4 QT Technical Application Papers

December 2006

ABB circuit-breakers inside LV switchboards

1SDC007103G0201

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Technical Application Papers

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Introduction

An electrical switchboard is the combination of more protection and switching devices assembled in one or more adjacent compartments.

A switchboard is formed by the compartment, which the Standards name "enclosure" (with support and mechanical protection functions for the different components enclosed), and the electrical equipment, constituted by the apparatus, the internal connections and the incoming and outgoing terminals for the connection to the installation.

This Technical Paper is intended to deal in detail with the equipment in the switchboard, providing the reader with the basic information necessary to choose the circuit-breakers to be installed inside low voltage switchboards in the easiest and most correct way, paying particular attention to ABB SACE range of products.

After a quick survey of the main product Standards concerning switchboards and circuit-breakers, IEC 60439-1 and IEC 60947-2 respectively, the main problems which a manufacturer has to face when designing a switchboard are analyzed.

This Technical Paper is divided into three main parts dealing with the problems of overheating in switchboards, general prescriptions to improve the current carrying capacity of the circuit-breakers inside enclosures and the problems caused by short-circuit in switchboards

[1] The product Std. IEC 60439-1 applies to low voltage and controlgear assemblies, the rated voltage of which does not exceed 1000 Va.c. at frequencies not exceeding 1000 Hz, or 1500 Vd.c.; the product Std. IEC 60947-2 applies to circuit-breakers, the main contacts of which are intended to be connected to circuits, the rated voltage of which does not exceed 1000 Va.c. or 1500 Vd.c.

1 Problems of overheating inside switchboards

1.1 General aspects

One of the main problems which makes difficult the identification of the correct typology of circuit-breakers to be installed inside a switchgear or controlgear assembly is calculating the maximum continuous current which the circuit-breaker can carry without damages or premature ageing according to the service temperature.

The total freedom of the manufacturer in designing switchboards using components different for number, position and dimensions makes the installation conditions of the same circuit-breaker so different that it results impossible to determine exactly its "maximum current carrying capacity" which, affected by peculiar operating conditions, results different from that defined by the manufacturer and referred to standard conditions.

1.2 The current carrying capacity

Now we shall take into consideration how the concept of current carrying capacity is dealt with in the different Standards, in particular, in the product Standard concerning circuit-breakers and in that one regarding low-voltage switchgear and controlgear assemblies.

The circuit-breakers, according to the prescriptions of the European Low Voltage Directive 2006/95/CE, are manufactured and tested in compliance with the product Std. IEC 60947-2 "Low-voltage switchgear and controlgear – Part 2: Circuit-breakers".

As regards the verification of the current carrying capacity in uninterrupted duty (Iu), the Std. IEC 60947-2 states the conditions of the test performance. Here are the main requirements to be met :

- the current carrying capacity shall be verified in free-air

the Std. IEC 60947-1 "Low-voltage switchgear and controlgear - Part 1: General rules" specifies in detail what is meant by "free air":

"Free air is understood to be air under normal indoor conditions (indoor conditions are understood to be not the conditions inside switchgear or controlgear assemblies or enclosures, but the conditions inside buildings or similar environments), reasonably free from draughts and external radiation"

therefore, no external radiations (e.g. those due to the sun's rays-Figure 1) or draughts which are not caused simply by the natural convective motion originated by heating (Figure 1a) are admitted.

Figure 1

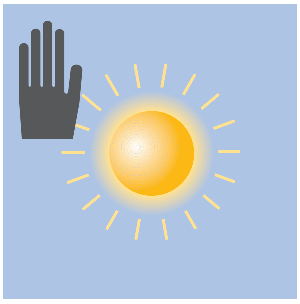
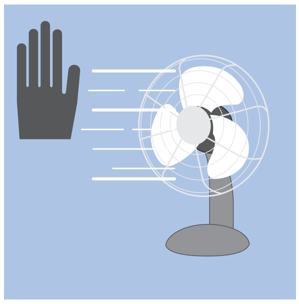


Figure 1a



- **the carrying capacity is verified by connecting the circuit-breakers with conductors having size (maximum) and length (minimum) as specified in the relevant Standard**

this means that the standard conditions are referred also to the connection modalities of the circuit-breaker

- **the carrying capacity is verified by ensuring that during the test, the maximum temperature-rise limits admitted on the different parts of the circuit-breaker are not exceeded**

such temperature-rise, not meant as absolute temperature, but as a temperature difference expressed in Kelvin, are referred to an ambient air temperature of 40°C.

The circuit-breakers are generally installed inside enclosures which have different functions; among these the following :

- making inaccessible to people the connections of the different apparatus (if not for voluntary actions);
- giving a place to house the circuit-breakers where steady positioning is guaranteed;
- ensuring an adequate protection against ingress of solid foreign objects and ingress of water.

These enclosures are called controlgear and switchgear assemblies (hereafter referred to as assemblies) and comply with the specific product Std. IEC 60439-1 "Low-voltage switchgear and controlgear assemblies – Part 1: Type-tested (TTA) and partially type-tested assemblies (PTTA)"

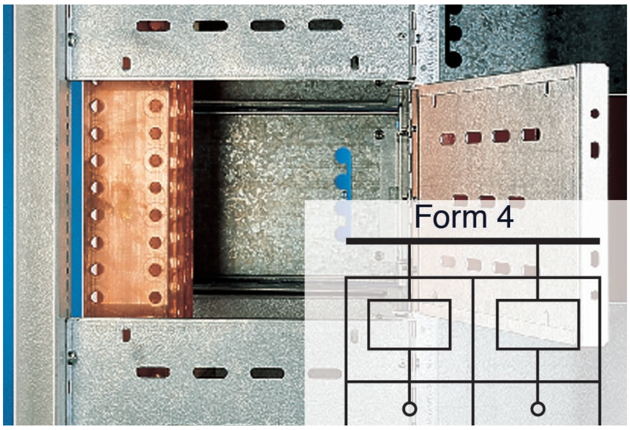
However, the installation conditions inside an assembly differ from the conditions specified by the Std. IEC 60947-2, which are the verification conditions of a circuit-breaker current carrying capacity in free air.

The conditions inside the switchboard (wiring, separations, arrangement of the different apparatus) force the circuit-breaker to operate under conditions characterized by the following aspects:

- **not in free air, but with particular prescriptions regarding air circulation**

in particular, it is possible to have assemblies with complex forms of internal separations (Figure 2), or assemblies with forced ventilation or air-conditioned assemblies

Figure 2



- **the circuit-breakers are connected through conductors of size and length stated by the manufacturer**
- **with an air ambient temperature around the circuit-breaker depending on the assembly design and on the devices it houses.**

In particular, the different degree of protection and the modality of arrangement of the assembly in the environment cause a modification of the amount of heat exchanged towards the outside of the assembly and, consequently, also of the air temperature inside it.
After these considerations, it is evident that the conditions leading the manufacturer to define a rated uninterrupted current for a single circuit-breaker are different from the conditions under which the circuit-breaker shall be used inside an assembly; as a consequence, it is obvious that the current carrying capacity of circuit-breakers determined in compliance with the relevant product Standard cannot be considered equal to their carrying capacity when they are installed inside an assembly, without the appropriate evaluations.
This concept is also recalled in the Std. IEC 60947-1, which in the performance prescriptions regarding temperature-rise, states that in normal service the current carrying capacities may differ from the test values, depending, for example, on the different installation conditions and on the size of the connected conductors.
Besides, also the Std. IEC 60947-2, relevant to the low voltage circuit-breakers, as regards the general test conditions, reminds that the prescribed tests do not preclude the need for additional tests on circuit-breakers incorporated in assemblies, for example in accordance with IEC 60439-1.

1.3 Verification of temperature-rise by test (in compliance with IEC 60439-1)

The product Std. IEC 60439-1 concerning low voltage controlgear and assemblies does not refer to the individual components present, but to the “equipment” meant as a combination of one or more protection and switching apparatus equipped with any possible switching, measuring, protection and setting, mounted and wired with internal electrical and mechanical connections.
As a consequence, making reference to the current carrying capacity, this Standard deals with the rated current of the single electrical circuit and not with the rated current of the individual components, such as circuit-breakers or conductors. In accordance with the definition, the rated current of a circuit is defined by the switchboard manufacturer as a function of the ratings of the electrical components of the circuit, of their disposition and application.
This current shall be carried out without the temperature-rise of the various parts of the assembly exceeding the limits specified when the test is performed in accordance with prescriptions of the Standard itself.
The performance modalities of the temperature-rise test include two main prescriptions:
- the circuits of the switchboard shall be tested at a current which is equal to the rated current multiplied by the rated diversity factor fn, understood as the ratio between the maximum value of the sum of the currents flowing through all the main circuits considered, at any moment, and the sum of the rated currents of the same circuits

$$I_{test} = In_c \times fn$$

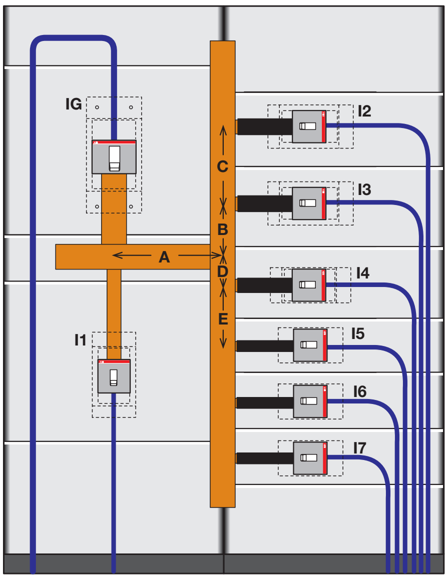
- if no d etailed information about the external conductors to be used under normal operating conditions are known, cross-sections depending on the rated current of the circuits are imposed by the Standard.

For further information about correlated subjects, reference shall be made to the indications given in the Standard itself.
From the prescriptions above it results that:
- if a rated diversity factor fn<1 is present (not all the loads are supplied with 100% of their rated current) the switchboard circuits are tested at a current value lower than the rated one at full load; however, the test shall be carried out on those circuits which allow the heaviest temperature-rise conditions to be reproduced;
- if the switchboard is cabled with conductors having a cross-section reduced with respect to that prescribed

by the Standard and used in the test, temperature-rise higher than the maximum acceptable values measured in the test might occur during normal operations.

The following numerical example has the purpose of making clear what explained above. Reference is made to the switchboard of Figure 3, whose loads are cabled with the same conductors through which it is put into service; the manufacturer assigns the rated current for the load circuits and assigns a rated diversity factor "fn" to the enclosure to be tested. Under these conditions, the switchboard, or a part of the switchboard, is tested by "applying" simultaneously to all the circuits a test current equal to the assigned rated current multiplied by "fn".

Figure 3



I2 = 160A	fn=0.8	I2test= 128A
I3 = 400A	fn=0.8	I3test = 320A
I4 = 250A	fn=0.8	I4test = 200A
I5 = 630A	fn=0.8	I5test = 504A
I6 = 160A	fn=0.8	I6test = 128A
I7 = 400A	fn=0.8	I7test = 320A

Therefore, in a switchboard, the rated current of a circuit is not that assigned, but it is determined by considering the assigned diversity factor. In accordance with these test conditions, the absolute temperature values T_T (expressed in °C) at which the different parts of the assembly operate are determined and, with reference to an average ambient temperature T_A lower than or equal to 35 °C, the temperature-rise limits $T = (T_T – T_A)$ imposed by the Std. IEC 60439-1 must not be exceeded.
For the different components of assemblies, Table 1 below shows the temperature-rise limits and the relevant remarks of the Std. IEC 60439-1 (updating of Annex A1 dated March 2005) which are valid when the temperature-rise test is carried out in compliance with the prescriptions of the Standard itself.

