INTRODUCTION

The CableApp chooses the “technical” conductor cross-section by checking three sizing methods - current rating at steady-state operation, voltage drop and short circuit current - adopting the largest cross-section obtained in each one of them.

The use of cross-sections above the technical, which is the minimum size acceptable for a correct installation, produces a reduction in the consumption of electric energy as well as in the CO_2 emission by the energy generating source. This savings is quantified over a period of one year, in two hypotheses:

- “economic and environmental solution” - one conductor cross-section above the technical solution;
- “additional savings” - two conductor cross-sections above the technical solution and the presented values are additional to the previous one.

Note: In both cases CableApp uses the values of the electricity price (R$/kWh) and CO_2 emissions (kg CO_2/kWh) informed by the user, which can also inform the mean square value of the current line (% of line current, see below) or leave the default of 100%.

The CableApp presents results on the device's screen and the user can also optionally issue a report (in PDF) and / or save the results.

CONDUCTOR CROSS SECTION CALCULATION DUE TO CURRENT RATING AT STEADY-STATE OPERATION

The CableApp uses the NBR 5410 current ratings tables, valid for direct and alternating current at 50 and 60 Hz frequencies. It also uses the correction factors defined there. This allows the user to tailor a circuit rating for their given prescribed installation. These correction factors cover the following parameters: ambient temperature (air and ground), soil thermal resistivity and grouping of circuits (air and ground).

The base conditions for the published current ratings in NBR 5410 are as follows.

PARAMETER	CONDITIONS
Ambient air temperature	30 °C
Ambient ground temperature	20 °C
Installation depth (for cables installed in the ground)	0.7 m
Soil resistivity (for cables installed in the ground)	2,5 K.m/W

CONDUCTOR CROSS SECTION CALCULATION DUE TO VOLTAGE DROP

To calculate the conductor cross section of a cable based on the voltage drop criterion, it is convenient to take into account the effect of inductive reactance, especially for sections larger than 35 mm2 in copper conductors or 70 mm2 in aluminum conductors.

The following formulas for calculating the voltage drop can be used, which take into account the effect of inductive reactance:

SINGLE-PHASE	THREE-PHASE
$S = \frac{2\,.\,L\,.\,I\,.\,cos\varphi}{\sigma\,.\,\left(\Delta U - 2.10^{-3}.\,\frac{x}{c}\,.\,L\,.\,I\,.\,sen\varphi\right)}$	$S = \frac{\sqrt{3}\,.\,L\,.\,I\,.\,cos\varphi}{\sigma\,.\,\left(\Delta U - \sqrt{3}.10^{-3}.\,\frac{x}{c}\,.\,L\,.\,I\,.\,sen\varphi\right)}$

Where:

- S = conductor cross section in mm2
- cos φ = power factor
- L = line length in m
- I = line current in A (see below)
- σ = conductivity of the conductor in m/Ω•mm2 (see below)
- ΔU = maximum voltage drop in V
- x = line inductive reactance = 0.10 Ω/km
- c = number of conductors per phase

Note: For the simplicity of the calculation the skin and proximity effects were neglected which, in a certain way, interfere in AC conductor electrical resistance (larger cross sections), as well as the reactance value is fixed and equal to 0.10 Ω / km, regardless the cross section and physical arrangement of the conductors.

The voltage drop calculated as indicated is acceptable in the majority of cases. More accurate values of AC resistance (considering the skin and proximity effects) and inductive reactance can be obtained in the Cable Sizing Guide available on the Prysmian website click here.

LINE CURRENT INTENSITY

SINGLE-PHASE	THREE-PHASE
$I = \frac{P}{U\,.\,\cos\varphi\,.\,\eta}$	$I = \frac{P}{\sqrt{3}\,.\,U\,.\,\cos\varphi\,.\,\eta}$
$I = \frac{S}{U}$	$I = \frac{S}{\sqrt{3}\,.\,U}$

Where:

- I = line current (A)
- P = power (W)
- U = phase-to-neutral voltage (single-phase) or between phases (three-phase) (V)
- cos φ = power factor
- S = apparent power (VA)
- η = engine efficiency (when applicable).

