PACKAGING GUARANTEES QUALITY

For optimal performance, it is very important that the busbars arrive at their destination undamaged and free of corrosion.
To be able to guarantee this, Nedal Aluminium B.V. has put together its packaging specifications with great care.
In consultation with the client, a choice can be made from three packaging qualities:

Quality Class III
Nedal packs the busbars, per diameter, in stable packages, in which the bars are stacked without distance blocks.
The bars are deburred, chips are removed from inside the bars, and they are fitted with a plastic seal, so that no internal contamination can occur. The bars are also coated with a thin layer of oil, for conservation purposes.

Quality Class II
Nedal clusters the busbars into stable packages. Distance blocks ensure that the bars are not able to knock against each other.
When the bars are to be transported over longer distances (transportation by sea), they are oiled, and packages are sealed completely in a plastic cover.

Quality Class I
Identical to Class II, but:
for optimal protection and conservation, Nedal packs each (completely oiled) busbar in plastic, and, each packaging unit is placed in a wooden crate.

For further information about packaging, please feel free to request a copy of our packaging conditions from Nedal Aluminium B.V.

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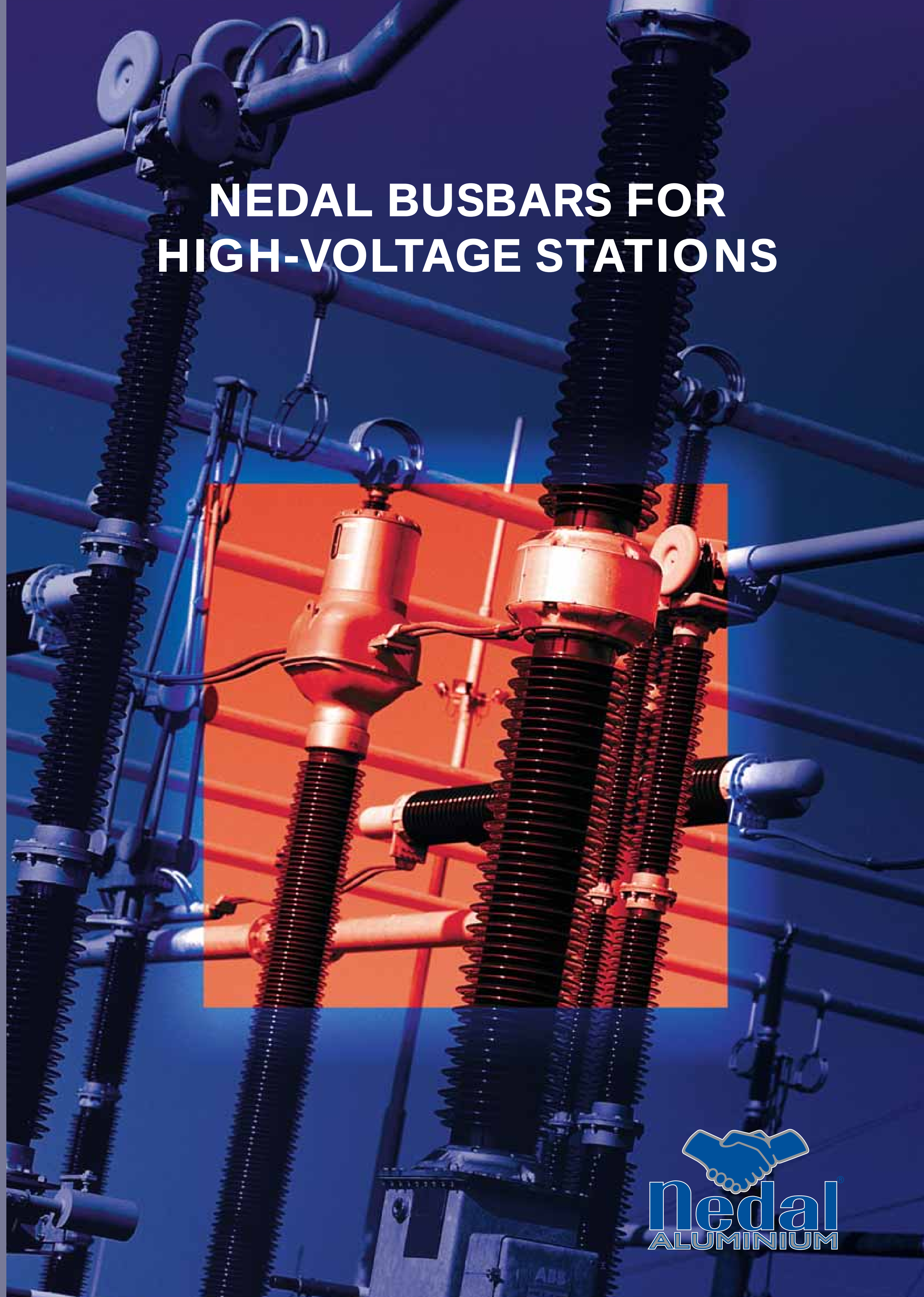
NEDAL BUSBARS FOR HIGH-VOLTAGE STATIONS



NEDAL BUSBARS FOR HIGH-VOLTAGE STATIONS

NEDAL ALUMINIUM

As the first Dutch Aluminium Processing Industry, since 1938, Nedal has specialised in the development and production of extruded aluminium profiles.
Nedal supplies its quality products to clients all over the world. Thanks to our many years of experience, modern production techniques and, particularly, our client-oriented approach, our clients find us a valued partner.