Table 1

Parts of assemblies	Temperature-rise (values or prescriptions)
Built in components For example conventional switchgear and controlgear; electronic sub-assemblies (e.g. rectifier bridge and printed circuit); parts of equipment (e.g. regulator, stabilized power supply unit, operational amplifier).	In accordance with the relevant requirements for the individual components, or in accordance with the manufacturer's instructions, taking into consideration the temperature in the assembly.
Terminals for external insulated conductors	**70K** An assembly used or tested under installation conditions may have connections, the type, nature and disposition of which will not be the same as those adopted for the test and a different temperature rise of terminals may result and may be required or accepted. When the terminals of the built-in components are also the terminals for the external insulated conductors the lowest temperature-rise limits shall be applied.
Busbars and conductors, plug-in contacts of removable or withdrawable parts which connect to busbars	Limited by: - mechanical strength of conducting material; - possible effects on adjacent equipment; - permissible temperature limit of the insulating materials in contact with the conductor; - the effect of the temperature of the conductor on the apparatus connected to it; - for plug-in contacts, nature and surface treatment of the contact material. By assuming that all the other mentioned criteria have been fulfilled, a maximum temperature of 105K shall not be exceeded for bare busbars and copper conductors so that the mechanical strength of conducting material is guaranteed.
Manual operating means:	
accessible with closed assembly	
of metal	**15K**
of insulating material	**25K**
accessible with open assembly	
of metal	**40K**
of insulating material	**50K**
Accessible external enclosures and covers:	
which need to be touched during normal operation	
of metal	**30K**
of insulating material	**40K**
which need to be touched during normal operation	
of metal	**40K**
of insulating material	**50K**
Discrete arrangements of plug and socket type connection	Determined by the limits of those components of the equipment of which they form part.

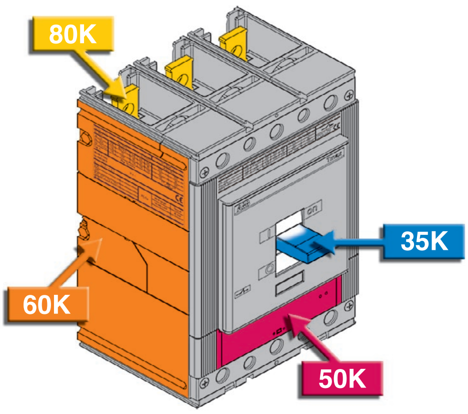
Circuit-breakers can be defined as built-in components and therefore they must comply with the prescriptions of the product Standards. However, it is evident that circuit-breakers and in particular some parts of them (e.g. accessible parts and operating means) can be also considered in all respects as part of controlgear or switchgear assemblies. In particular this applies to the terminals where external insulated conductors are connected, which, in accordance with the comments reported in Table 1, must comply with the most demanding or restricting prescription of the two product Standards.

To make clear this concept, Table 2 and figure 4 hereunder show the indications concerning temperature-rise limits given in the Std. IEC 60947-2 for circuit-breakers considered as an individual component in free-air.

Table 2

Parts of assemblies-description	Temperature-rise limits	Temperature limits (starting from T_A =40°C)
Terminals	**80K**	**120 °C**
Manual operating means:		
parts of metal	**25K**	**65 °C**
parts of insulating material	**35K**	**75 °C**
Parts intended to be touched but not gripped:		
parts of metal	**40K**	**80 °C**
parts of insulating material	**50K**	**90°C**
Parts which need not to be touched during normal operation:		
parts of metal	**50K**	**90°C**
parts of insulating material	**60K**	**100°C**

Figure 4



From Table 2 it results how for a circuit-breaker in free-air the accepted temperature-rise on the terminals is ΔT=80K; therefore, taking as reference an ambient temperature T_A = 40°C, it can be deduced that the maximum permissible temperature is $T_T = (\Delta T + T_A)$ = 120°C.

The prescriptions regarding temperature-rise defined by the switchboard Standard instead refer to an average ambient temperature T_A = 35°C; the maximum temperature-rise limit of the switchboard terminals for insulated external connections is 70K and consequently the maximum operating temperature is 105°C.

If the circuit-breaker is installed inside a switchboard, a reference ambient temperature of 35°C shall be considered, and Table 1, with the comments reported for the built-in components (circuit-breakers are components of the switchboard), allows the manufacturer to state for the circuit-breaker terminals a maximum temperature of 120°C; thus, by difference, it can be obtained that the maximum temperature-rise limit is equal to 85K.

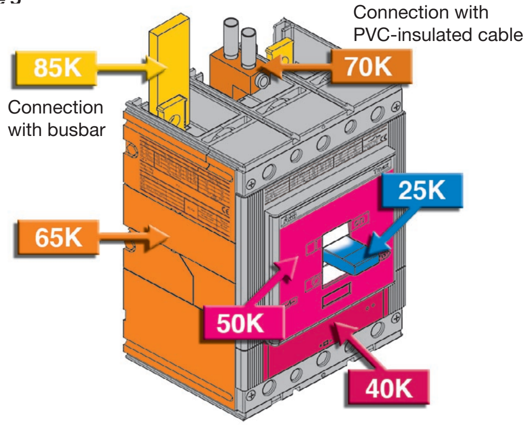
When the connection to the terminals is realized through PVC insulated conductors, it is the temperature of the cable component to determine the maximum acceptable temperature on the terminals, in this case 70°C . On the contrary, if the connection to the circuit-breaker is constituted by bare copper busbars, whose maximum operating temperature is 105°C, it is the prescription for the terminals of the circuit-breaker component which determines the maximum operating temperature, consequently equal to 85°C.

As a summary of the above, Table 3 and Figure 5 show the maximum acceptable temperature-rise and temperature limits for the different parts of the assemblies as stated by the switchboard Standard, and the temperature-rise limits for a circuit-breaker installed inside a LV switchboard recalculated for a reference ambient temperature T_A = 35°C.

Table 3

Parts of assemblies-description	Temperature-rise limits	Temperature limits (starting from T_A =35°C)
Terminal for external insulated connections (IEC 60439-1)	**70K**	**105 °C**
Terminals for external connections (IEC 60947-2)	**85K**	**120 °C**
Manual operating means:		
Accessible with enclosed assembly		
of metal	**15K**	**50 °C**
of insulating material	**25K**	**60 °C**
Accessible only with open assembly		
of metal	**30K**	**65 °C**
of insulating material	**40K**	**75 °C**
Parts intended to be touched but not gripped: (CEI EN 60439-1)		
of metal	**30K**	**65 °C**
of insulating material	**40K**	**75°C**
Accessible parts which need not to be touched during normal operation (IEC 60439-1):		
of metal	**40K**	**75°C**
of insulating material	**50K**	**85°C**
Non-accessible parts which need not to be touched during normal operation (IEC 60947-2):		
of metal	**55K**	**90°C**
of insulating material	**65K**	**100°C**

Figure 5



1.4 Verification of temperature-rise by extrapolation

The Standard regarding low voltage controlgear and switchgear assemblies provides that temperature-rise verification for the PTTA type can be carried out also by extrapolation making specific reference to the prescriptions given in IEC/TR 60890 "A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low-voltage switchgear and controlgear".

The method proposed allows temperature-rise to be determined inside PTTA enclosures without forced ventilation.

The calculation validity is limited by a series of initial assumptions:
- there is an approximately even distribution of power losses inside the enclosure;
- the installed equipment is so arranged that air circulation is but little impeded;
- the equipment installed is designed for direct current or alternating current up to and including 60 Hz, with the total of supply currents not exceeding 3150 A;
- conductors carrying high currents and structural parts are so arranged that eddy current losses are negligible;
- for enclosures with ventilation openings, the cross-section of the air outlet openings is at least 1.1 times the cross-section of the air inlet openings;
- there are no more than three horizontal partitions in the assembly or in a section of it;
- where the enclosures with external ventilating openings have compartments, the surface of the ventilating openings in each horizontal partition shall be at least 50% of the horizontal cross-section of the compartment.

The following data are needed to calculate the temperature-rise of the air inside an enclosure:
- geometric dimensions (height/width/depth);
- effective power loss of equipment, busbars, cables and connections;
- type of installation of the enclosure (exposed, covered, etc....);
- presence and dimensions of ventilation openings;
- number of internal horizontal partitions.

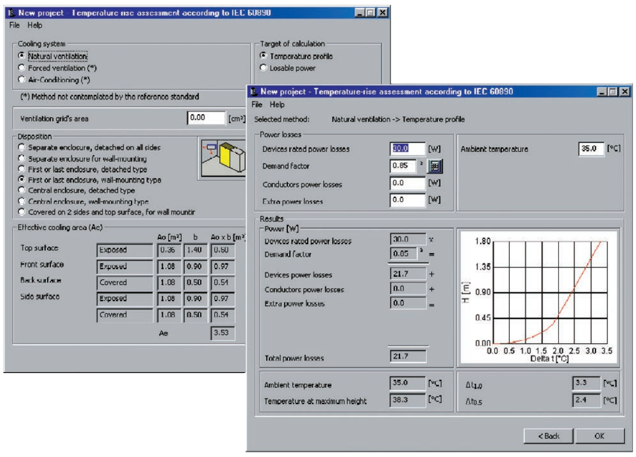
As regards the analysis of the suggested calculation methods, the reader is required to consult the Standard itself.
To carry out an analysis of temperature-rise in accordance with this calculation method, ABB SACE offers its free software program OTC. Starting from the required input data, this program calculates the temperature of the air at different heights of the enclosure through a dedicated interface which appears as in the figure below.

Once the temperature of the air at the different heights of the enclosure is known, it is possible to verify if the components which are in a certain position are suitable to operate at that temperature or if they need to be replaced by other components.
To this purpose, with reference to circuit-breakers, ABB SACE gives a derating of the current carrying capacity as a function of the temperature of the air around the circuit-breaker: thus it becomes possible to calculate if the carrying capacity admitted for the circuit-breaker at the temperature calculated at its installation point results to be higher than the current of the supplied load.

As regards the above, the mere knowledge of the temperature of the air around the circuit-breakers would not allow the calculation of the current carrying capacity.

However, it shall be taken into account that the calculation method suggested by IEC/TR 60890 is a conservative one which generally results into values higher than those which can be verified in reality. As a consequence it is possible to state that, if the minimum dimensions of the connections suggested by ABB (see Tables 16 and 17 at page 21) are complied with, the power losses of all the components are calculated correctly and the results thus obtained are integrated with the manufacturer's experience, then the suggested calculation method can be used without running into errors.