CONDUCTOR CONDUCTIVITY IN m/Ω•mm^2

CONDUCTOR MATERIAL	CONDUCTOR TEMPERATURE		
	20°C	70°C (thermoplastic)	90°C (thermosetting)
Copper	58,00	48,47	45,49
Aluminum	35,71	29,67	27,80

CONDUCTOR CROSS SECTION CALCULATION DUE TO SHORT-CIRCUIT CURRENT

It is possible to calculate the maximum short-circuit current that a cable conductor can support with the expression:

$$Icc = k \cdot S / \sqrt{t}$$

Where:

- Icc = short-circuit current in A.
- k = constant depending on the conductor material (Cu or Al) and type of insulation: thermoplastic (PVC, LSHF / A) or thermoset (HEPR, XLPE).
- S = conductor cross-section in mm^2.
- t = duration of the short circuit in s (5 seconds maximum).

"K"	**CONDUCTOR MATERIAL**	
	Copper	Aluminum
Thermoplastic (160ºC)	115	76
Thermosetting (250ºC)	143	94

ENERGY CONSCIOUS SOLUTION ON ELECTRIC LINES

The electrical power (P) dissipated by a conductor of resistance R when carry current (I) is:

$$P = R \cdot I^2$$

(Joule's law)

The thermal energy lost in an electric line corresponds to the following general expression:

$$EP = n \cdot R \cdot (I/c)^2 \cdot L \cdot t / 1000$$

Where:

EP: line energy lost [kWh]

n: number of loaded conductors

c: number of conductors per phase

R: conductor resistance [Ω/km]

L: line length [km]

I: line current [A]

t: time [h]

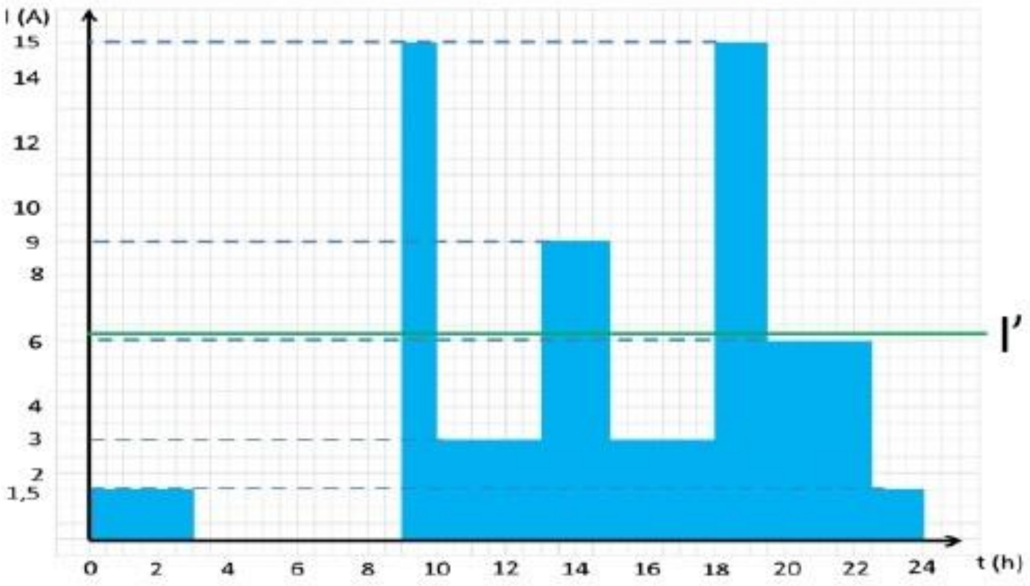
If the cross-sectional area (S) of a cable is increased, there will be a corresponding reduction in the resistance (R). When carrying the same current I, there will be a reduction in the energy lost (EP). This energy saving can be quantified both as a cost saving in electricity bills and a reduction in CO_2 emissions.

