable to calculate the amplification for each harmonic number and to reduce the total rms value circulating in the transformer and the capacitor.

Protecting capacitor banks against resonance effects

It is now understood why, with harmonic currents present, it is necessary to protect the capacitor banks from the effects of resonance. To do so, anti-harmonic inductors are inserted in series with capacitors. The aim is to adjust the inductance value in such a way that the resonance peak does not appear on the existing harmonic currents.



Equivalent installation impedance with capacitor bank protected against the effects of harmonic currents.



Equivalent installation impedance and harmonic currents spectrum present in the installation.

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Calculating the capacitors' power

Coefficient K

The table below, with the network's cos j value before compensation and the value required after compensation, gives a coefficient to be applied to the active power by multiplication in order to find the power of capacitor bank to be installed. In addition, it gives the corresponding values between cos φ and tg φ.

Qc = P (kW) x K

			Coefficient K to be applied to the active power to increase the cos φ or tg φ power factor to the following levels												
prior to power factor correction		tg φ	0,75	0,59	0,48	0,46	0,43	0,40	0,36	0,33	0,29	0,25	0,20	0,14	0,0
tg j	cos j	cos φ	0,80	0,86	0,90	0,91	0,92	0,93	0,94	0,95	0,96	0,97	0,98	0,99	1
2,29	0,40		1,557	1,691	1,805	1,832	1,861	1,895	1,924	1,959	1,998	2,037	2,085	2,146	2,288
2,22	**0,41**		**1,474**	**1,625**	**1,742**	**1,769**	**1,798**	**1,831**	**1,840**	**1,896**	**1,935**	**1,973**	**2,021**	**2,082**	**2,225**
2,16	0,42		1,413	1,561	1,681	1,709	1,738	1,771	1,800	1,836	1,874	1,913	1,961	2,022	2,164
2,10	**0,43**		**1,356**	**1,499**	**1,624**	**1,651**	**1,680**	**1,713**	**1,742**	**1,778**	**1,816**	**1,855**	**1,903**	**1,964**	**2,107**
2,04	0,44		1,290	1,441	1,558	1,585	1,614	1,647	1,677	1,712	1,751	1,790	1,837	1,899	2,041
1,98	**0,45**		**1,230**	**1,384**	**1,501**	**1,532**	**1,561**	**1,592**	**1,628**	**1,659**	**1,695**	**1,737**	**1,784**	**1,846**	**1,988**
1,93	0,46		1,179	1,330	1,446	1,473	1,502	1,533	1,567	1,600	1,636	1,677	1,725	1,786	1,929
1,88	**0,47**		**1,130**	**1,278**	**1,397**	**1,425**	**1,454**	**1,485**	**1,519**	**1,532**	**1,588**	**1,629**	**1,677**	**1,758**	**1,881**
1,83	0,48		1,076	1,228	1,343	1,370	1,400	1,430	1,464	1,497	1,534	1,575	1,623	1,684	1,826
1,78	**0,49**		**1,030**	**1,179**	**1,297**	**1,326**	**1,355**	**1,386**	**1,420**	**1,453**	**1,489**	**1,530**	**1,578**	**1,639**	**1,782**
1,73	0,50		0,982	1,232	1,248	1,276	1,303	1,337	1,369	1,403	1,441	1,481	1,529	1,590	1,732
1,69	**0,51**		**0,936**	**1,087**	**1,202**	**1,230**	**1,257**	**1,291**	**1,323**	**1,357**	**1,395**	**1,435**	**1,483**	**1,544**	**1,686**
1,64	0,52		0,894	1,043	1,160	1,188	1,215	1,249	1,281	1,315	1,353	1,393	1,441	1,502	1,644
1,60	**0,53**		**0,850**	**1,000**	**1,116**	**1,144**	**1,171**	**1,205**	**1,237**	**1,271**	**1,309**	**1,349**	**1,397**	**1,458**	**1,600**
1,56	0,54		0,809	0,959	1,075	1,103	1,130	1,164	1,196	1,230	1,268	1,308	1,356	1,417	1,559
1,52	**0,55**		**0,769**	**0,918**	**1,035**	**1,063**	**1,090**	**1,124**	**1,156**	**1,190**	**1,228**	**1,268**	**1,316**	**1,377**	**1,519**
1,48	0,56		0,730	0,879	0,996	1,024	1,051	1,085	1,117	1,151	1,189	1,229	1,277	1,338	1,480
1,44	**0,57**		**0,692**	**0,841**	**0,958**	**0,986**	**1,013**	**1,047**	**1,079**	**1,113**	**1,151**	**1,191**	**1,239**	**1,300**	**1,442**
1,40	0,58		0,665	0,805	0,921	0,949	0,976	1,010	1,042	1,076	1,114	1,154	1,202	1,263	1,405