Nedal supplies special aluminium busbars for the power connections in open-air switching stations in high-voltage systems. In these strategic points in the power supply, the busbars are a very reliable alternative to cable connections, and they are attractive in a technical and economical sense too.

NEDAL BUSBAR'S STRONG POINTS

The natural qualities of aluminium give the busbars many advantages.

Nedal aluminium busbars
- are lighter and have a greater stiffness than cables with the same current transfer capacity
  - this facilitates larger free spans;
  - which require fewer points of support (and foundations);
  - the load on the foundation points is lower than is the case with cables
- impose a lower load on supports, switches and transformers than shunted cables do in the event of short-circuiting
- are good conductors, thanks to the skin effect: a busbar's surface has a current density that is relatively lower than that of a cable.
- are permanently corrosion-resistant
- possess excellent electric conductance properties
- have a smooth surface
- are maintenance-free
- have a very long life span

Technically perfected
The excellent quality of Nedal busbars is the result of many years of experience, combined with continual research and product development.

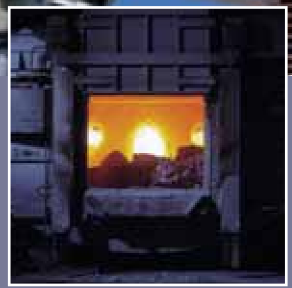
Client-oriented solutions
Nedal offers tailor-made solutions. The busbars' specifications are fully adapted to suit each individual client's requirements.

Maintenance-free and environmentally friendly
Thanks to aluminium's natural properties, aluminium busbars require hardly any maintenance. Because corrosion is not an issue, costly conservative treatments and coatings, with their great impact on the environment, are unnecessary.
Of course, the fact that aluminium busbars can be recycled also benefits the environment.

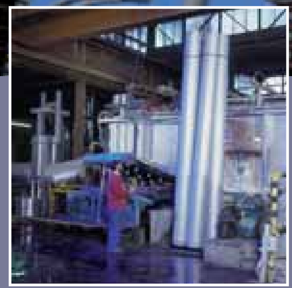
Tailor-made
Nedal ensures that its busbars possess the optimal specifications and metallurgical properties required for each individual situation. After consultation with the client, Nedal determines the alloy and dimensions required. Throughout the production process, the specifications are monitored closely. This starts at the melting process, and extends through to packaging and dispatch.

CALCULATION OF SPECIFICATIONS ACCORDING TO KEMA PROVISIONS

Using the booklet in this brochure, you can calculate which specifications the busbars used in your projects must meet. The guidelines and methods of calculations have been determined by KEMA (Dutch quality-control institute for electrical material and appliances). Of course, the specialists at Nedal's Technical Centre will be only too please to calculate these specifications for you, or offer you advice on them.