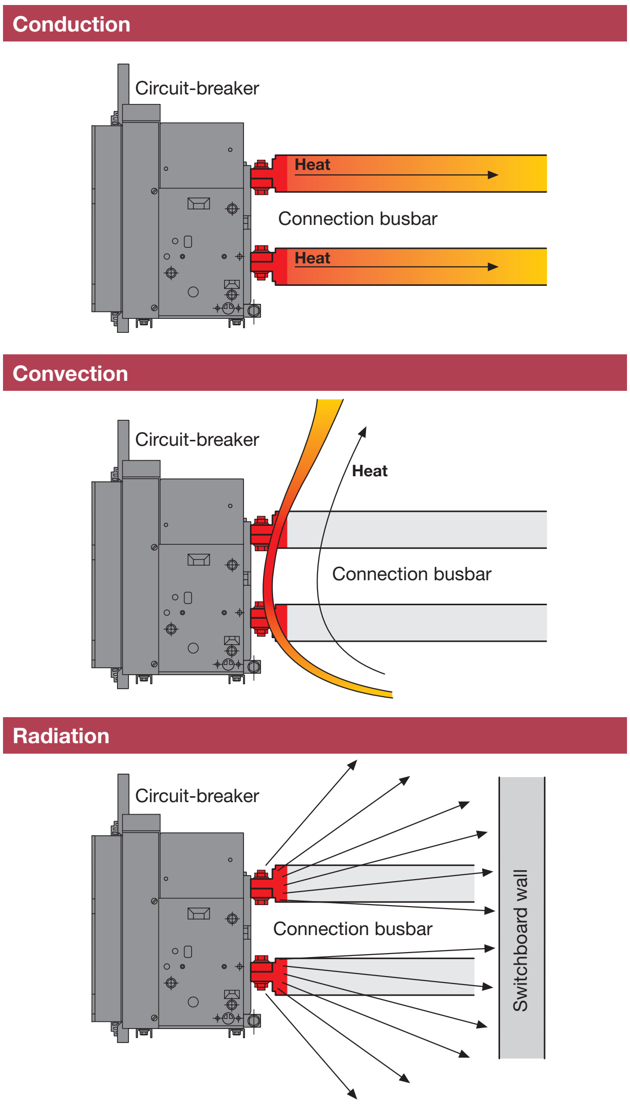
OTC interface



2 Advice to improve the current carrying capacity of the circuit-breakers inside switchboards

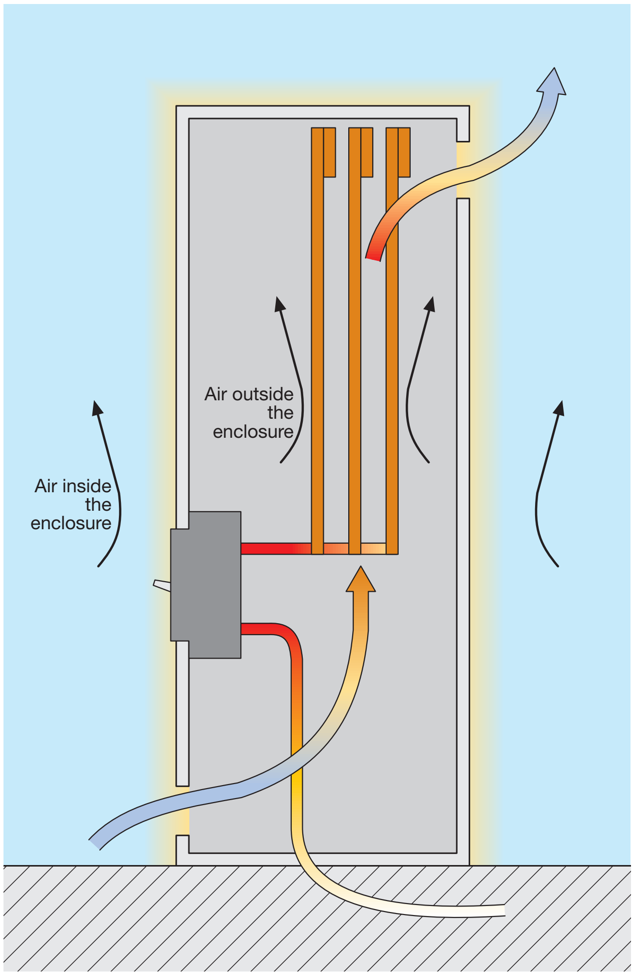
In order to give the necessary indications on the methods intended to improve the current carrying capacity of the circuit-breakers inside switchboards, first of all it is necessary to analyze an assembly from a thermodynamic point of view.
A switchboard can be considered as an enclosure housing a series of elements generating heat and able to dissipate heat towards the outside.
The elements generating heat inside the enclosure exchange heat between them (conduction), with the air inside the switchboard (convection) and with the walls of the switchboard itself (radiation) as shown in Figure 6.

Figure 6



In its turn, the enclosure exchanges heat towards the external environment. Also this heat exchange occurs by conduction (through the cables connected to the assembly), convection and radiation, as shown in Figure 7. In enclosures with a degree of protection not very high or with ventilation openings, part of the heat is exchanged through a real air circulation between the assembly and the external environment.

Figure 7



All these phenomena of circulation and exchange of internal and external air, together with the structure of the enclosure, affect temperature at each point of the enclosure itself and of each component installed inside it. This chapter analyses the main elements which contribute to generate and influence the temperature inside a switchboard and tries to give some useful information for their optimization with the purpose of decreasing the temperature and consequently of reducing the derating of the current carrying capacity of circuit-breakers.
These elements are:
- the power loss inside the enclosure;
- the dissipation of the heat produced inside the enclosure;
- the dissipation of the heat produced by the terminals.

2.1 Power loss inside switchboards

As known, a modification of the temperature may be caused by a power loss due to the current flow. Now, the different components which constitute the main power sources and which consequently represent also heat sources inside a switchboard shall be considered in detail, together with the measures to be taken in order to reduce the power loss and limit its effects. These elements are: the internal structure, the typology of the circuit-breaker installed, the cross-sectional area of the internal conductors of the switchboard, and the current paths.

2.1.1 Internal structure

The material used to realize structure and partitions inside switchboards is often ferromagnetic and conductive. If the system structure is such as to create a closed configuration embracing the conductors, Joule-effect losses due to eddy currents and hysteresis losses are induced, with consequent local heating of remarkable importance. The same phenomenon occurs in the bus ducts between the enclosure and the conductor bars.

As an example to illustrate the influence of this phenomenon, Table 4 shows the percentage value representing the part of losses developing inside the enclosure related to the power loss inside the conductor bars.

From these data, it results that the increase of the rated current and consequently the number of busbars in parallel per phase and the material used for the separation of the conductor bars may considerably affect heating.

For a correct assessment of the power losses it is necessary to take into consideration also the configuration of the separation form: in fact, if a ferromagnetic ring embraces all the three conductors of a three-phase system, as Figure 8 shows (or all the four conductors in a system with the neutral conductor), the sum of the currents shall result into null induction; on the contrary, if each conductor is enclosed by a single ring (Figure 8a), the total induction is not null, with the consequent circulation of induced current, power loss and therefore heat generation.

Table 4

No. of phases	No. of busbars in parallel per phase	Cross-section [mm]	In [A]	Material of the encasement (of the bus duct)	Losses inside the enclosure (% referred to the total loss inside the conductor bars)
3	1	100x10	1000	ferromagnetic	35% - 45%
3	3	100x10	3000	ferromagnetic	55% - 65%
3	3	100x10	3000	amagnetic (aluminum)	15% - 20%

Figure 8

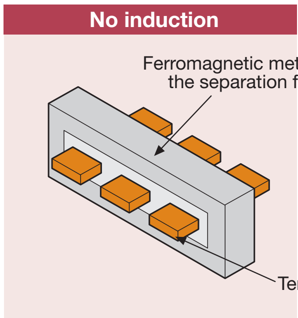
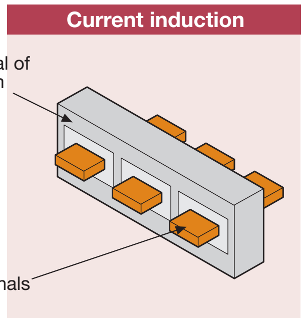
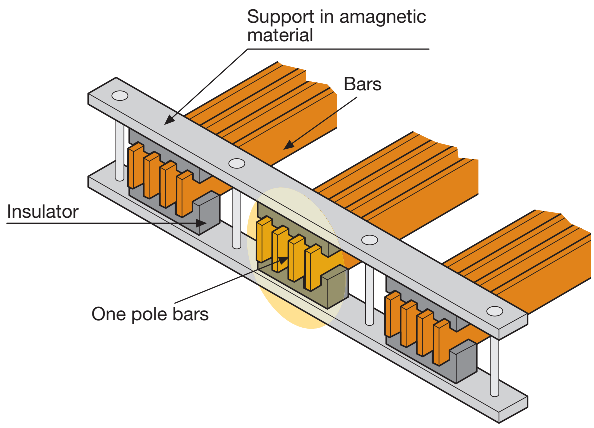


Figure 8a



Also the mechanical fixing of conductors could cause this inconvenient; therefore it is important that the formation of close rings is prevented by the insertion of insulators or anchor clamps made of amagnetic and/or insulating material (see Figure 9).

Figure 9



2.1.2 Typology of the circuit-breaker installed

Circuit-breakers are components of switchboards which cannot be disregarded when calculating total power loss.
To make this evaluation easier, ABB SACE offers some tables which are reported below and refer to molded-case circuit-breakers of Tmax series (Table 5) and air circuit-breakers type Emax (Table 6) respectively.
As the tables below show, the power loss of the same circuit-breaker varies depending both on its version as well as on the type of protective release installed.

Taking reference to these two variables, it is possible to observe that :
- the power losses of withdrawable circuit-breakers are higher than those of the fixed ones
- the power losses of the circuit-breakers equipped with thermo-magnetic releases are higher than those of the circuit-breakers with electronic releases.

Under heavy conditions from a thermal point of view, it is advisable to use circuit-breakers in fixed version and equipped with electronic type releases.

The difference between the power loss of a circuit-breaker in three-pole version compared with a four-pole version is not considered, since in a normal circuit the current flowing in the neutral conductor is assumed to be null.

Table 5

Total (3/4 poles) power loss	In	T11P	T1	T2		T3		T4		T5		T6		T7 S,H,L		T7 V	
[W]	[A]	F	F	F	P	F	P	F	P/W	F	P/W	F	W	F	W	F	W
Releases	1			4.5	5.1												
	1.6			6.3	7.5												
	2			7.5	8.7												
	2.5			7.8	9												
	3.2			8.7	10.2												
	4			7.8	9												
	5			8.7	10.5												
	6.3			10.5	12.3												
	8			8.1	9.6												
	10			9.3	10.8												
	12.5			3.3	3.9												
	16	1.5	4.5	4.2	4.8												
TMF	20	1.8	5.4	5.1	6			10.8	10.8								
TMD	25	2	6	6.9	8.4												
TMA	32	2.1	6.3	8.1	9.6			11.1	11.1								
MF	40	2.6	7.8	11.7	13.8												
MA	50	3.7	11.1	12.9	15			11.7	12.3								
	63	4.3	12.9	15.3	18	12.9	15.3										
	80	4.8	14.4	18.3	21.6	14.4	17.4	13.8	15								
	100	7	21	25.5	30	16.8	20.4	15.6	17.4								
	125	10.7	32.1	36	44.1	19.8	23.7	18.6	21.6								
	160	15	45	51	60	23.7	28.5	22.2	27								
	200					39.6	47.4	29.7	37.2								
	250					53.4	64.2	41.1	52.8								
	320									40.8	62.7						
	400									58.5	93						
	500									86.4	110.1						
	630											92	117				
	800											93	119				
	10			1.5	1.8												
	25			3	3.6												
	63			10.5	12												
	100			24	27.2			5.1	6.9								
	160			51	60			13.2	18								
	250							32.1	43.8								
	320							52.8	72	31.8	53.7						
PR221	400									49.5	84			15	27	24	36
PR222	630									123	160.8	90	115	36	66	60	90
PR223	800											96	125	57,9	105,9	96	144
	1000											150		90	165	150	225
	1250													141	258	234,9	351,9
	1600													231	423		

F: fixed W: withdrawable P: plug-in

Table 6

Total (3/4 poles) power loss	X1B-N		X1L		E1B-N		E2B-N-S		E2L		E3N-S-H-V		E3L		E4S-H-V		E6H-V	
[W]	F	W	F	W	F	W	F	W	F	W	F	W	F	W	F	W	F	W
In=630	41	63	50	87														
In=800	65	100	80	140	65	95	29	53			22	36						
In=1000	102	157	125	219	96	147	45	83			38	58						
In=1250	159	257	196	342	150	230	70	130	105	165	60	90						
In=1600	260	400			253	378	115	215	170	265	85	150						
In=2000							180	330			130	225	215	330				
In=2500											205	350	335	515				
In=3200											330	570			235	425	170	290
In=4000															360	660	265	445
In=5000																	415	700
In=6300																	650	1100

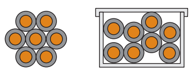
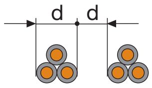
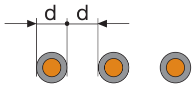
F: fixed W: withdrawable

2.1.3 Cross-section of the conductors within switchboards

In primary distribution switchboards, the power loss of the connection systems (busbars/cables) is usually from 20% to 40% of the total power loss of the switchboard.
The Std. IEC/TR 60890 includes a series of tables which give the power loss of cables and busbars inside switchboards per unit length, making reference to the current carrying capacity.
By applying these tables (here defined as Tables 7 – 8 – 9) it is possible to point out how a reduction in the power loss corresponds to an increased cross-section.

In addition, it is important to remark how the cables entering the enclosure give a contribution not negligible to power loss, whereas they are often not considered since they are not "strictly" part of the switchboard.
Here is an example to show how the contribution of the connection cables is fundamental for a correct assessment of the total power loss of the components inside the switchboard.