1,37	**0,59**		**0,618**	**0,768**	**0,884**	**0,912**	**0,939**	**0,973**	**1,005**	**1,039**	**1,077**	**1,117**	**1,165**	**1,226**	**1,368**
1,33	0,60		0,584	0,733	0,849	0,878	0,905	0,939	0,971	1,005	1,043	1,083	1,131	1,192	1,334
1,30	**0,61**		**0,549**	**0,699**	**0,815**	**0,843**	**0,870**	**0,904**	**0,936**	**0,970**	**1,008**	**1,048**	**1,096**	**1,157**	**1,299**
1,27	0,62		0,515	0,665	0,781	0,809	0,836	0,870	0,902	0,936	0,974	1,014	1,062	1,123	1,265
1,23	**0,63**		**0,483**	**0,633**	**0,749**	**0,777**	**0,804**	**0,838**	**0,870**	**0,904**	**0,942**	**0,982**	**1,030**	**1,091**	**1,233**
1,20	0,64		0,450	0,601	0,716	0,744	0,771	0,805	0,837	0,871	0,909	0,949	0,997	1,058	1,200
1,17	**0,65**		**0,419**	**0,569**	**0,685**	**0,713**	**0,740**	**0,774**	**0,806**	**0,840**	**0,878**	**0,918**	**0,966**	**1,007**	**1,169**
1,14	0,66		0,388	0,538	0,654	0,682	0,709	0,743	0,775	0,809	0,847	0,887	0,935	0,996	1,138
1,11	**0,67**		**0,358**	**0,508**	**0,624**	**0,652**	**0,679**	**0,713**	**0,745**	**0,779**	**0,817**	**0,857**	**0,905**	**0,966**	**1,108**
1,08	0,68		0,329	0,478	0,595	0,623	0,650	0,684	0,716	0,750	0,788	0,828	0,876	0,937	1,079
1,05	**0,69**		**0,299**	**0,449**	**0,565**	**0,593**	**0,620**	**0,654**	**0,686**	**0,720**	**0,758**	**0,798**	**0,840**	**0,907**	**1,049**
1,02	0,70		0,270	0,420	0,536	0,564	0,591	0,625	0,657	0,691	0,729	0,769	0,811	0,878	1,020
0,99	**0,71**		**0,242**	**0,392**	**0,508**	**0,536**	**0,563**	**0,597**	**0,629**	**0,663**	**0,701**	**0,741**	**0,783**	**0,850**	**0,992**
0,96	0,72		0,213	0,364	0,479	0,507	0,534	0,568	0,600	0,634	0,672	0,712	0,754	0,821	0,963
0,94	**0,73**		**0,186**	**0,336**	**0,452**	**0,480**	**0,507**	**0,541**	**0,573**	**0,607**	**0,645**	**0,685**	**0,727**	**0,794**	**0,936**
0,91	0,74		0,159	0,309	0,425	0,453	0,480	0,514	0,546	0,580	0,618	0,658	0,700	0,767	0,909
0,88	**0,75**		**0,132**	**0,282**	**0,398**	**0,426**	**0,453**	**0,487**	**0,519**	**0,553**	**0,591**	**0,631**	**0,673**	**0,740**	**0,882**
0,86	0,76		0,105	0,255	0,371	0,399	0,426	0,460	0,492	0,526	0,564	0,604	0,652	0,713	0,855
0,83	**0,77**		**0,079**	**0,229**	**0,345**	**0,373**	**0,400**	**0,434**	**0,466**	**0,500**	**0,538**	**0,578**	**0,620**	**0,687**	**0,829**
0,80	0,78		0,053	0,202	0,319	0,347	0,374	0,408	0,440	0,474	0,512	0,552	0,594	0,661	0,803
0,78	**0,79**		**0,026**	**0,176**	**0,292**	**0,320**	**0,347**	**0,381**	**0,413**	**0,447**	**0,485**	**0,525**	**0,567**	**0,634**	**0,776**
0,75	0,80			0,150	0,266	0,294	0,321	0,355	0,387	0,421	0,459	0,499	0,541	0,608	0,750
0,72	**0,81**			**0,124**	**0,240**	**0,268**	**0,295**	**0,329**	**0,361**	**0,395**	**0,433**	**0,473**	**0,515**	**0,582**	**0,724**
0,70	0,82			0,098	0,214	0,242	0,269	0,303	0,335	0,369	0,407	0,447	0,489	0,556	0,698
0,67	**0,83**			**0,072**	**0,188**	**0,216**	**0,243**	**0,277**	**0,309**	**0,343**	**0,381**	**0,421**	**0,463**	**0,530**	**0,672**
0,65	0,84			0,046	0,162	0,190	0,217	0,251	0,283	0,317	0,355	0,395	0,437	0,504	0,645
0,62	**0,85**			**0,020**	**0,136**	**0,164**	**0,191**	**0,225**	**0,257**	**0,291**	**0,329**	**0,369**	**0,417**	**0,478**	**0,620**
0,59	0,86				0,109	0,140	0,167	0,198	0,230	0,264	0,301	0,343	0,390	0,450	0,593
0,57	**0,87**				**0,083**	**0,114**	**0,141**	**0,172**	**0,204**	**0,238**	**0,275**	**0,317**	**0,364**	**0,424**	**0,567**
0,54	0,88				0,054	0,085	0,112	0,143	0,175	0,209	0,246	0,288	0,335	0,395	0,538
0,51	**0,89**				**0,028**	**0,059**	**0,086**	**0,117**	**0,149**	**0,183**	**0,230**	**0,262**	**0,309**	**0,369**	**0,512**
0,48	0,90					0,031	0,058	0,089	0,121	0,155	0,192	0,234	0,281	0,341	0,484