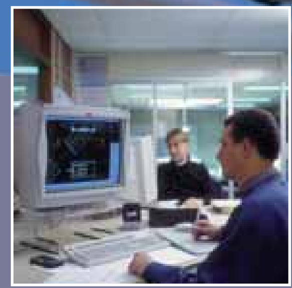


In the melting furnaces, the alloy required is produced precisely



The alloy leaves the casting pit in the form of billets

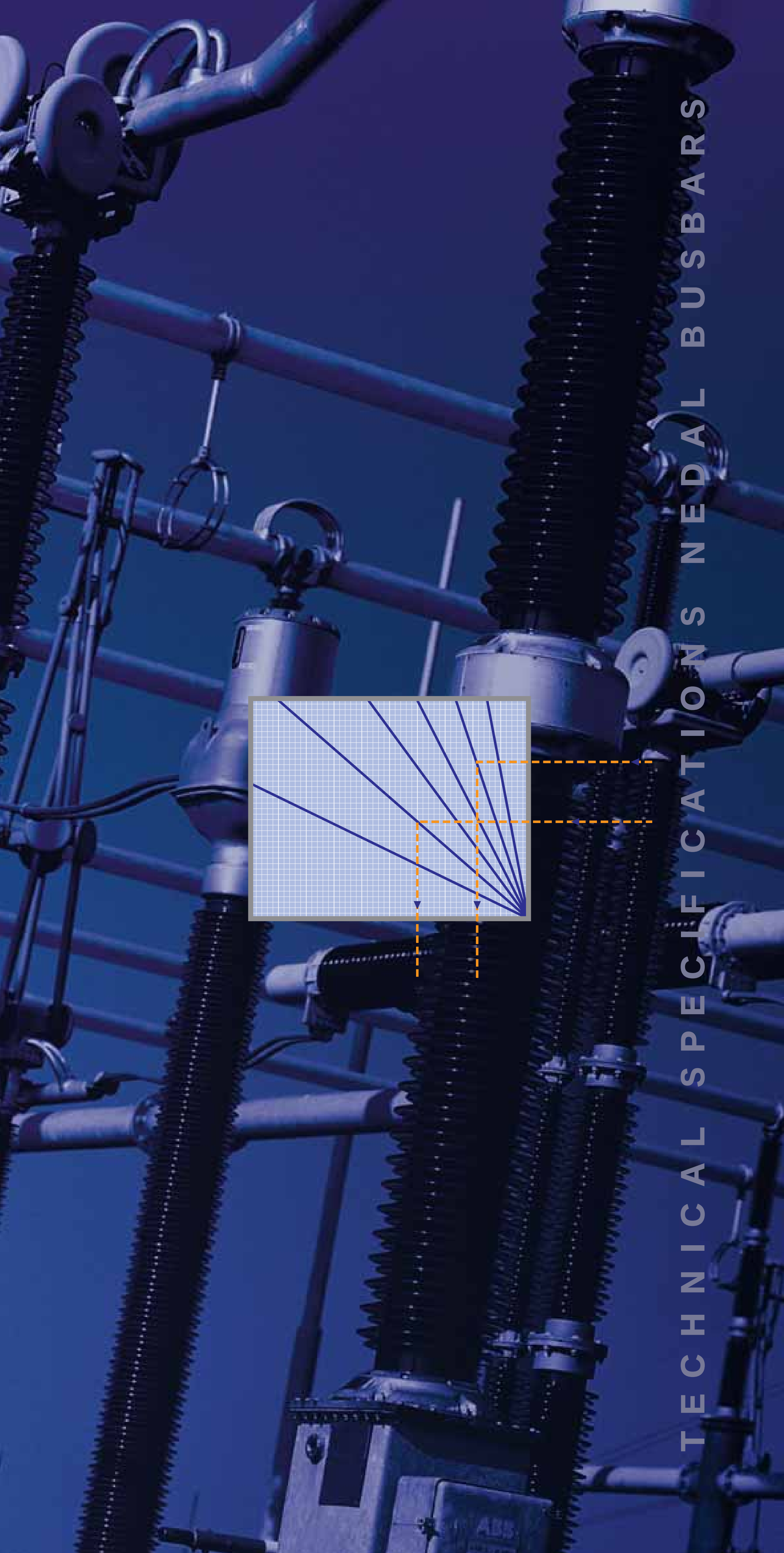
The billets are homogenised before busbars are extruded from them



Precise measurements and checks throughout the production process guarantee an optimal product

Nedal extrudes the busbars from one piece, exactly according to the dimensions required, up to lengths of 28 metres

A protective packaging ensures that the busbars arrive at their destination undamaged and ready for installation



TECHNICAL SPECIFICATIONS NEDAL BUSBARS

DETERMINING BUSBAR CROSS-SECTION

This part of our documentation describes a method for determining the right choice of busbar cross-section. This method was formulated in co-operation with KEMA in Arnhem, the Netherlands.

It is assumed that the client knows the following details:
The nominal current during normal operation
The required short-circuit current
The applicable centre-line distance between busbars
The maximum span between two busbar supports.

Based on these details a correct choice of busbar diameter and wall thickness can be made using the method described below.

The dimensions of a busbar are mainly determined by two physical loads, i.e. the thermal and mechanical loads on the busbar.

MATERIAL PROPERTIES

The alloys listed below, which comply with EN 755-2, are those most commonly used for electrical busbars. Alloy 6101B T6 has more mechanical strength but less electrical conductivity. If higher electrical conductivity is required, alloy 6101B T7 can be used. However, this alloy has less mechanical strength. Of course busbars made of other alloys can also be supplied. Please contact Nedal Aluminium B.V. for further information about the properties of these alloys.

Property	Unit	Alloy	
		6101B T6	6101B T7
Specific gravity ρ	kg/m^3	2,700	2,700
Young's modulus E	N/mm^2	70,000	70,000
Stress corresponding to the yield point (R_ρ)	N/mm^2	160	120
Ultimate tensile strength (R_m)	N/mm^2	215	170
Elongation	%	8	12
Coefficient of linear expansion ∂ (0 - 100°C)	K^{-1}	23.5x10^{-6}	23.5x10^{-6}
Electrical conductivity (at 20°C)	MS/m (m/Ωmm^2)	30	32

THERMAL CAPACITY OF BUSBARS

The thermal capacity of a busbar is mainly determined by:
- the environment: temperature and solar radiation
- the nominal current
- the maximum busbar temperature as determined by the client.