Table 7: Operating current and power losses of insulated conductors

Section (Cu)	Maximum permissible conductor temperature 70 °C											
	 1)				 d d				 d d			
	Air temperature inside the enclosure around the conductors											
	35 °C		55 °C		35 C		55 °C		35 °C		55 °C	
	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)	operating current	power losses 2)
mm²	A	W/m	A	W/m	A	W/m	A	W/m	A	W/m	A	W/m
1.5	12	2.1	8	0.9	12	2.1	8	0.9	12	2.1	8	0.9
2.5	17	2.5	11	1.1	20	3.5	12	1.3	20	3.5	12	1.3
4	22	2.6	14	1.1	25	3.4	18	1.8	25	3.4	20	2.2
6	28	2.8	18	1.2	32	3.7	23	1.9	32	3.7	25	2.3
10	38	3.0	25	1.3	48	4.8	31	2.0	50	5.2	32	2.1
16	52	3.7	34	1.6	64	5.6	42	2.4	65	5.8	50	3.4
25					85	6.3	55	2.6	85	6.3	65	3.7
35					104	7.5	67	3.1	115	7.9	85	5.0
50					130	7.9	85	3.4	150	10.5	115	6.2
70					161	8.4	105	3.6	175	9.9	149	7.2
95					192	8.7	125	3.7	225	11.9	175	7.2
120					226	9.6	147	4.1	250	11.7	210	8.3
150					275	11.7	167	4.3	275	11.7	239	8.8
185					295	10.9	191	4.6	350	15.4	273	9.4
240					347	12.0	225	5.0	400	15.9	322	10.3
300					400	13.2	260	5.6	460	17.5	371	11.4

Conductors for auxiliary circuits

mm²	A	W/m	A	W/m	Diam.
0.12	2.6	1.2	1.7	0.5	0.4
0.14	2.9	1.3	1.9	0.6	-
0.20	3.2	1.1	2.1	0.5	-
0.22	3.6	1.3	2.3	0.5	0.5
0.30	4.4	1.4	2.9	0.6	0.6
0.34	4.7	1.4	3.1	0.6	0.6
0.50	6.4	1.8	4.2	0.8	0.8
0.56		1.6		0.7	-
0.75	8.2	1.9	5.4	0.8	1.0
1.00	9.3	1.8	6.1	0.8	-

1) Any arrangement desired with the values specified referring to six cores in a multi-core bundle with a simultaneous load 100%
2) single length

Table 8: Operating current and power losses of bare conductors, in vertical arrangement, without direct connections to the apparatus

Width x Thickness	Cross-section (Cu)	Maximum permissible conductor temperature 85 °C															
		Air temperature inside the enclosure around the conductors 35 °C								Air temperature inside the enclosure around the conductors 55 °C							
		50 Hz 60 Hz ac				dc and ac to 16 2/3 Hz				50 Hz 60 Hz ac				dc and ac to 16 2/3 Hz			
		operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)
mm x mm	mm²	A*	W/m	A**	W/m	A*	W/m	A**	W/m	A*	W/m	A**	W/m	A*	W/m	A**	W/m
12 x 2	23.5	144	19.5	242	27.5	144	19.5	242	27.5	105	10.4	177	14.7	105	10.4	177	14.7
15 x 2	29.5	170	21.7	282	29.9	170	21.7	282	29.9	124	11.6	206	16.0	124	11.6	206	16.0
15 x 3	44.5	215	23.1	375	35.2	215	23.1	375	35.2	157	12.3	274	18.8	157	12.3	274	18.8
20 x 2	39.5	215	26.1	351	34.8	215	26.1	354	35.4	157	13.9	256	18.5	157	12.3	258	18.8
20 x 3	59.5	271	27.6	463	40.2	271	27.6	463	40.2	198	14.7	338	21.4	198	14.7	338	21.4
20 x 5	99.1	364	29.9	665	49.8	364	29.9	668	50.3	266	16.0	485	26.5	266	16.0	487	26.7
20 x 10	199	568	36.9	1097	69.2	569	36.7	1107	69.6	414	19.6	800	36.8	415	19.5	807	37.0
25 x 5	124	435	34.1	779	55.4	435	34.1	78	55.6	317	18.1	568	29.5	317	18.1	572	29.5
30 x 5	149	504	38.4	894	60.6	505	38.2	899	60.7	368	20.5	652	32.3	369	20.4	656	32.3
30 x 10	299	762	44.4	1410	77.9	770	44.8	1436	77.8	556	27.7	1028	41.4	562	23.9	1048	41.5
40 x 5	199	641	47.0	1112	72.5	644	47.0	1128	72.3	468	25.0	811	38.5	469	24.9	586	38.5
40 x 10	399	951	52.7	1716	88.9	968	52.6	1796	90.5	694	28.1	1251	47.3	706	28.0	1310	48.1
50 x 5	249	775	55.7	1322	82.9	782	55.4	1357	83.4	566	29.7	964	44.1	570	29.4	989	44.3
50 x 10	499	1133	60.9	2008	102.9	1164	61.4	2141	103.8	826	32.3	1465	54.8	849	32.7	1562	55.3
60 x 5	299	915	64.1	1530	94.2	926	64.7	1583	94.6	667	34.1	1116	50.1	675	34.4	1154	50.3
60 x 10	599	1310	68.5	2288	116.2	1357	69.5	2487	117.8	955	36.4	1668	62.0	989	36.9	1814	62.7
80 x 5	399	1170	80.7	1929	116.4	1200	80.8	2035	116.1	858	42.9	1407	61.9	875	42.9	1484	61.8
80 x 10	799	1649	85.0	2806	138.7	1742	85.1	3165	140.4	1203	45.3	2047	73.8	1271	45.3	1756	74.8
100 x 5	499	1436	100.1	2301	137.0	1476	98.7	2407	121.2	1048	53.3	1678	72.9	1077	52.5	1756	69.8
100 x 10	999	1982	101.7	3298	164.2	2128	102.6	3844	169.9	1445	54.0	2406	84.4	1552	54.6	2803	90.4
120 x 10	1200	2314	115.5	3804	187.3	2514	115.9	4509	189.9	1688	61.5	2774	99.6	1833	61.6	3288	101.0

*) one conductor per phase **) two conductors per phase 1) single length

Table 9: Operating current and power losses of bare conductors used as connections between the apparatus and the main busbars

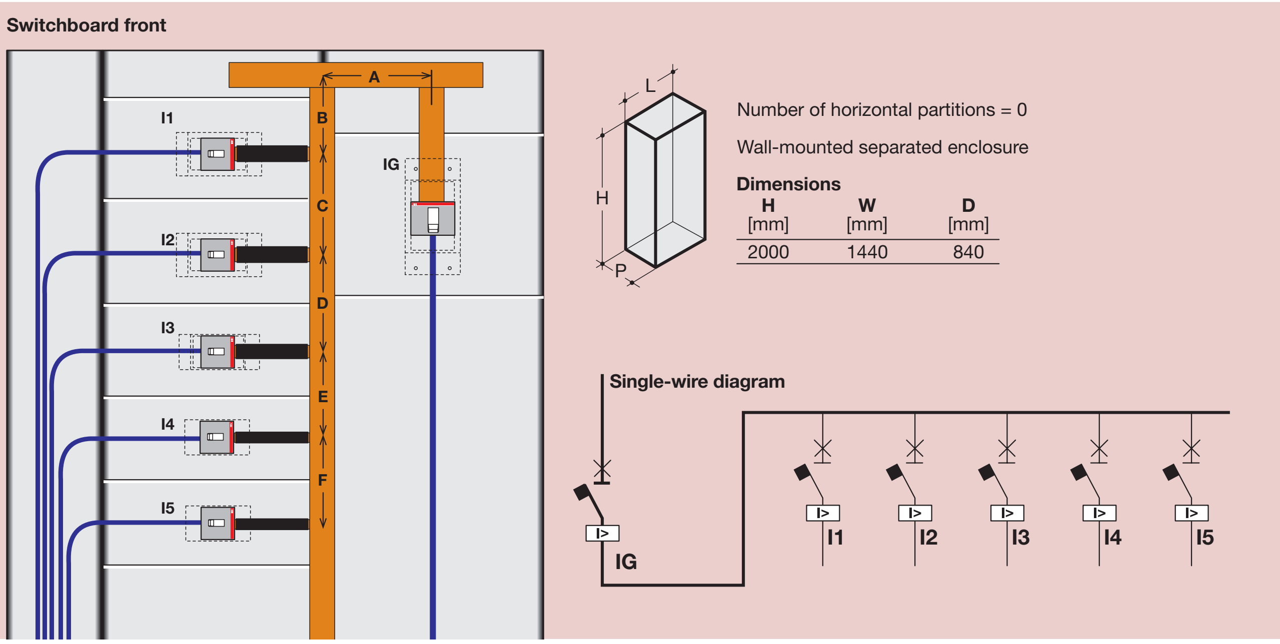
Width x Thickness	Cross-section (Cu)	Maximum permissible conductor temperature 65 °C							
		Air temperature inside the enclosure around the conductors 35 °C				Air temperature inside the enclosure around the conductors 55 °C			
		50 Hz to 60 Hz ac and dc				50 Hz to 60 Hz ac and dc			
		operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)	operating current	power losses 1)
mm x mm	mm²	A*	W/m	A**	W/m	A*	W/m	A**	W/m
12 x 2	23.5	82	5.9	130	7.4	69	4.2	105	4.9
15 x 2	29.5	96	6.4	150	7.8	88	5.4	124	5.4
15 x 3	44.5	124	7.1	202	9.5	102	4.8	162	6.1
20 x 2	39.5	115	6.9	184	8.9	93	4.5	172	7.7
20 x 3	59.5	152	8.0	249	10.8	125	5.4	198	6.8
20 x 5	99.1	218	9.9	348	12.7	174	6.3	284	8.4
20 x 10	199	348	12.8	648	22.3	284	8.6	532	15.0
25 x 5	124	253	10.7	413	14.2	204	7.0	338	9.5
30 x 5	149	288	11.6	492	16.9	233	7.6	402	11.3
30 x 10	299	482	17.2	960	32.7	402	11.5	780	21.6
40 x 5	199	348	12.8	648	22.3	284	8.6	532	15.0
40 x 10	399	648	22.7	1245	41.9	532	15.3	1032	28.8
50 x 5	249	413	14.7	805	27.9	338	9.8	655	18,5
50 x 10	499	805	28.5	1560	53.5	660	19.2	1280	36.0
60 x 5	299	492	17.2	960	32.7	402	11.5	780	21.6
60 x 10	599	960	34.1	1848	63.2	780	22.5	1524	43.0
80 x 5	399	648	22.7	1256	42.6	532	15.3	1032	28.8
80 x 10	799	1256	45.8	2432	85.8	1032	30.9	1920	53.5
100 x 5	499	805	29.2	1560	54.8	660	19.6	1280	36.9
100 x 10	999	1560	58.4	2680	86.2	1280	39.3	2180	57.0
120 x 10	1200	1848	68.3	2928	85.7	1524	46.5	2400	57.6

*) one conductor per phase **) two conductors per phase 1) single length

Example

This example has the purpose of evaluating – as first approximation – the total power loss inside the switchboard of which Figure 10 shows the arrangement of the components, the dimensions, the structure and the relevant single-wire diagram.

Figure 10



The components which form the switchboard are circuit-breakers, busbars and cables.
The power loss is calculated for each component and then the total power loss is determined.

Circuit-breakers

As regards circuit-breakers, the power loss can be determined on the basis of the dissipated power “Pn ” at the rated current “In_{CB}” (see previous Tables 5 and 6) referred to the current which really flows through the circuit-breaker “Ib” (full load current of the circuit).
The formula linking these three quantities is the following :

$$P_{CB} = Pn_{CB} \times (Ib / In_{CB})^2$$

Then, according to the type of apparatus installed inside the switchboard, the contribution to the load current in terms of power loss of the individual circuit-breaker and the total power loss are reported in the following table:

Table 10

Circuit-breaker		In CB [A]	Ib [A]	Power loss [W]
IG	E2 1600 EL	1600	1340	80.7
I1	T5 400 EL	400	330	33.7
I2	T5 400 EL	400	330	33.7
I3	T5 400 EL	400	330	33.7
I4	T3 250 TMD	250	175	26.2
I5	T3 250 TMD	250	175	26.2
Total power loss of the circuit-breakers [W]				**234**

Busbars

As regards main busbars, distribution busbars and the busbars connecting circuit-breakers and cables, the effective power loss can be determined from the dissipated powers, at the nominal current and per unit length, as shown in the previous Tables 8 and 9.