Example: installation power = 653 kW ; cos φ measured in the installation: cos φ = 0.70 i.e. tg φ = 1.02
cos φ required: cos φ = 0.93 i.e. tg φ = 0.4 ; Qc = 653 x 0.625 = 410 kvar.

Choosing compensation for a fixed load

Compensating asynchronous motors

Motor cos phi is low when off-load or running on low load. To avoid this type of operating, it is possible to connect the capacitor bank directly to the motor terminals, taking into account the following precautions:

During motor start-up

If the motor starts up with the aid of a special device (resistor, inductor, star / delta device, autotransformer), the capacitor bank should not be activated until after start-up.

For special motors

Compensation for special motors is not recommended (stepping motors, double rotation motors, etc.).

In case of auto-excitation

During cut-off of motors with high-inertia loads, a phenomena of motor auto-excitation may cause high overvoltages. To avoid this, the following relation should be verified:

If $Q_c \leq 0.9 \times I_o \times U_n \times \sqrt{3}$

I_o: motor no-load current (kA)
Q_c: capacitor bank power (kvar)
U_n: nominal voltage (400 V)

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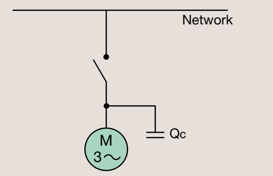

If $Q_c \leq 0.9 \times I_o \times U_n \times \sqrt{3}$

I_o: motor no-load current (kA)
Q_c: capacitor bank power (kvar)
U_n: nominal voltage (400 V)

cosys 008 b 1 gb cat

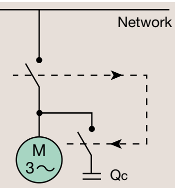

Table A: indicative value of capacitor bank power not to be exceeded to avoid motor auto-excitation