When the amount of heat absorbed by the busbar is the same as the amount of heat it emits, equilibrium is reached. In this situation the busbar temperature will remain constant. The current at this point of equilibrium is the current-carrying capacity of the busbar.

This heat balance must be considered under normal operating conditions and under the extreme condition of a short-circuit. During a short-circuit extra heating of the busbars may occur in a short space of time.

Normal operating conditions
In this documentation the allowable current was calculated in accordance with DIN 43 670 with an ambient temperature of 35°C, a final busbar temperature of 80°C, an absorption coefficient of 0.6 and a solar radiation of 600 W/m^2.

The allowable currents for the busbar dimensions and standard aluminium alloys available from Nedal are given in *table 2 and table 3.*

It can be seen from the tables that when using aluminium alloy 6101B T7 for a current-carrying capacity of 3000 A, the minimum busbar dimensions (diameter/wall thickness) of 100/10, 120/6 or 160/4 are acceptable.

For different ambient temperatures or final busbar temperatures the current carrying capacity can be determined using the load factor from *figure 1*.

Example:
At an ambient temperature of 30°C and a final busbar temperature of 65°C, the current carrying capacity from *table 2 or 3* has to be multiplied by a factor 0.86.

If, under these conditions, a busbar has to be selected for a nominal current of 3000 A, the method is as follows. The fictive load on the busbar is 3000 : 0.86 = 3488 A. From the table (6101B T7) it can then be seen that possible choices for busbar dimensions are 120/10 or 160/5.

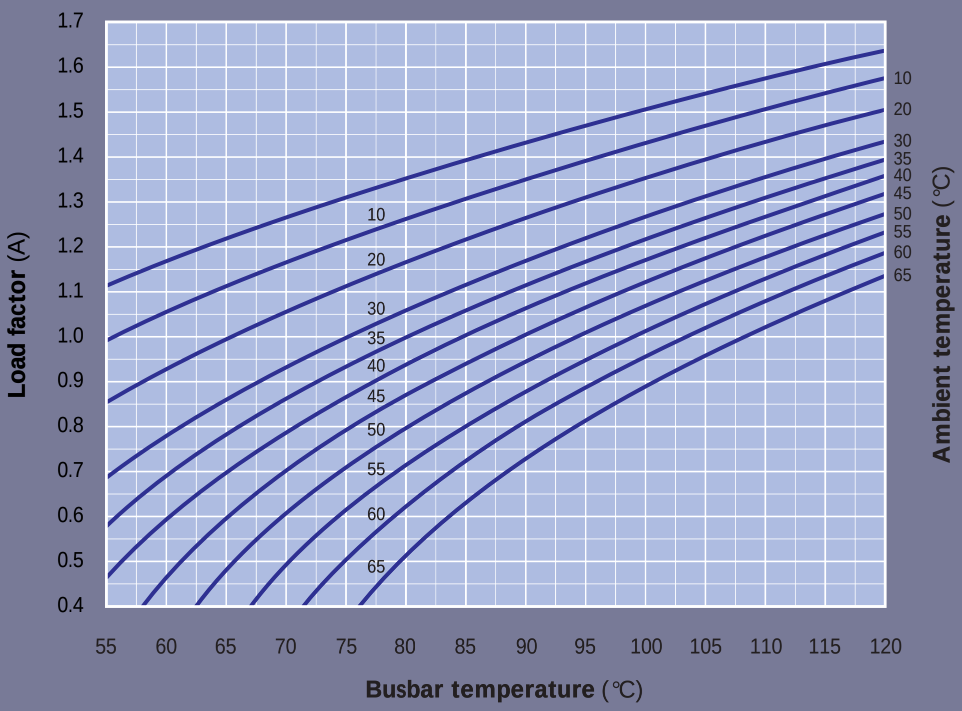


Figure 1. Current carrying capacity as function of ambient temperature and final busbar temperature.

Short-circuit

Under short-circuit conditions the final busbar temperature must not exceed 200°C, based on an initial temperature of 80°C. Higher temperatures can affect the structure of the aluminium alloy, which results in changes in its mechanical properties. During short-circuits the temperature will generally remain below the allowable temperature of 200°C, based on a busbar temperature of 80°C during normal operation.

After determining the busbar cross-section the current density during a short-circuit can be determined. This current density (J) can be determined from the short-circuit current I_k and the cross-section of the busbar.