The formula to relate the data in the table to the characteristics (load current and length) of the busbars installed in the switchboard is the following:

$$P_{SB} = Pn_{SB}\ (Ib/In_{SB})^2 \times 3 \times L_{SB}$$

Therefore, with reference to the typology, the length "L" and the load current of the busbars installed inside the switchboard, the contribution in terms of power loss of the single length and the total power loss are reported in Table 11 below:

Table 11

Connection busbar	Cross-sectional area nx[mm]x[mm]	Length [m]	Ib [A]	Power loss [W]
IG	2x60x10	0.450	1340	54
I1	30x10	0.150	330	3.8
I2	30x10	0.150	330	3.8
I3	30x10	0.150	330	3.8
I4	20x10	0.150	175	1.6
I5	20x10	0.150	175	1.6
Total power loss of the connection busbars [W]				68

Cables

As regards cables, taking reference to Table 8 above, the same method used for the busbars can be applied and the relevant results are reported in Table 12.

Cable	Cross-sectional area [n]xmm²	Length [m]	Ib [A]	Power loss [W]
IG	4x240	1.0	1340	133.8
I1	240	2.0	330	64.9
I2	240	1.7	330	55.2
I3	240	1.4	330	45.4
I4	120	1.1	175	19
I5	120	0.8	175	13.8
Total power loss of the connection busbars [W]				**332**

Then, the total power dissipated inside the switchboard is given by the sum of the three contributions already determined above, therefore:

$$P_{TQ} = 234+68+332=784W$$

It is important to note how the total power loss would be equal to 452W and therefore the estimated temperature would be much lower than the effective one if the cable contribution (332W) were not taken into account.

2.1.4 Paths of the current

The positioning of apparatus and conductors may result into a different power loss inside the switchboard. It is a good rule to position the circuit-breakers as shown in Figure 11, so that the paths of the highest currents are as short as possible. Thus, contrary to what occurs in a type of installation as that of Figure 11a, the dissipated power inside the switchboard is reduced and unquestionable advantages from the thermal point of view are achieved.

Figure 11

Suggested positioning:
The highest current (500 A) flows through the shortest path

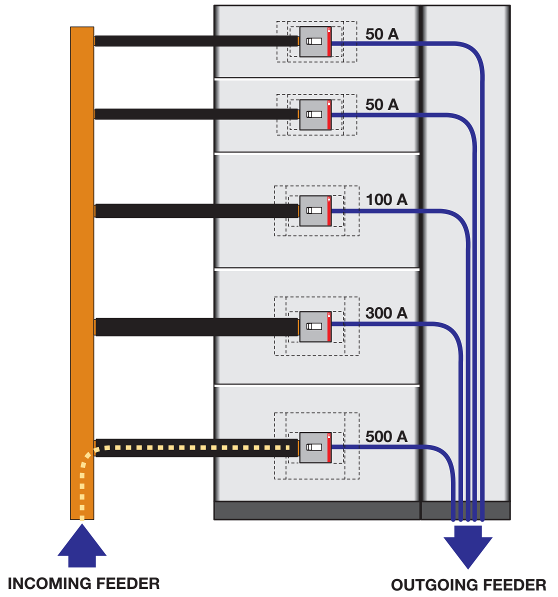
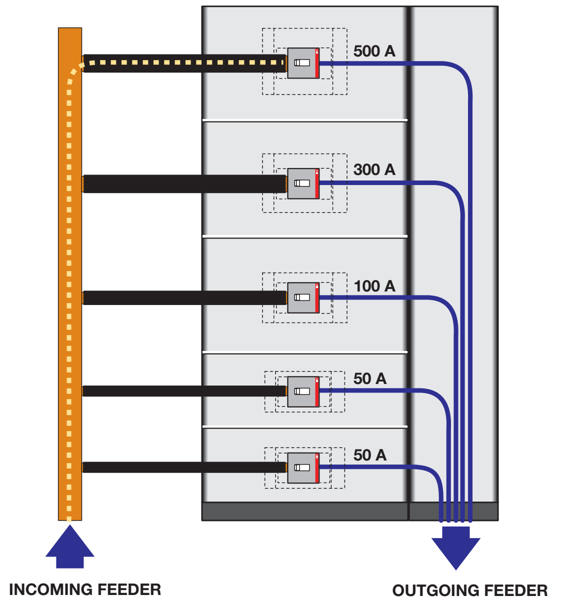


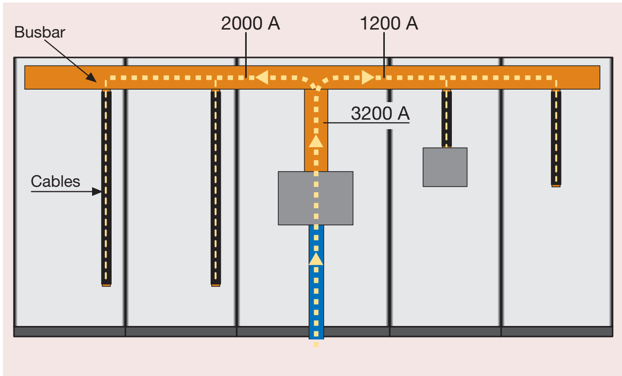
Figure 11a

NOT suggested positioning:
The highest current (500 A) flows through the longest path



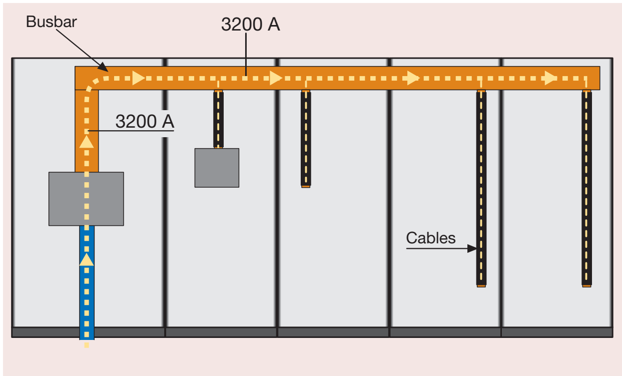
In case of switchboards with many columns, whenever possible, it is advisable that the main circuit-breaker is installed in the middle column or, however, in barycentric position with respect to the load distribution, as shown in Figure 12. Thus, by dividing the current into the two branches of the switchboard busbar system, a remarkable reduction in the power loss is obtained – with the same cross-section – in comparison with a configuration having the incoming feeder at both ends of the switchboard as in Figure 12a, which is a solution implying the circulation of highest currents.

Figure 12



Advisable solution from a thermal point of view

Figure 12a



Heavier solution from a thermal point of view

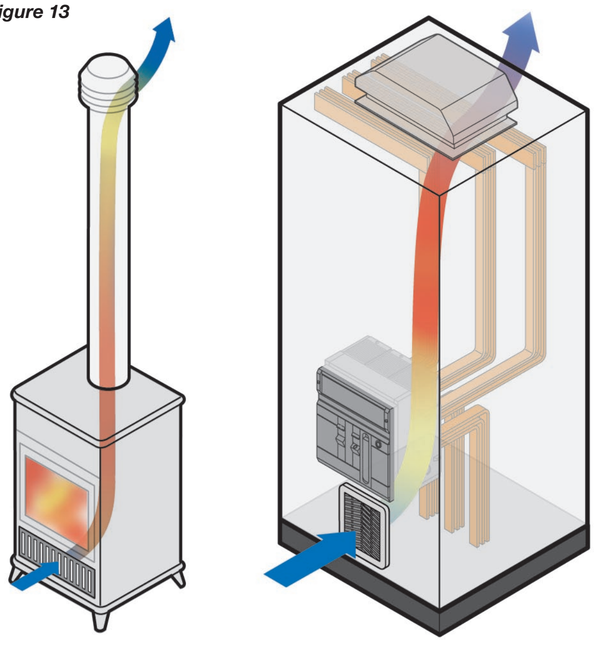
2.2 Dissipation of the heat generated inside switchboards

After an analysis of the main heat sources and of the measures to limit heat generation, the modalities through which switchboards can dissipate the heat towards the outside are described now.
Many of these considerations derive from the Std. IEC/TR 60890, which gives formulas and tables where constructional characteristics and installation modalities are in relation with the temperature-rise at the same power loss. In particular, this chapter shall take into consideration the switchboard ventilation, the surfaces of the switchboard and their positioning, the form of internal separation of the switchboard and the degree of protection of the switchboard.

2.2.1 Switchboard ventilation

To increase the switchboard cooling, it is important that a good circulation of air inside the switchboard is realized (see Figure 13) and maintained. To this purpose, for example, the possible ventilation openings are to be properly dimensioned and positioned.
As regards dimensioning, IEC/TR 60890 for temperature-rise assessment inside low voltage switchgear and controlgear assemblies prescribes for the enclosures with ventilation openings that the cross section for air outlets is 1.1 times the cross section of the inlets.
This requirement is due to the greater volume of hot air (going out of the switchboard) in comparison with the cold air (going into the switchboard).
When disregarding this prescription, the air inlet surface of the switchboard is not fully exploited.

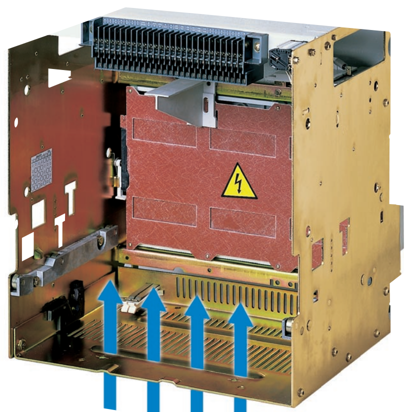
Figure 13



As regards the positioning of the ventilation openings, these are to be located so that the "draught chimney" effect is achieved: an opening shall be positioned at the bottom of the switchboard, on the front part, the other one shall be positioned at the top, on the rear part, or on the "roof" of the switchboard. It is important to remind that any openings at mid height could reduce the "draught chimney" effect, thus causing a reduction of the air "draught".

The equipment inside the switchboard shall be positioned so that the circulation of the air is not excessively impeded by a reduction of the section for the air flow.
In case of withdrawable circuit-breakers, particular attention shall be paid to prevent the obstruction of the ventilation openings in the fixed part of the circuit-breaker (Figure 14).

Figure 14



2.2.2 Side surfaces and positioning of switchboards

It is necessary to take into account that a switchboard exchanges heat with the surrounding environment through its surfaces (top, bottom and side walls) and therefore, at the same power dissipation level by the internal components, the larger the exchange surface towards the outside and the better the exchange conditions depending on the installation modality are, the greater amount of heat is released. For example, the switchboard should be positioned so that the air circulation around its external surface is facilitated or, however, is little impeded, thus improving heat exchange.
IEC/TR 60890, which, as already said, suggests a method for the temperature-rise assessment inside switchboards, does not consider the real external geometric surface of the switchboard, but introduces the concept of effective cooling surface "Ae", intended as the sum of the individual surface areas (top, front, side, ...) "A_0" multiplied by the surface factor "b". This factor takes into account the heat dissipation of the individual surfaces according to the type of installation of the enclosure, that is the different capacity of dissipating heat according to

the surface positions and to their being either exposed or covered. The values of the parameter "b" related to the different surface types are shown in Table 13.

$$Ae = \sum (A_0 \times b)$$

Table 13

Type of installation	Surface factor "b"
Exposed top surface	1.4
Covered top surface, e.g. of built-in enclosures	0.7
Exposed side faces, e.g. front, rear and side walls	0.9
Covered side faces, e.g. rear side of wall-mounted enclosures	0.5
Side faces of central enclosures	0.5
Floor surface	Not taken into account

2.2.3 Forms of internal separation of switchboards

With separation form it is meant the type of division provided for the different circuits inside the switchboard.
Separation is obtained by means of metallic or insulating barriers or partitions.
For further information about the different forms of separation reference shall be made to the content of the Annex B or to the prescriptions of Std. IEC 60439-1.
As evident, remarkable separation forms tend to limit air circulation inside the switchboard, thus affecting the temperature inside the switchboard itself. To take into consideration this phenomenon, Tables 14 and 15 show the multiplying factor "d" which IEC/TR 60890 suggests to use under particular conditions to increase the temperature-rise of the air inside the switchboard as a function of the number of horizontal partitions in the column under examination.