400 V three-phase motor					
Nominal power		Maximum power (kvar) Maximum rotation speed (rpm.)			
kW	Ch	3000	1500	1000	750
8	11	2	2	3	
11	15	3	4	5	
15	20	4	5	6	
18	25	5	7	7,5	
22	30	6	8	9	10
30	40	7,5	10	11	12,5
37	50	9	11	12,5	16
45	60	11	13	14	17
55	75	13	17	18	21
75	100	17	22	25	28
90	125	20	25	27	30
110	150	24	29	33	37
132	180	31	36	38	43
160	218	35	41	44	52
200	274	43	47	53	61
250	340	52	57	63	71
280	380	57	63	70	79
355	482	67	76	86	98
400	544	78	82	97	106
450	610	87	93	107	117

Motor protections

Protection upstream of the motor compensation device needs to be adapted. In fact, for equal mechanical operating of the motor, the current passing in the protection will be lower because the capacitor bank supplies the reactive energy.

Table B: reduction factor for protection adjustment if capacitor bank power is equal to the maximum power indicated in table A

Speed (rpm)	Reduction factor
750	0,88
1000	0,90
1500	0,91
3000	0,93

Choosing compensation for a fixed load (continued)

Transformer compensation

A transformer consumes reactive power in order to magnetise its circuits. The table below indicates standard consumption values (for more details, please consult the transformer manufacturer).

Example: At cos phi 0.7. 30% of the transformer's power is unavailable because of the reactive energy it must produce.

Transformer nominal power	Compensation power in kvar Transformer operation		
kVA	Off-load	75% of load	100% of load
100	3	5	6
160	**4**	**7,5**	**10**
200	4	9	12
250	**5**	**11**	**15**
315	6	15	20
400	**8**	**20**	**25**
500	10	25	30
630	**12**	**30**	**40**
800	20	40	55
1000	**25**	**50**	**70**
1250	30	70	90
2000	**50**	**100**	**150**
2500	60	150	200
3150	**90**	**200**	**250**
4000	160	250	320
5000	**200**	**300**	**425**

When defining the installation of compensation equipment, the use of a fixed capacitor corresponding to the internal consumption of a transformer with 75% load should be envisaged.

Power factors for other types of loads

Indicative values of power factors for most standard machines consuming reactive energy.

Device		cos φ	tg φ
Asynchronous motors	Off-load	0,17	5,80
	25% load	0,55	1,52
	50% load	0,73	0,94
	75% load	0,80	0,75
	100% load	0,85	0,62
Lamps	**incandescent**	**approx. 1**	**approx. 0**
	fluorescent	**approx. 0.5**	**approx. 1.73**
	discharge	**0.4 to 0.6.**	**approx. 2.29 to 1.13**
Furnaces	resistance	approx. 1	approx. 0
	induction with integrated compensation	approx. 0.85	approx. 0.62
	electric heaters	approx. 0.85	approx. 0.62
Resistance welding machines		**0.8 to 0.9.**	**0.75 to 0.48.**
Fixed single-phase arc welding sets		approx. 0.5	approx. 1.73
Arc-welding motor-generating sets		**0.7 to 0.9.**	**1.02 to 0.48.**
Arc-welding transformer-rectifier sets		0.7 to 0.9.	1.02 to 0.48.
Arc furnace		**0,8**	**0,75**
Thyristor-based power rectifiers		0.4 to 0.8.	2.25 to 0.75.

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Enclosures

Thermal effects

Device power dissipation

Nominal powers are given for Ith current (nominal rating in the table below).
For the device's operational current:

$$P = P_N \times \left[\frac{I_e}{I_{th}} \right]^2$$

D power dissipation in W.
P_N: nominal power dissipation in W (see table below).
I_e device's operational current
I_{th}: device rating.

Thermal characteristics

Calculation of temperature rise

$$\Delta T\ (°K) = \frac{P\ (W)}{K \times S\ (m^2)}$$

D power dissipation inside enclosure (equipment, connections, cables, etc.).
T: temperature rise in °K.
S: enclosure surface area (not counting surfaces in contact with walls or other obstacles).
k: heat exchange coefficient.
K = 4 W/m² °C for polyester enclosures.
K = 5.5 W/m² °C for metal enclosures.

When the cubicle or enclosures are fitted with air admission, apply standard IEC 60890 for the calculation, or consult us.

Air/air exchanger determination: *See page 120.*

Calculating ventilation

Where there is forced ventilation, the air flow necessary D is:

$$D\ (m^3/h) = 3.1 \times \left[\frac{P}{T:} \quad \times k \right]$$

Ventilators are offered as accessories in the CADRYS range.