Table 1. Current density (J) as a function of material type and duration of the short-circuit current

	6101B T6	6101B T7
Duration of the short-circuit current (s)	J_{eff} (Amp./mm^2)	J_{eff} (Amp./mm^2)
0.5	118	122
1.0	83	86
1.5	68	70
2.0	59	61
3.0	48	50
5.0	37	38

MECHANICAL CAPACITY OF BUSBARS

The busbar's diameter and wall thickness are not determined on the basis of the current carrying capacity only. The sag as a result of normal and exceptional loads must also be taken into account.

In accordance with the harmonisation document 'HD 637 Power installations exceeding 1 kV a.c.', busbars must meet mechanical requirements that have been derived from the following loads and operating conditions:

Normal loads taking into account:
- the busbar's mass
- ice load
- wind load

These loads determine the sag of the busbar under normal operating conditions. The amount of sag depends on the stiffness of the busbar. If the busbar's diameter and wall thickness are determined, the sag under normal operating conditions can be determined. This can be important for the design of a switchyard.

The sag resulting from the mass and span length of the busbar can be determined from *figure 2.*

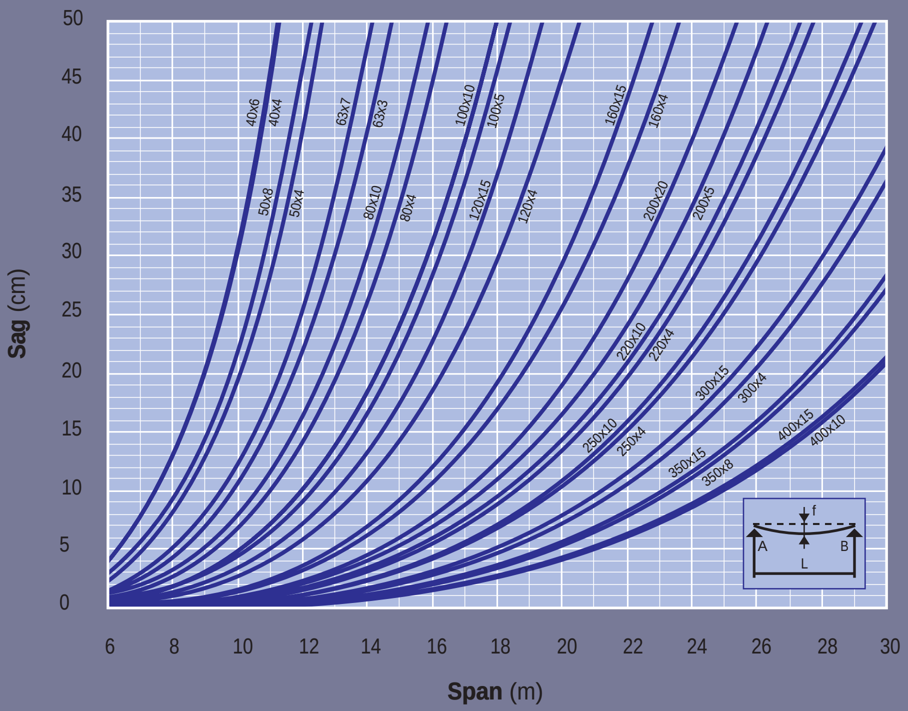


Figure 2. Busbar sag as function of span length (as a result of the mass of the busbar itself)

Exceptional loads, taking into account:
- short-circuit forces
- switching forces.

Only forces on the busbar during short-circuits are considered below, since these forces are the determining factor in most cases.

In a three-phase system with three busbars in the same plane, the greatest force during short-circuits will occur in the centre busbar. Electromagnetic forces will occur between the conductors as a result of the short-circuit current. The busbar must have a certain stiffness to absorb these forces. The required section modulus was determined in accordance with the simplified calculation method of IEC 865.

Based on the required short-circuit current and phase-to-phase distance, the electromagnetic force per metre busbar can be determined using *figure 3 and figure 4* (depending on the alloy used). With this data and the required span length the required section modulus can be seen.

The calculations are based on:
- a two-point support for the busbar
- a factor of plasticity of 1.4
- automatic reclosing after the short-circuit.

DETERMINING THE BUSBAR DIAMETER AND CROSS-SECTION

With the required nominal current carrying capacity and the required section modulus one or more suitable busbar dimensions that meet both requirements can be found in *table 2 or 3*.

Example of determining a busbar dimension:

Criteria:

I_{normal}	*: 4000 A*	*nominal current during normal operation*
I_k	*: 50 kA*	*short-circuit current*
$a_{phase\text{-}phase}$	*: 4 m*	*phase-phase distance*
L_{max}	*: 12 m*	*span length, distance between supports*
Al alloy	*: 6101B T6*	

The following busbar dimensions (diameter/wall thickness) are acceptable for the required nominal current of 4000 A: 120/15, 160/8, 200/5 and 220/4 *(see table 2)*.