Table 14: For enclosures without ventilation openings and effective cooling surface >1.25m^2

Number of horizontal partitions n	Factor d
0	1
1	1.05
2	1.15
3	1.3

Table 15: For enclosures with ventilation openings and effective cooling surface >1.25m^2

Number of horizontal partitions n	Factor d
0	1
1	1.05
2	1.10
3	1.15

From the tables above, it results how horizontal partitions can cause air temperature rises up to 30% (3 partitions without ventilation openings).

2.2.4 Degree of protection of switchboards

The degree of protection IP shows the protection of the enclosure against access to hazardous parts, against ingress of solid foreign objects and ingress of water. The code IP is the identification system of the degrees of protection based on the prescriptions of the Std. IEC 60529.
The degree of protection of a switchboard affects its capacity of dissipating heat: the higher the degree of protection is, the less heat is dissipated by the switchboard. Therefore, the choice of high degrees of protection is not recommended when they are unnecessary. Besides, it should be kept in mind that a defined degree of protection may be reached through different modalities.
For example, the protection against the vertical fall of drops of water (IPX1) can be realized by such modalities so as not to affect heat dissipation and so as to keep the "chimney effect" inside the switchboard.

2.3 Dissipation of the heat generated in the terminals

After a study of the main power sources inside the switchboard and of the modalities through which switchboards can dissipate the generated heat, an analysis of how the circuit-breaker current carrying capacity can be improved by reducing local heating phenomena near the terminals shall be carried out.
In practice, when heat dissipation has not been optimized, the presence of localized heating phenomena limiting the maximum service current of the circuit is quite frequent, even with low average air temperatures inside the switchboard.
The phenomena affecting heat dissipation by the circuit-breaker terminals are mainly convection (through the air moving inside the switchboard) and conduction (through the bars connected to the terminals); these phenomena are to be related with the typology of terminals used and to the version (fixed, withdrawable or plug-in) of the circuit-breaker installed.

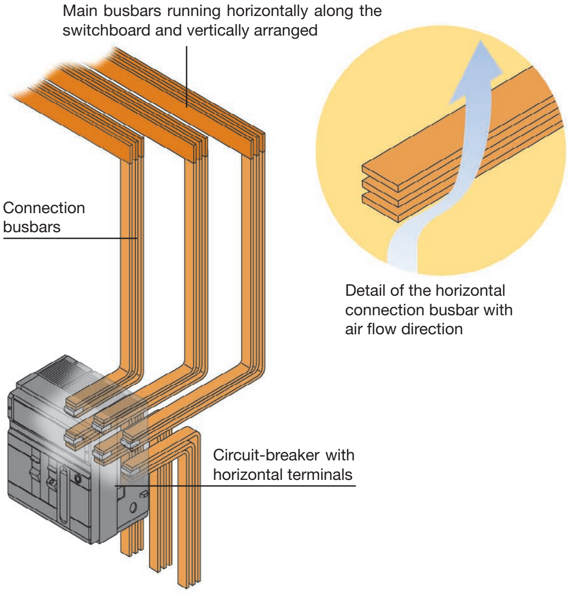
2.3.1 Problems linked to convection

As a general principle linked to the phenomenon of convection, based on the convective motion of the air which, while heating, tends to rise to the top, the busbar arrangement should be such as to present the minimum cross-sectional area to the air flow and to be licked by the air flow on its maximum surface, therefore in a "comb-like" arrangement. The circuit-breaker typology which is most suitable for this configuration is the version providing vertical rear terminals.

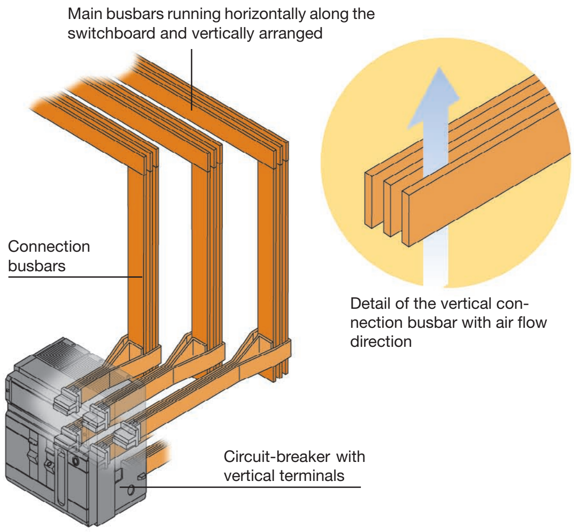
Here are some practical considerations regarding use and installation modalities of vertical rear terminals for Emax series circuit-breakers. The use of these terminals allows a better heat dissipation since, compared with the horizontal ones, they oppose a smaller cross-section to the natural motion of the air and a greater surface to thermal exchange. Yet, one of the main problems to be faced when using vertical terminals is their complicated connection to the main busbar system when this runs horizontally along the switchboard with the busbar section arranged vertically. This problem is not present with the same busbar system when the circuit-breaker terminals are horizontal, since both busbars and terminals are oriented according to two simple connection planes. This concept is definitely more evident when making reference to Figure 15.

Figure 15

Circuit-breaker with horizontal terminals and vertical main busbars



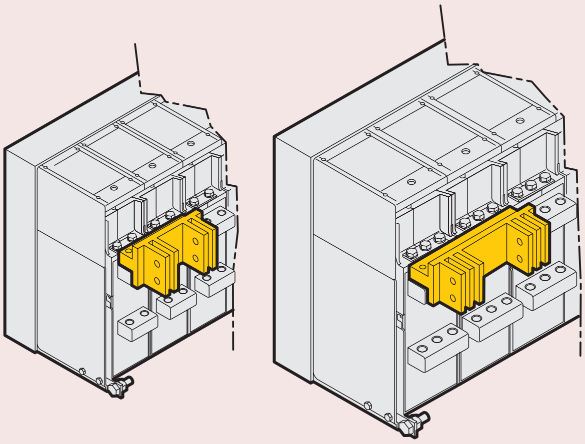
Circuit-breaker with vertical terminals and vertical main busbars



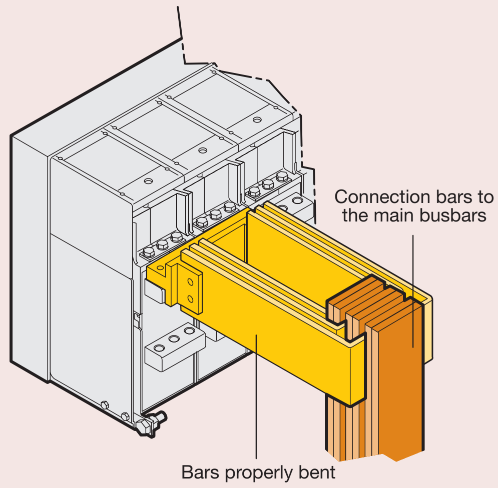
For example, in the case of E4 and E6 circuit-breakers, to facilitate the connection between the vertical terminals and the vertical connection busbars, it is possible to use bars suitably bent as shown in Figure 16.

Figure 16

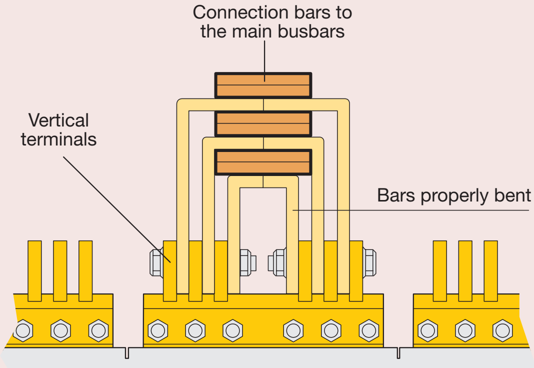
Vertical terminals for E4 and E6 CBs (detail referred to one pole)



Emax E6

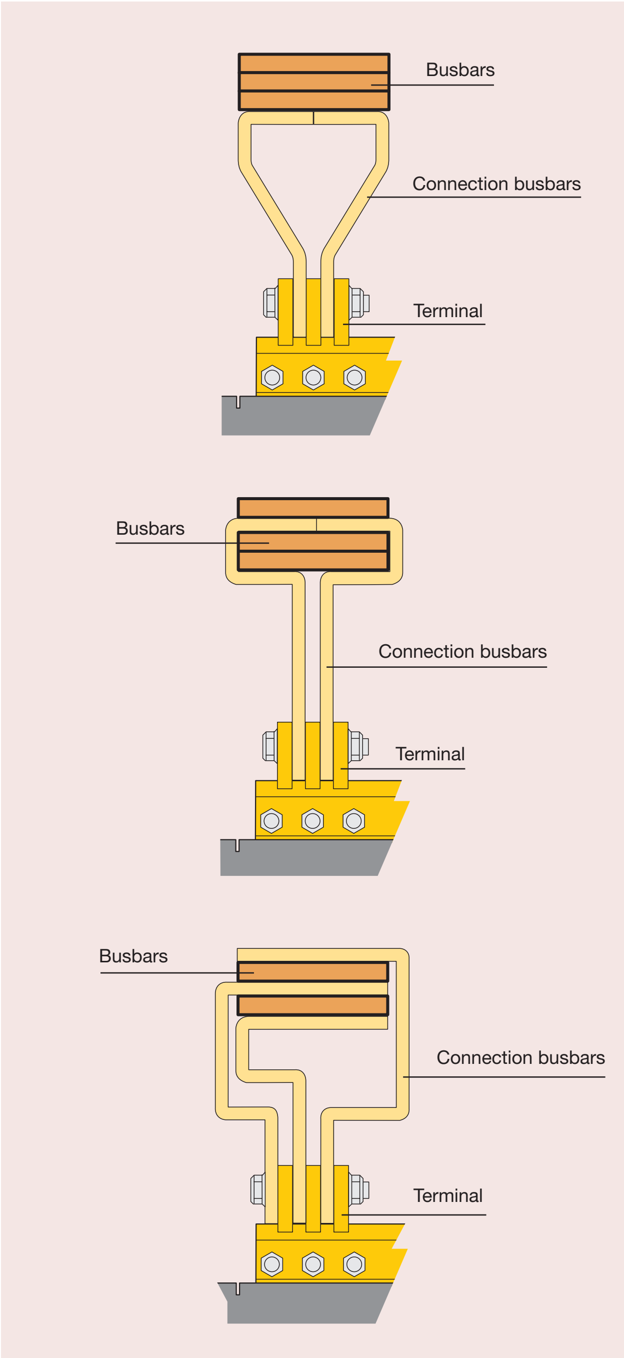


Top view



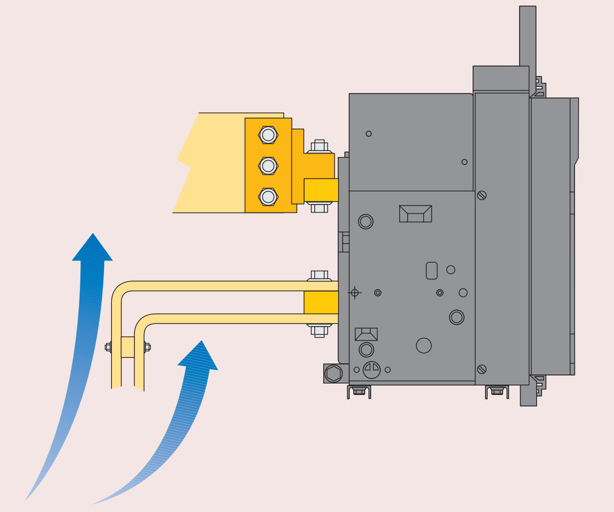
As further example, Figure 17 shows two other pictures representing an hypothesis of solution for the connection of the vertical terminals to the vertical connection busbar system for Emax E3 circuit-breakers.