The cable itself will be more expensive because it will have a higher cross-sectional area (S) but the installer will benefit from the following:

- Lower running costs, reduced energy bills.
- Reduced CO2 emissions, therefore an environmentally better proposition.
- Extended design life for the cable because it is operating at a lower temperature.
- Improved short circuit capability - larger cross-sectional areas will carry higher currents in a fault condition.
- Potential to uprate the cable to carry higher loads in the future.

As general rule, power lines do not carry the same current (I) all the time (t), the current (I) varies over time in most installations. Therefore, to avoid that the result does not reflect reality, it is advisable to consider a constant current value (I') that produces the same energy as the variable current (I), in the same period of time. This current (I') is called the mean square value of the current (I) (not to be confused with the average value, since the current in Joule's Law is raised to the square).

In the figure below (I) is the variable current of 15 A, represented by the blue rectangles and (I') is the mean square value of the current (approx. 6 A).



By default, CableApp uses the mean square value of the current (I') equal to 100% of I, but it also suggests others (as shown below) and allows the end user to manually enter values more appropriate for their installation.

I'= 100% I (default)

40% I (residential)

60% I (public place)

75% I (industrial)

others %

Thus, the energy saved (EA) by installing conductors of lower resistance (R_2) than (R_1) will be:

$$EA = n \cdot (R1-R2) \cdot L \cdot (I'/c)^2 \cdot t / 1000 \ (S2 > S1)$$

With this energy saved, it is possible to calculate the economic gain (in R$) as well as the reduction in CO_2 emissions, since the values of the electricity tariff in R$/kWh and CO_2 emissions per kWh generated are known.

Electricity tariff = R $ 0.70/kWh (proposed standard value)

Note: for more information, consult your energy dealer.

CO_2 emissions = 0.10 kg CO_2/kWh (proposed approximate value, taking account the country's energy mix, according to data of Brazilian Government)

Note: more information see:
https://www.mctic.gov.br/mctic/opencms/ciencia/SEPED/clima/textogeral/emissao_corporativos.html

EXAMPLE

Energy conscious calculation of a 130 m three-phase line with 150 mm² copper conductors and a current of 268 A.

To calculate the savings, we must consider increasing the cross-section area to a larger size.

The next largest standard cross-section to the 150 mm² would be 185 mm².

	Conductor Resistence Ω/km	
Size (mm²)	**Copper**	**Aluminum**
1.5	15.91	-
2.5	9.55	-
4	5.92	-
6	3.95	-
10	2.29	
16	1,48	2,3
25	0,934	1,446
35	0,663	1,042
50	0,463	0,772
70	0,326	0,56
95	0,248	0,386
120	0,195	0,305
150	0,157	0,249
185	0,13	0,199
240	0,1	0,152
300	0,082	0,129
400	0,064	0,101

If the calculation is undertaken for an annual usage, then the time (t) will be 365d x 24h = 8760 h

Assuming that the line is from a public place and the suggested value (above) is accepted, the avarage usage is 60% and I'= 60% I.

It is possible to calculate the energy that can be saved in a year, using conductors of 185 mm² instead of 150 mm².

EA = (n • (R185-R150) • L • (I'/c)² • t) / 1,000 = (3 x (0.157-0.13) x 0.13 x (0.6 x 268/1) ² x 8760)/1000 = 2385 kWh

With the energy tariff and CO2 emission values reported above, we have:

- in R$ = 2385 kWh x 0.70 R$/kWh = R$ 1,669.50
- in CO_2 = 2385 kWh x 0.10 kg CO_2/kWh = 238.50 kg CO_2

Note: this calculation method is not related to the standard ABNT NBR 15920: 2011 Electrical cables - Calculation of the rated current - Operating conditions - Economic optimization of the power cable sections.

MULTIPLES CONDUCTORS PER PHASE

If the electrical current indicated by the user exceeds the maximum limit supported by only one conductor, CableApp considers the application of 2 or more conductors per phase, the spacing between cables of the same circuit as spacing between circuits as well as the application of grouping factors when necessary.

The user must pay attention in this situation regarding the filling in the field “separation between circuits”, because if this field is filled with ≤2De it will be considered the grouping factor but if it is filled with “> 2De” no grouping factor will be applied.