Heating resistor determination

This is necessary when interior condensation must be avoided inside the enclosure. The resistor power Pc is given by:

$$Pc\ (W) = (T \times K \times S) - P$$

Air conditioning determination: *See page 120.*

Power dissipation in W/pole for each piece of equipment

	Ratings (A)	16	20	25	32	40	63	63	80	100	100	125	160	200	200	250	250	315	400	500
SIRCO M	Frame size	M1						M2			M3									
	Power dissipation (w/pôle)	0,15	0,25	0,4	0,6	0,9	2,4	1,5	2,4	4	4,3	7,1								
SIRCO MV	Frame size										MV									
	Power dissipation (w/pôle)										5	7	9							
SIRCO	Frame size											B3			B4					
	Power dissipation (w/pôle)											1,8	3	4,8	4	5,8	-	9,5	14,4	14,4
SIRCO AC	Frame size														B4					
	Power dissipation (w/pôle)														4	6				
SIDER	Frame size											ND 36 mm					ND 60 mm			
	Power dissipation (w/pôle)											12	-	24	-	36	48	58		
SIDERMAT	Frame size															1				
	Power dissipation (w/pôle)															-	8,2	-	15,6	-
SIRCO MC PV (1)	Frame size			1																
	Power dissipation (w/pôle)			4,97	-	15,61														
SIRCO MV PV (1)	Frame size							MV												
	Power dissipation (w/pôle)							0,97	1,56	-	2,43	4,5	6,3							
SIRCO PV (1)	Frame size										B4 (2)						B4 (2)			
	Power dissipation (w/pôle)										0,8	-	2				4,7	8		

(1) 1 PV circuit to 1000 VDC.
(2) Device 500 VDC/P.
(3) Device 250 VDC/P.

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Thermal effects (continued)

Thermal characteristics (continued)

Power dissipation in W/pole for each piece of equipment (continued)

	Ratings (A)	315	400	500	630	800	800	1000	1250	1000	1250	1600	1800	2000	2500	3200	4000	5000
SIRCO	Frame size	B5					B6			B7				B8			B9	
	Power dissipation (w/pôle)	7,6	10,8	16	30,9	30,9	39,7	44,7	-	-	85	122	161	140	205	340	420	480
SIRCO AC	Frame size	B5			B6						B7			B8			B9	
	Power dissipation (w/pôle)	9,6	12,8	20	24,8	-	40	52,2	80		58	95		340			500	
SIDER	Frame size		ND 66 mm		6						7							
	Power dissipation (w/pôle)		41	58	20,7	-	32				42,5	102						
SIDERMAT	Frame size	1					2				3							
	Power dissipation (w/pôle)	-	-	-	45		66,4				80	113	?					
SIRCO PV (1)	Frame size	B4 (3)			B5 (3)						B6 (3)			B7 (3)				
	Power dissipation (w/pôle)	10	20	30	40	70					32			80				

(1) 1 PV circuit to 1000 VDC.
(2) Device 500 VDC/P.
(3) Device 250 VDC/P.

	Ratings (A)	32	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	1800	2000	2500	3200	4000
FUSERBLOC	Power dissipation (w/pôle)	4,6 (CD)	-	7,1	10,4	-	15	18	22	33	39	55,3	57	-	118	131	-	234	-	-	-	-	-	-
FUSOMAT	Power dissipation (w/pôle)	-	-	-	-	-	-	-	-	-	30,3	-	50	-	83,5	-	-	222	-	-	-	-	-	-
ATyS	Power dissipation (w/pôle)	-	-	-	-	-	-	1,9	3,2	4,1	5,9	7,8	15,1	17	32,4	41,7	46,9	93,3	122	153	178	255	330	-
ATyS M	Power dissipation (w/pôle)	-	0,6	-	1,2	2,2	4	5	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Example: A cubicle consists of a master switch (FUSERBLOC 4 x 630 A) and several cable leadouts. Nominal current is 550 A.
- Power dissipation at 630 A (table below): 97.7 x 3 = 293 W
- Power dissipation at 550 A:

$$293 \times \left[\frac{500}{630}\right]^2 = 223\ W$$

Total power in the cubicle (equipment, cables, etc.) reaches 400 W. Cubicle dimensions: H = 2000 mm, D = 600 mm, L = 800 mm.
The cubicle is placed between two others and against a wall. The free surface area is: S (m^2) = 2 x 0.8 (front) + 0.6 x 0.8 (top) = 2.08 m^2