Using *figure 3* it can be determined that, at the given short-circuit current, phase-to-phase distance and span length, the required section modulus is approximately 100 cm^3. Among others, the following busbar dimensions meet this requirement: 120/12, 160/6, 200/5 and 220/4.

Busbars 120/15, 160/8, 200/5 and 220/4 meet both the current carrying capacity requirements and the requirements from the dynamic short-circuit load. Busbar 220/4 is the lightest in weight but is vulnerable due to its small wall thickness. Therefore a choice should be made between 120/15, 160/8 or 200/5.

After determining the diameter and wall thickness, the client's choice of busbar may be based on the following:
- weight saving
- standardisation of busbars to be used (possibly a preference for 120 mm type)
- sag of the busbar as a result of busbar mass *(see figure 2)*
- current density in the busbar as a result of short-circuits *(see table 1)*
- ease of working on the busbar (it is easier to weld termination pieces to busbars with greater wall thickness)

Changing assumptions or parameters can be discussed with KEMA, if required. Optimisation can lead to significant savings, not just on busbar material but also on supports, e.g. lighter insulators, support structures and foundations. To this end, KEMA has advanced calculation methods and tools at its disposal.

Table 2 ***Current Carrying Capacity of available Busbars (metric)***
Busbar temperature 80ºC at ambient temperature 35ºC

						6101B T6	6101B T7
d_u (mm)	w_d (mm)	A (mm^2)	m (kg/m)	I (cm^4)	Z (cm^3)	I_n (A)	I_n (A)
40	4	452	1.2	7	3.7	940	970
40	5	550	1.5	9	4.3	1,040	1,070
40	6	641	1.7	10	4.8	1,120	1,150
50	4	578	1.6	15	6.2	1,150	1,180
50	5	707	1.9	18	7.2	1,270	1,310
50	6	829	2.2	20	8.2	1,370	1,410
50	8	1,056	2.9	24	9.6	1,540	1,590
63	3	565	1.5	26	8.1	1,230	1,260
63	4	741	2.0	32	10.3	1,400	1,450
63	5	911	2.5	39	12.3	1,550	1,600
63	7	1,232	3.3	49	15.6	1,700	1,850
80	4	955	2.6	69	17.3	1,720	1,780
80	5	1,178	3.2	83	20.8	1,900	1,970
80	6	1,395	3.8	96	24.0	2,080	2,140
80	8	1,810	4.9	119	29.7	2,350	2,430
80	10	2,199	5.9	137	34.4	2,580	2,660
100	5	1,492	4.0	169	33.8	2,320	2,390
100	6	1,772	4.8	196	39.3	2,520	2,600
100	8	2,312	6.2	246	49.3	2,860	2,950
100	10	2,827	7.6	290	58.0	3,140	3,240
120	4	1,458	3.9	245	40.9	2,440	2,510
120	5	1,806	4.9	299	49.9	2,700	2,790
120	6	2,149	5.8	350	58.3	2,950	3,040
120	8	2,815	7.6	444	73.9	3,340	3,450
120	10	3,456	9.3	527	87.8	3,680	3,800
120	12	4,072	11.0	601	100.2	3,960	4,090
120	15	4,948	13.4	696	116.0	4,300	4,440
160	4	1,960	5.3	597	74.6	3,110	3,210
160	5	2,435	6.6	732	91.5	3,450	3,570
160	6	2,903	7.8	862	107.7	3,760	3,880
160	8	3,820	10.3	1,106	138.3	4,280	4,420
160	10	4,712	12.7	1,331	166.4	4,710	4,860
160	15	6,833	18.4	1,815	226.9	5,520	5,700
200	5	3,063	8.3	1,457	145.7	4,170	4,310
200	6	3,657	9.9	1,722	172.2	4,540	4,690
200	8	4,825	13.0	2,227	222.7	5,160	5,330
200	10	5,969	16.1	2,701	270.1	5,690	5,880
200	12	7,087	19.1	3,144	314.4	6,200	6,400
200	15	8,718	23.5	3,754	375.4	6,650	6,870
200	20	11,310	30.5	4,637	463.7	7,410	7,660
220	4	2,714	7.3	1,584	144.0	4,070	4,200
220	6	4,034	10.9	2,311	210.1	4,920	5,080
220	8	5,328	14.4	2,998	272.5	5,590	5,780
220	10	6,597	17.8	3,645	331.4	6,170	6,370
250	4	3,091	8.3	2,339	187.1	4,530	4,680
250	5	3,848	10.4	2,889	231.1	5,030	5,200
250	6	4,599	12.4	3,425	274.0	5,470	5,650
250	8	6,082	16.4	4,457	356.6	6,220	6,420
250	10	7,540	20.4	5,438	435.0	6,860	7,080
300	4	3,720	10.0	4,074	271.6	5,290	5,470
300	6	5,542	15.0	5,990	399.3	6,370	6,580
300	8	7,339	19.8	7,828	521.8	7,250	7,480
300	10	9,111	24.6	9,589	639.3	7,920	8,180
300	12	10,857	29.3	11,276	751.8	8,560	8,840
300	15	13,430	36.3	13,674	911.6	9,370	9,680
350	8	8,595	23.2	12,574	718.5	8,230	8,500
350	10	10,681	28.8	15,448	882.7	9,100	9,400
350	12	12,742	34.4	18,220	1,041.1	9,880	10,210
350	15	15,787	42.6	22,190	1,268.0	10,530	10,880
400	10	12,252	33.1	23,310	1,165.5	10,130	10,460
400	12	14,627	39.5	27,552	1,377.6	10,850	11,210
400	15	18,143	49.0	33,666	1,683.3	11,740	12,130