EXAMPLE:

Afumex Flex Cable - Multipolar *

230V three-phase voltage

500A electrical current

*** Multipolar cables have conductor section manufacturing limit of 240mm².**

When selecting options:

Cable Calculator

Application

Single / Multicore 1kV cables for fixed installations

Installation Method

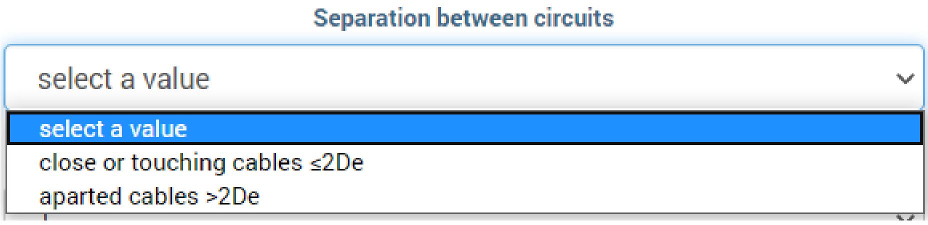
Cable trunking on the wall or suspended (B1, B2)

According to table 37 of NBR5410, 240mm² cross-section cables, method B2 and three loaded conductors, the current rating is 407A.

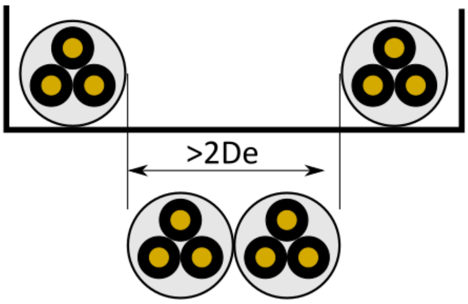
Tabela 37 — Capacidades de condução de corrente, em ampères, para os métodos de referência A1, A2, B1, B2, C e D
Condutores: cobre e alumínio
Isolação: EPR ou XLPE
Temperatura no condutor: 90°C
Temperaturas de referência do ambiente: 30°C (ar), 20°C (solo)

Seções nominais mm²	Métodos de referência indicados na tabela 33											
	A1		A2		B1		B2		C		D	
	Número de condutores carregados											
	2	3	2	3	2	3	2	3	2	3	2	3
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Cobre											
0,5	10	9	10	9	12	10	11	10	12	11	14	12
0,75	12	11	12	11	15	13	15	13	16	14	18	15
1	15	13	14	13	18	16	17	15	19	17	21	17
1,5	19	17	18,5	16,5	23	20	22	19,5	24	22	26	22
2,5	26	23	25	22	31	28	30	26	33	30	34	29
4	35	31	33	30	42	37	40	35	45	40	44	37
6	45	40	42	38	54	48	51	44	58	52	56	46
10	61	54	57	51	75	66	69	60	80	71	73	61
16	81	73	76	68	100	88	91	80	107	96	95	79
25	106	95	99	89	133	117	119	105	138	119	121	101
35	131	117	121	109	164	144	146	128	171	147	146	122
50	158	141	145	130	198	175	175	154	209	179	173	144
70	200	179	183	164	253	222	221	194	269	229	213	178
95	241	216	220	197	306	269	265	233	328	278	252	211
120	278	249	253	227	354	312	305	268	382	322	287	240
150	318	285	290	259	407	358	349	307	441	371	324	271
185	362	324	329	295	464	408	395	348	506	424	363	304
240	424	380	386	346	546	481	462	407	599	500	419	351

Current rating is less than required and so when selecting "separation between circuits" there are two options:

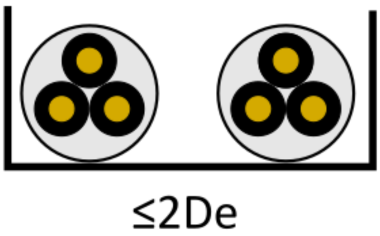


Case1: Considering the “separation between circuits” **>2De**, the result will be 2 cables of 120mm^2 each per phase. With this option selected, it is understood that the system will be similar as shown in the figure below – aparted cables - and **no grouping factor is applied**:



2 x 120mm^2 (268A) = 536A total.