- Temperature rise in cubicle:

$$T: \frac{400\ W}{5.5 \times 2.08\ m^2} 35\ °C$$

For an ambient temperature of 35 °C, the following is obtained: T = 35 °C + 35 °C = 70 °C
To maintain a maximum temperature T of 55 °C (ΔT = 20 °C), the following ventilation flow is necessary:

$$D = 3.1 \times \left[\frac{400}{20} - 5.5 \times 2.08\right] = 26.5\ m^3/h$$

Polyester enclosures

These enclosures can be used in public buildings. The French ministerial decree of 25.06.80 requires auto-extinguishing casings (resistant up to 750 °C minimum with glowing wire according to NF C 20-445).

	COMBIESTER			
Enclosure type	transparent cover	opaque cover	MINIPOL	
Glowing wire withstand	960 °C	850 °C	960 °C	960 °C

Thermal effects (continued)

Protection against thermal effects (according to NF C 15100)

The temperature of electrical equipment is limited to the values in the table below:

Accessible parts	Material	T (°) max
Manual control devices	Metallic	55
	Non metallic	65
Can be touched but not intended for holding	Metallic	70
	Non metallic	80
Not designed to be touched under normal operation	Metallic	80
	Non metallic	90

Thermal calculation of enclosures

Hypothesis

a) Define the maximum internal temperature at the enclosure, which is imposed by the most sensitive component

b) Define the maximum internal temperature of the ambient air (outside the cubicle)

c) Define enclosure dimensions
where Ti (°C) = Internal temperature
Ta (°C) = Ambient temperature
H - W - D (m) = Height - Width - Depth

Power contributed by the components

SOCOMEC Equipment

See details of nominal current power dissipation *(page 118)*

$$Pd = P_{nom} \times \left[\frac{I_e}{Ith}\right]^2$$

P_{nom} (W): Nominal power

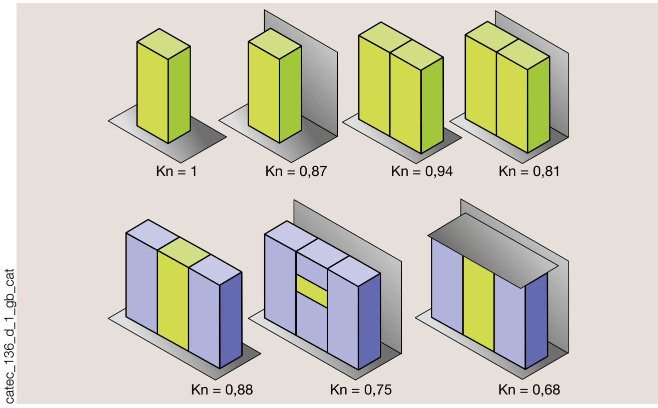
P_d (W): Power dissipation at operational current Ie (A):

I_e (A) Operating current

I_{th} (A) Nominal current

Corrected exchange surface

a) Define the Kn correction factor (depends on the method of installation)



b) Corrected surface area

$$S = Kn\ (1.8 \times H \times (W + D) + 1.4 \times W \times D)$$

Power necessary to maintain the temperature in the enclosure

$$Pn\ (W) = Pd - K \times S \times (Ti\ max - Ta\ max)$$

K = 5.5 W/m²/°C	*for a painted sheet metal enclosure*
K = 4 W/m²/°C	*for a polyester enclosure*
K = 3.7 W/m²/°C	*for a stainless steel enclosure*
K = 12 W/m²/°C	*for an aluminium enclosure*

Pn (W): Power necessary

Choice of adjustment method

a) Ventilation

Choose the ventilator whose flow is just above the value calculated.

$$Flow\ (m^3/h) = \frac{3.1 \times Pn}{Ti\ max - Ta\ max}$$

Note: this solution is only possible if Ti max - Ta max > 5 °C

b) Air/air exchanger

Choose the exchanger whose specific power is just above the value calculated.