Figure 17

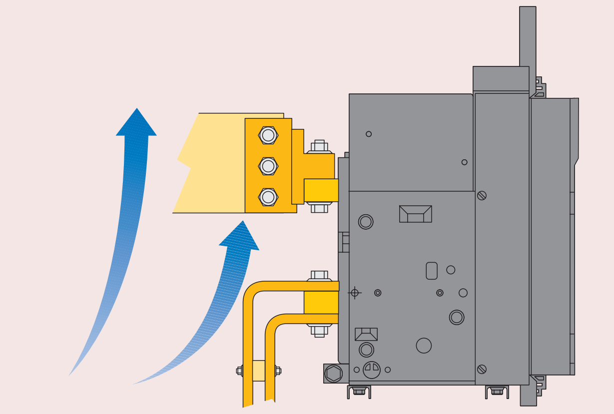


On the contrary, when in the presence of upper vertical terminals and lower terminals of different type or, however, when in the presence of different upper and lower terminals, the solutions to be adopted must not impede the circulation of air in the upper terminals. For example, as Figure 18 shows, the lower terminals shall not divert too much the air flow and prevent it from reaching the upper terminals causing the loss of the benefits of cooling by convection.

Figure 18



Lower connection with rear horizontal terminals.
Air circulation, near the upper terminals (vertical) is impeded.

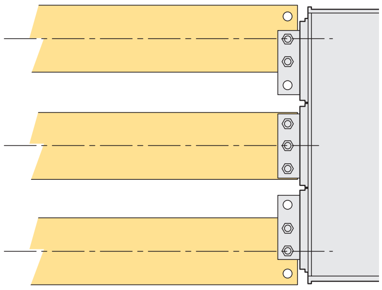


Lower connection with front terminals.
Air circulation, near the upper terminals (vertical), is only partially reduced.

Generally speaking, for the improvement of the heating condition of busbars and terminals, the positioning of the busbars acquires a remarkable importance; here is an example of the solutions which can be adopted.
It should be kept into consideration that, the more the clearance between the busbars, the more heat they dissipate and that the upper middle terminal is usually that with the most problems from the thermal point of view.
Therefore it is advisable to separate and keep apart as much as possible the connection busbars (from the main busbars to the circuit-breaker terminals) so that the heating condition does not get worse.

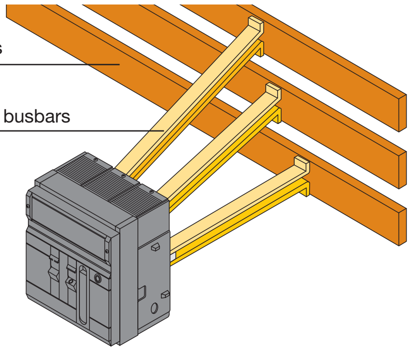
For example, as Figure 19 shows, in the case of three-pole circuit-breakers, the external connections can be taken out of alignment with the terminals, so that distance is increased.

Figure 19



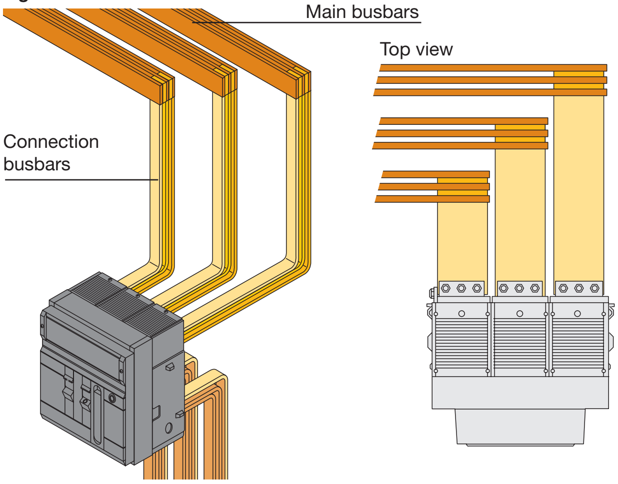
In case of circuit-breaker connection through busbar systems with the three phases vertically arranged, it is advisable that spacing of the 3 phases starts as near as possible to the circuit-breaker, with a solution as that shown in Figure 20.

Figure 20



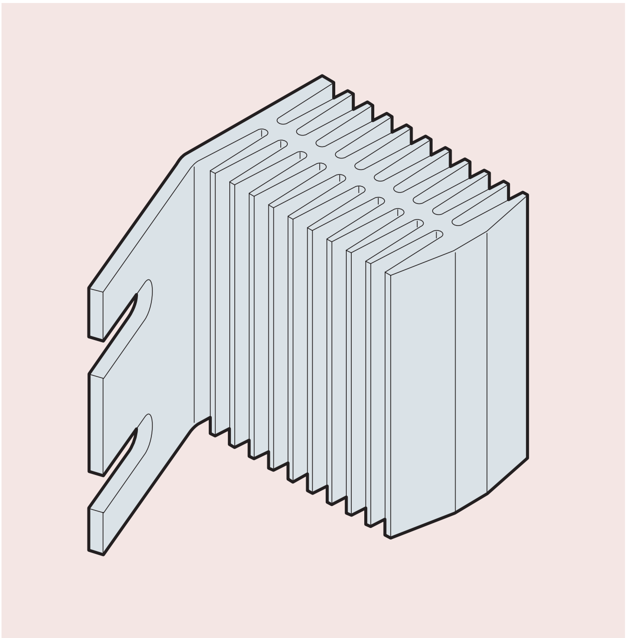
As already mentioned, the upper terminals and in particular the upper middle terminal are usually those which, due to their positions, reach the highest temperatures. Then, particular measures can be taken to improve the heat exchange of these terminals, for example by lengthening the horizontal part of the upper connection busbars in comparison with the lower ones, as shown in Figure 21.

Figure 21



Further increases in the carrying capacity of the circuits may be obtained by mounting some dissipators (see Figure 22) on the connection conductors – between the circuit-breaker and the busbar system – for a better heat dissipation, or by treating busbars and dissipators with special paints, which allow an increase in the radiated heat, without creating, on the other hand, a surface thermal insulation.

Figure 22



2.3.2 Problems linked to conduction

Instead, with reference to the thermal exchange through the phenomenon of conduction, the terminals of a circuit-breaker release heat also towards the busbars or the cables connected to them. In particular, besides carrying the current, the connection busbars convey heat far from the terminals. Therefore, their dimensioning and position shall have to take into account this double function.

There is a rise in the heat exchanged by conduction both when the cross-section through which heat is exchanged enlarges (contact section between the cables or the connection busbars and the circuit-breaker terminals), as well as when the temperature difference between the bodies in touch involved by this exchange increases. From this remark it results that, on their turn, the connection busbars shall effectively dissipate heat to keep their temperature low. To obtain a connection allowing a sufficient heat exchange between the terminals and the distribution system of the switchboard, ABB SACE indicates the minimum cross-sectional area of the cables and busbars to be used.

Here are the indications given for the molded-case circuit-breakers series Tmax and the air circuit-breakers series Emax, reported in Table 16 and in Table 17 respectively.

The cross-sectional areas of the cables and busbars reported in Tables 16 and 17 are those used to determine the rated current carrying capacity of the circuit-breakers in free air according to the Std. IEC 60947-2.

Table 16

Circuit-breaker type	In	Cables	Bars
Tmax	[A]	[n //] x [mm²]	[n //] x [mm x mm]
T2	<=8	1	
T2-T4	10	1,5	
T1-T2	16	2,5	
T1-T2-T4	20	2,5	
T1-T2-T4	25	4	
T1-T2-T4	32	6	
T1-T2-T4	40	10	
T1-T2-T4	50	10	
T1-T2-T3-T4	63	16	
T1-T2-T3-T4	80	25	
T1-T2-T3-T4	100	35	
T1-T2-T3-T4	125	50	
T1-T2-T3-T4	160	70	
T3-T4	200	95	20x5
T3-T4	250	120	25x5
T4-T5	320	185	40x5
T5	400	240	50x5
T5	500	2x150	2x30x5
T5-T6	630	2x185	2x40x5
T6	800	2x240	2x50x5
T6-T7	1000	3x240	2x60x5
T7	1250	4x240	2x80x5
T7	1600	5x240	2x100x5

Table 17

Circuit-breaker	Vertical terminals	Front horizontal terminals
Emax	[n //] x [mm x mm]	[n //]x[mm x mm]
E1B/N 08	1x(60x10)	1x(60x10)
E1B/N 12	1x(80x10)	2x(60x8)
E2B/N 12	1x(60x10)	1x(60x10)
E2B/N 16	2x(60x10)	2x(60x10)
E2B/N 20	3x(60x10)	3x(60x10)
E2L 12	1x(60x10)	1x(60x10)
E2L 16	2x(60x10)	2x(60x10)
E3S/H 12	1x(60x10)	1x(60x10)
E3S/H 16	1x(100x10)	1x(100x10)
E3S/H 20	2x(100x10)	2x(100x10)
E3N/S/H 25	2x(100x10)	2x(100x10)
E3N/S/H 32	3x(100x10)	3x(100x10)
E3L20	2x(100x10)	2x(100x10)
E3L 25	2x(100x10)	2x(100x10)
E4H 32	3x(100x10)	3x(100x10)
E4S/H 40	4x(100x10)	6x(60x10)
E6V 32	3x(100x10)	3x(100x10)
E6V 40	4x(100x10)	4x(100x10)
E6H/V 50	6x(100x10)	6x(100x10)
E6H/V 63	7x(100x10)	----------------------

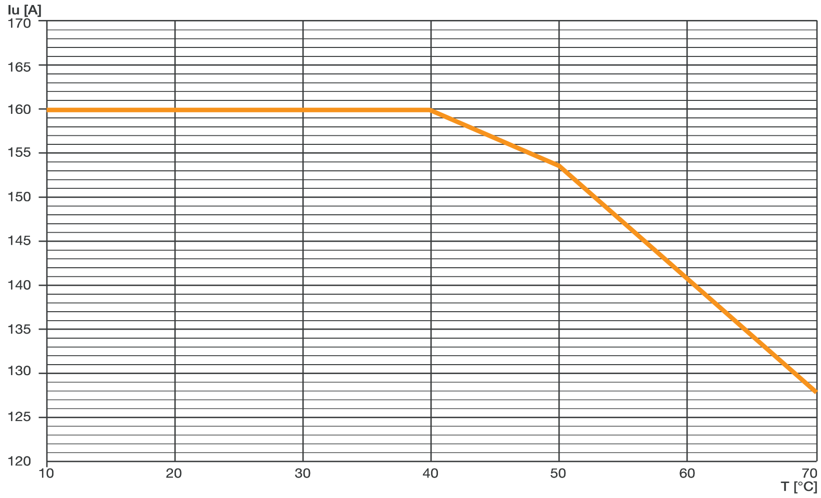
2.3.3 Current carrying capacity of circuit-breakers and busbars

To conclude this chapter, Figure 23 shows the curves reporting the carrying capacity of the Tmax molded-case circuit-breakers equipable with electronic relays, referred to the different temperatures and the different types of terminals and available versions, whereas Table 18 reports the current carrying capacity of the Tmax molded-case circuit-breakers equipable with thermomagnetic releases. As regards the air circuit-breakers of Emax series, Table 19 reports the carrying capacity of the single apparatus at the different temperatures.