Case2: Considering the “separation between circuits” **≤2De**, the result will be 2 cables of 185mm2 each per phase, because in this case, the reduction factor 0.8 must be applied (Table 42 of NBR5410). If this option is selected, the system will be similar as shown in the figure below – close or touching cables.



2 x 120mm2 (268A) x 0.8 = total 428A. Less than 500A, not good!

2 x 150mm2 (307A) x 0.8 = total 491.2A. Less than 500A, not good!

2 x 185mm2 (348A) x 0.8 = total 556.8A. Greater than 500A, OK!

METHODS OF INSTALLATION – NBR 5410

Electric line type	Installation method [2]	Insulated Conductor	Single-core Cable	Multi-core Cable
		Superastic, Superastic Flex e Afumex Green.	Sintenax, Sintenax Flex, Gsette Easy, Voltenax, Voltalene e Afumex Flex.	Sintenax, Sintenax Flex, Gsette Easy, Voltenax, Voltalene e Afumex Flex.
		Reference method		
Conduit embedded in thermally insulated wall	1/2	A1	A1	A2
Direct embedding in thermally insulated wall	51	-	-	A1
Moulding	71	A1	A1	-
Conduit embedded in door architrave or window frames	73/74	A1		-
Direct embedding in door architrave or window frames	73/74	-	A1	A1
Apparent conduit	3/4/5/6	B1	B1	B2
Conduit embedded in masonry	7/8	B1	B1	B2
Directly in a construction void – $1,5D_e \le V < 5D_e$ [5]	21	-	B2	B2
Directly in a construction void – $5D_e \le V < 50D_e$ [5]	21	-	B1	B1
Conduit in a construction void – $1,5D_e \le V < 5D_e$ [5]	22/24	B2	-	-
Conduit in a construction void – $V \ge 20\ D_e$ [5]	22/24	B1	-	-
Conduit in a construction void	23/25	-	B2	B2
Non-circular conduit embedded in masonry – $1.5D_e$ £ $V < 5\ D_e$ [5]	26	B2	-	-
Non-circular conduit embedded in masonry – $5D_e \le V < 50D_e$ [5]	26	B1	-	-
Non-circular conduit embedded in masonry	27	-	B2	B2
Ceiling void or raised floor – $1,5D_e \le V < 5D_e$ [5]	28	-	B2	B2
Ceiling void or raised floor – $5D_e \le V < 50D_e$ [5]	28	-	B1	B1
Cable trunking on the wall or suspended	31/31A/32/32A/35/36	B1	B1	B2
Flush cable trunking in the floor, ground or wall	33/34/72/72A/75/75A	B1	B1	B2
Conduit in an unventilated cable channel – $1,5D_e \le V < 20D_e$ [5]	41	B2	B2	-
Conduit in an unventilated cable channel – $V \ge 20$ De [5]	41	B1	B1	-
Conduit in an open or ventilated cable channel in the floor or ground	42	B1	-	-
Open or ventilated cable channel in the floor or ground	43	-	B1	B1
Fixed directly on wall or under ceiling [4]	11/11A/11B	-	C	C
Unperforated cable tray (run horizontally or vertically)	12	-	C	C
Direct embedding in masonry - with or without mechanical protection	52/53	-	C	C
Conduit or cable ducting in the ground	61/61A	-	D	D
Direct in the ground	63	-	D	D
Perforated cable tray (run horizontally or vertically)	13	-	F	E
Ladder, brackets or wire mesh tray (run horizontally or vertically)	14/16	-	F	E
Spaced from a wall or suspended by a supporting cable [3]	15/17	-	F	E
On insulators	18	G	G	-

(1) The locations marked with (-), according to NBR 5410:2004 the installation of insulated conductor or cable is not recommended.
(2) method of installation according to table 33 of NBR 5410:2004.
(3) spaced more than 0,3 times cable diameter from a wall.
(4) spaced less than 0,3 times cable diameter from a wall.
(5) V = height of the construction void or cable channel / D_e = cable external diameter