Legend

d_u = external diameter
W_d = wall thickness
A = cross section
m = mass per unit length
I = second moment
Z = section modulus
I_n = current carrying capacity

Table 3 ***Current Carrying Capacity of available Busbars (inches)***
Busbar temperature 80ºC at ambient temperature 35ºC

								6101B T6	6101B T7
Pipe Size (in)	**Schedule number**	d_u (mm)	w_d (mm)	**A** (mm^2)	**m** (kg/m)	**I** (cm^4)	**Z** (cm^3)	I_n (A)	I_n (A)
$1^{1/4}$	40	42.20	3.55	431.05	1.16	8	4	938	969
	80	42.20	4.85	569.09	1.54	10	5	1,077	1,112
	160	42.20	6.35	715.18	1.93	12	6	1,206	1,245
$1^{1/2}$	40	48.30	3.70	518.43	1.40	13	5	1,076	1,111
	80	48.30	5.10	692.16	1.87	16	7	1,240	1,280
	160	48.30	7.15	924.33	2.50	20	8	1,432	1,479
2	40	60.30	3.90	691.02	1.87	28	9	1,337	1,381
	80	60.30	5.50	946.88	2.56	36	12	1,562	1,613
	160	60.30	8.75	1,417.05	3.83	48	16	1,898	1,961
$2^{1/2}$	40	73.00	5.15	1,097.76	2.96	64	17	1,792	1,851
	80	73.00	7.00	1,451.42	3.92	80	22	2,051	2,119
	160	73.00	9.50	1,895.17	5.12	98	27	2,326	2,402
3	40	88.90	5.50	1,441.05	3.89	126	28	2,189	2,261
	80	88.90	7.60	1,941.13	5.24	162	36	2,529	2,612
	160	88.90	11.15	2,723.49	7.35	210	47	2,957	3,054
$3^{1/2}$	40	101.60	5.75	1,731.45	4.67	200	39	2,504	2,586
	80	101.60	8.10	2,379.29	6.42	262	52	2,919	3,015
4	40	114.30	6.00	2,041.41	5.51	300	53	2,832	2,925
	80	114.30	8.55	2,840.51	7.67	400	70	3,302	3,410
	120	114.30	11.15	3,613.22	9.76	486	85	3,703	3,824
	160	114.30	13.50	4,275.08	11.54	553	97	3,980	4,111
5	40	141.30	6.55	2,772.81	7.49	631	89	3,531	3,646
	80	141.30	9.50	3,933.59	10.62	859	122	4,149	4,285
	120	141.30	12.70	5,130.91	13.85	1,071	152	4,672	4,825
	160	141.30	15.85	6,246.69	16.87	1,248	177	5,080	5,247
6	40	168.30	7.10	3,595.62	9.71	1,170	139	4,238	4,377
	80	168.30	11.00	5,435.90	14.68	1,689	201	5,095	5,262
	120	168.30	14.30	6,918.42	18.68	2,069	246	5,583	5,766
	160	168.30	18.30	8,623.67	23.28	2,462	293	6,102	6,302
8	60	219.10	10.30	6,756.43	18.24	3,691	337	6,237	6,442
	80	219.10	12.70	8,234.99	23.23	4,402	402	6,777	7,000
	100	219.10	15.10	9,677.36	26.13	5,062	462	7,203	7,439
	120	219.10	18.30	11,544.22	31.17	5,867	536	7,719	7,972
	140	219.10	20.65	12,874.22	34.76	6,406	585	8,068	8,333
	160	219.10	23.00	14,169.53	38.26	6,905	630	8,303	8,603
10	40	273.10	9.30	7,707.39	20.81	6,713	492	7,146	7,381
	60	273.10	12.70	10,389.50	28.05	8,827	646	8,132	8,398
	80	273.10	15.10	12,239.02	33.05	10,218	748	8,712	8,998
	100	273.10	18.30	14,648.74	39.55	11,949	875	9,258	9,562
12	20	323.90	6.35	6,334.84	17.10	7,988	493	6,977	7,206
	30	323.90	8.40	8,325.85	22.48	10,367	640	7,888	8,147
	40	323.90	10.35	10,195.23	27.53	12,543	774	8,574	8,855
	60	323.90	14.30	13,908.71	37.55	16,700	1,031	9,699	10,017
	80	323.90	17.50	16,845.22	45.48	19,833	1,225	10,502	10,846