$$Specific\ power\ (W/°K) = \frac{Pn}{Ti\ max - Ta\ max}$$

Note: this solution is only possible if Ti max - Ta max > 5 °C

c) Air conditioner

Choose an air conditioner whose refrigerating power is just above the power necessary (Pn).

d) Heating resistor

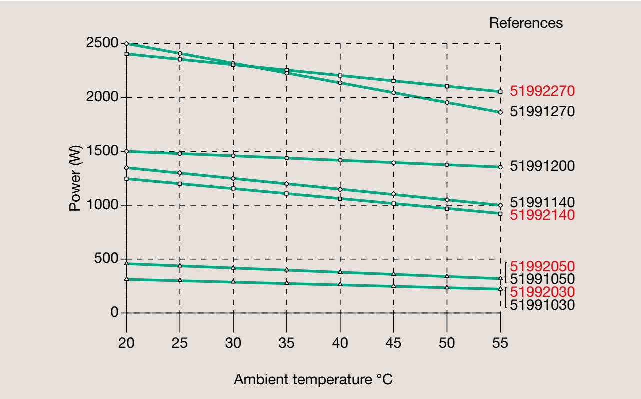
Choose the heating resistor whose power is just above the value calculated.

$$Pc\ (W) = [(Ti\ max - Ta\ max) \times K \times S] - Pn$$

Choosing the air conditioning

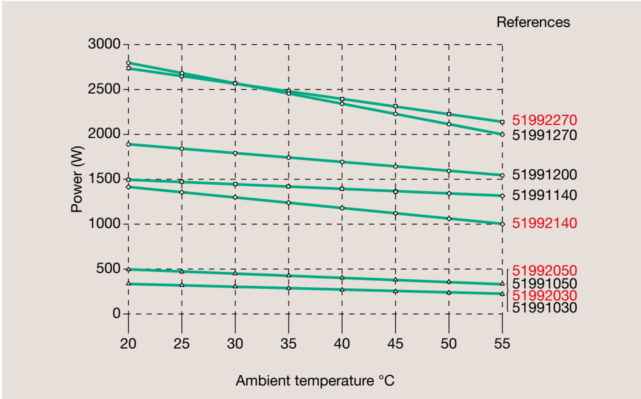
The curves below determine the choice of air conditioner based on the required temperature in the enclosure, the ambient temperature and the necessary power *(see calculation on page 120).*

Required temperature in enclosure = 25 °C



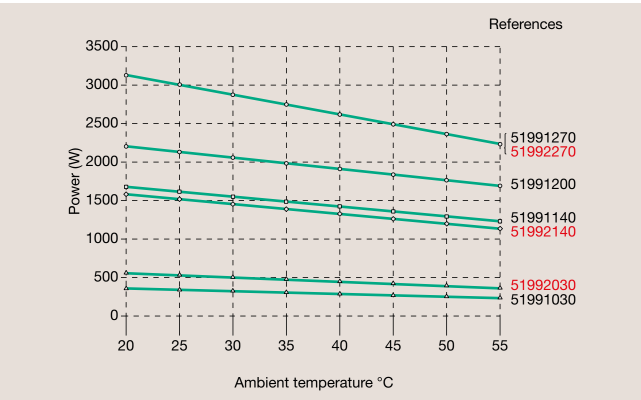
catec 137 b 1 gb cat

Required temperature in enclosure = 30 °C



catec 138 b 1 gb cat

Required temperature in enclosure = 35 °C



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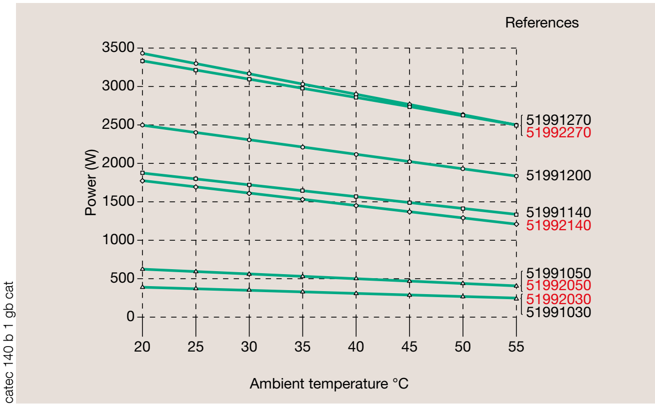
Required temperature in enclosure = 40 °C



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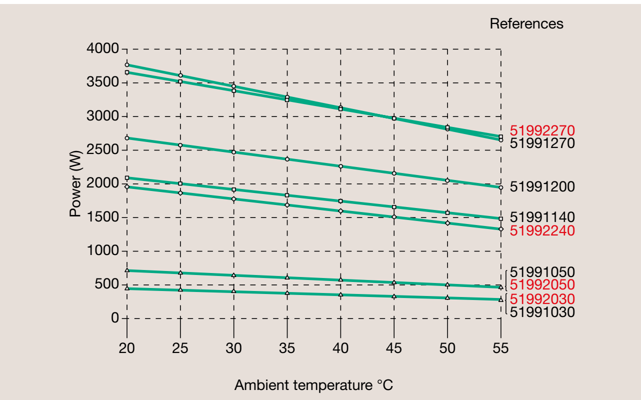
Required temperature in enclosure = 45 °C



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■ Roof-mounted

■ Front-mounted

Example

Max. internal temperature (Ti max)	25 °C
Max. ambient temperature (Ta max)	45 °C
Power necessary (Pn)	2000 W

Busbars

Choosing bar material

Table A: physical constants of copper and aluminium

	Copper	Aluminium
Standards	EN 165251-100	HN 63 J 60. CNET 3072.1. 6101T5 quality
Type	**ETP-H12 (EN 1652) Cu A1 (NFA 51-100)**	**tin plated Al Mg Si 15 µm alloy**
Density	8890 kg/m^3	2700 kg/m^3
Linear expansion factor	**17×10^{-6} per °C (17×10^{-3} mm/m)**	**23×10^{-6} per °C (23×10^{-3} mm/m)**
Minimal breaking strength	250 mm^2	150 mm^2
Specific resistance at 20°C	**≤ 18 mW mm^2/m**	**≤ 30 mW mm^2/m**
Elastic modulus	120000 mm^2	67000 mm^2

Determining the peak Icc according to Icc rms

Table B: According to EN 61439-1

Short circuit rms values	n
I 5 kA	1.5
5 kA < I 10 kA	**1.7**
10 kA < I 20 kA	2
20 kA < I 50 kA	**2.1**
I 50 kA	2.2

$$I_{cc}\ peak = n \times I_{cc}\ rms$$

Thermal effects of short circuit

Short circuit currents cause the busbar temperature rise. The busbar's final temperature must be lower than 160 °C so as not to damage the busbar support. The thermal constraints must be such that:

$$(I_{cc})^2 \times t \leq K_E^2\ S^2$$

I_{sc}: rms short circuit current in A

t: short circuit duration (generally equal to protection device operating time).

S: busbar section in mm^2

K_E: coefficient given in table C in relation to busbar temperature in normal operating conditions (before short circuit).

Table C

Tf	40	50	60	70	80	90	100	110	120	130
KE	89.2	84.7	80.1	75.4	70	65.5	60.2	54.6	48.5	41.7

Electrochemical coupling

To avoid excessive temperature rise due to electrochemical coupling (corrosion), connecting conductors having electrochemical potentials greater than 300 mV must be avoided (see table D).

Table D

	Silver	Copper	Alu	Tin	Steel	Brass	Nickel
Silver	yes	yes	no	no	no	yes	yes
Copper	**yes**	**yes**	**no**	**yes**	**no**	**yes**	**yes**
Alu	no	no	yes	yes	yes	no	no
Tin	**no**	**yes**	**yes**	**yes**	**yes**	**yes**	**no**
Steel	no	no	yes	yes	yes	no	no
Brass	**yes**	**yes**	**no**	**yes**	**no**	**yes**	**yes**
Nickel	yes	yes	no	no	no	yes	yes

Example: An aluminium busbar cannot be directly connected to a copper busbar. Therefore, inserting a tin-plated aluminium busbar is necessary:

- Alu/Tin → YES
- Tin/Copper → YES

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