Legend

d_u	= external diameter	I	= second moment
W_d	= wall thickness	Z	= section modulus
A	= cross section	I_n	= current carrying capacity
m	= mass per unit length		

Figure 3. *Section modulus as function of short-circuit current, phase-to-phase distance (a) and required span (L).* ***6101B T6***

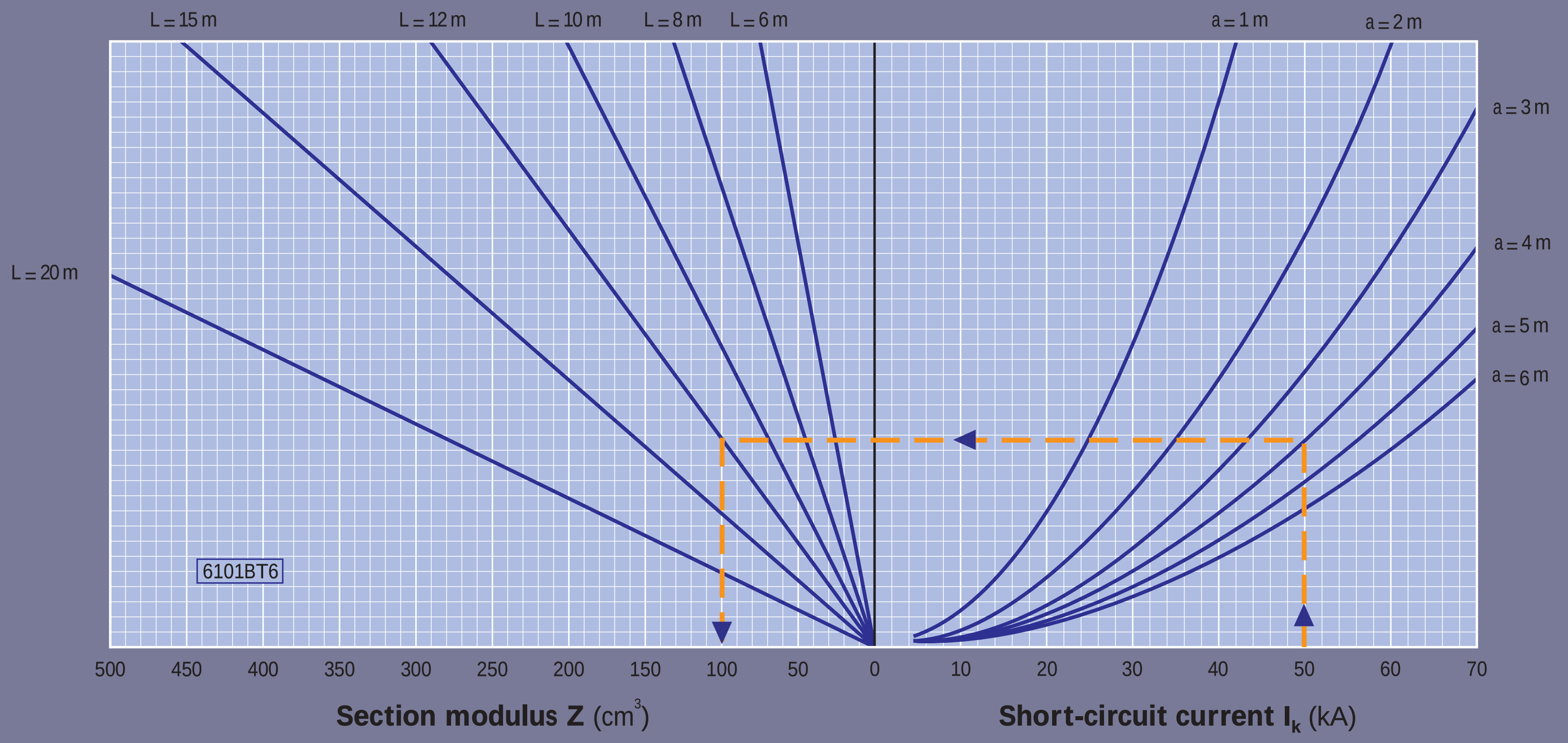


Figure 4. Section modulus as function of short-circuit current, phase-to-phase distance (a) and required span (L) ***6101B T7***