Figure 23

T2 160

Fixed



Note: in the plug-in version the maximum setting is derated by 10%

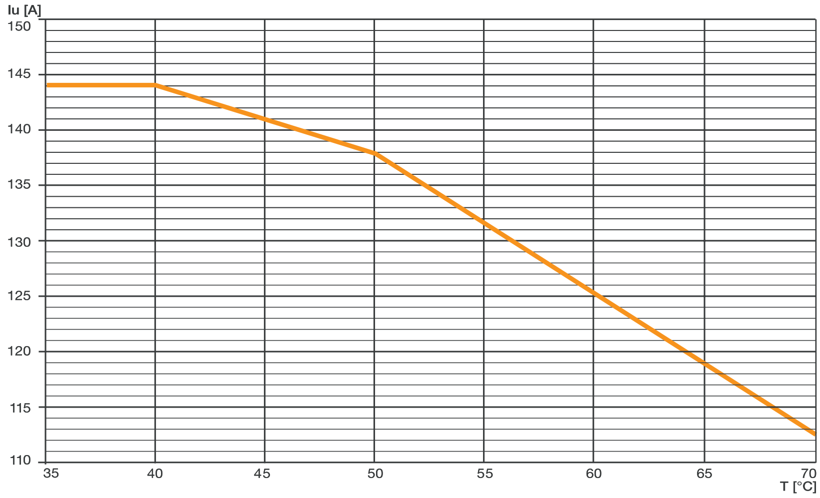
F = Front flat terminals
FC Cu = Front terminals for copper cables

EF = Front extended terminals
FC CuAl = Front terminals for CuAl cables

ES = Front extended spread terminals
R = Rear terminals

T2 160

Plug-in



F = Front flat terminals
FC Cu = Front terminals for copper cables

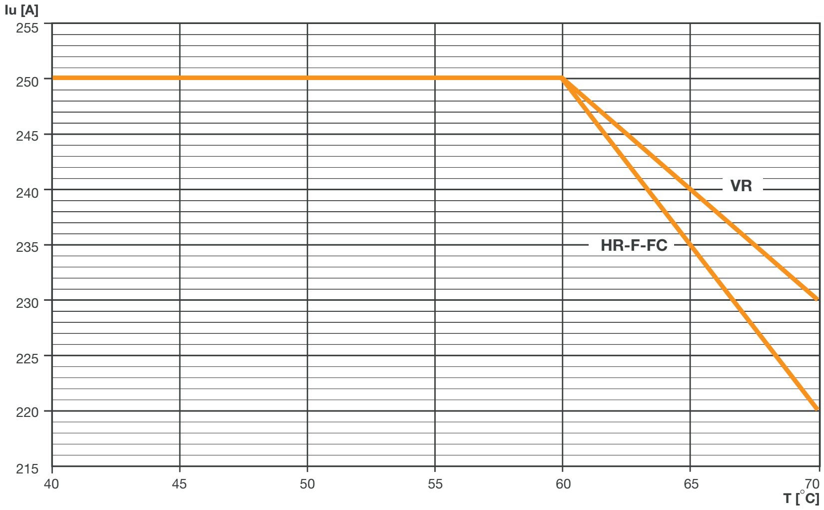
EF = Front extended terminals
FC CuAl = Front terminals for CuAl cables

ES = Front extended spread terminals
R = Rear terminals

Note: in the plug-in version the maximum setting is derated by 10%

T4 250

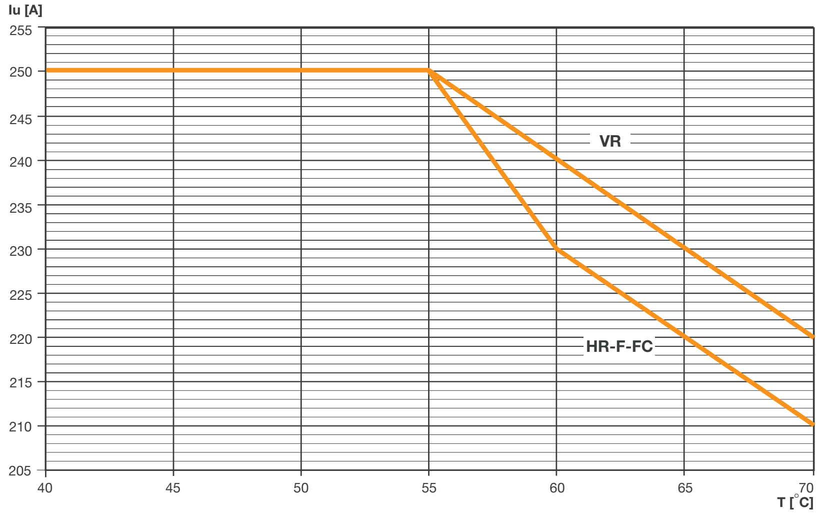
Fixed



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T4 250

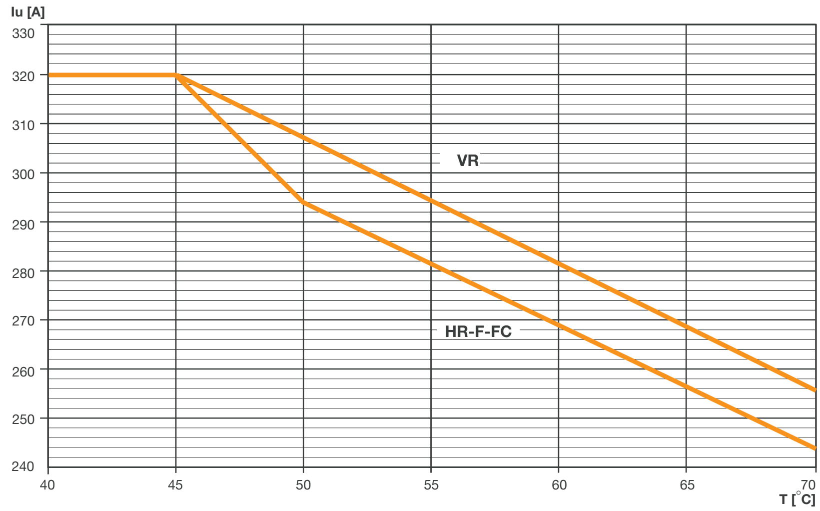
Plug-in / Withdrawable



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T4 320

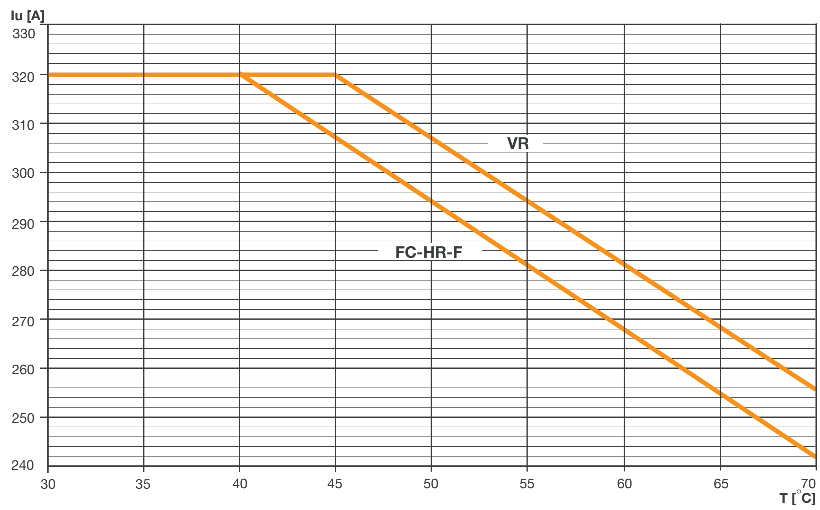
Fixed



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T4 320

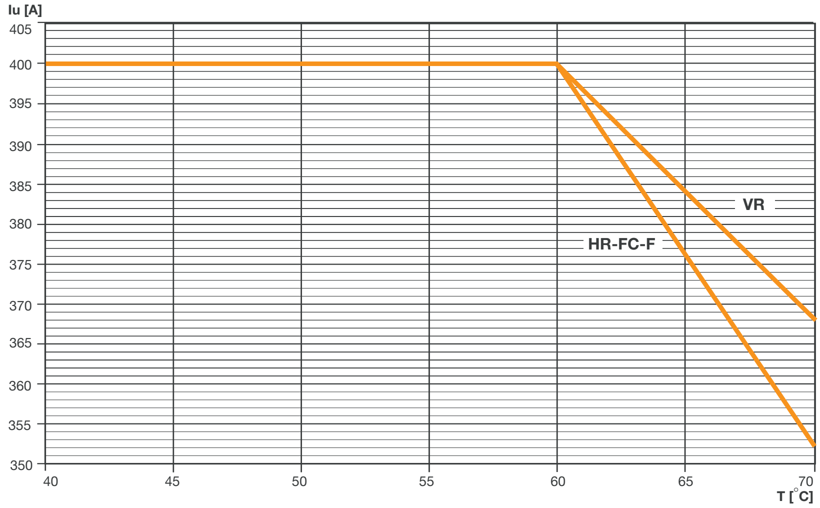
Plug-in / Withdrawable



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T5 400

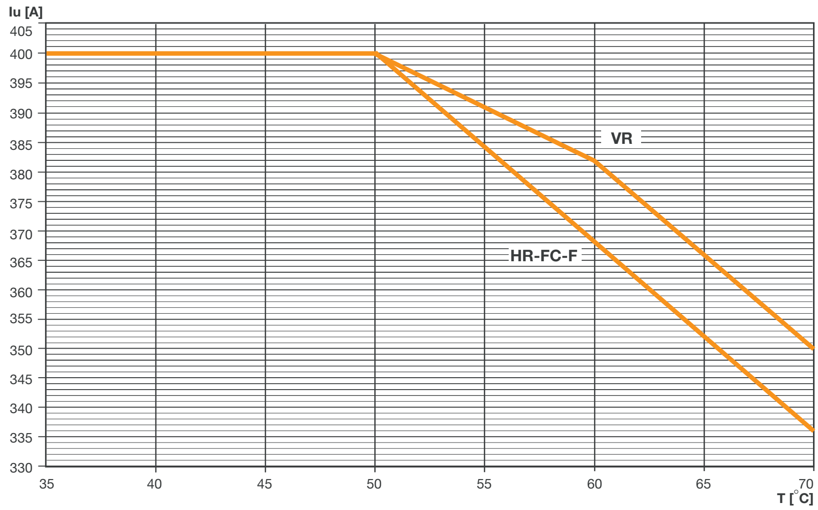
Fixed



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T5 400

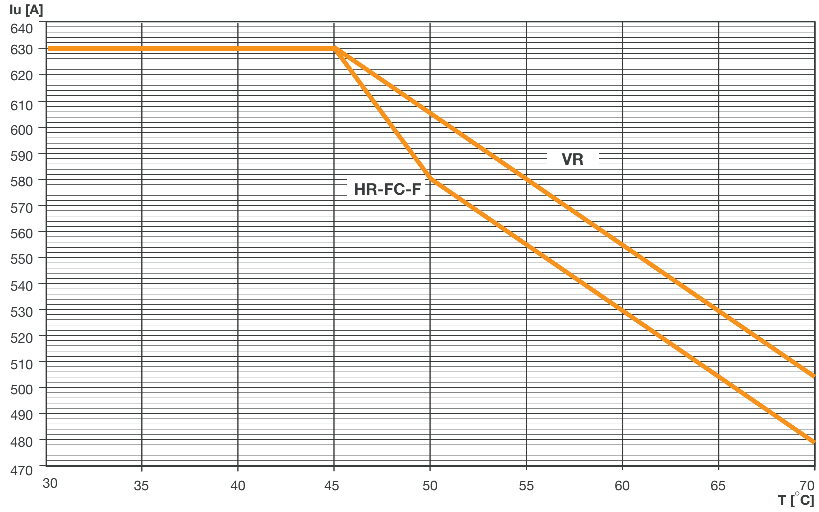
Plug-in / Withdrawable



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T5 630

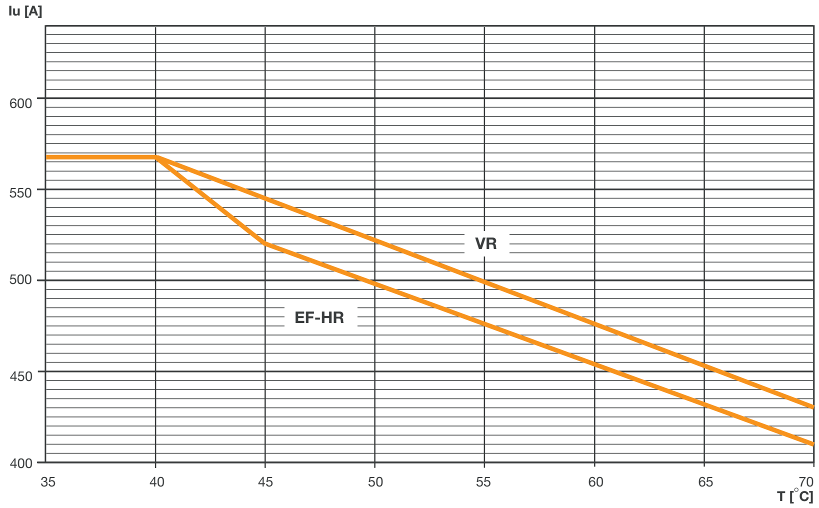
Fixed



FC = Front terminals for cables F = Front flat terminals HR = Rear flat horizontal terminals
VR = Rear flat vertical terminals

T5 630

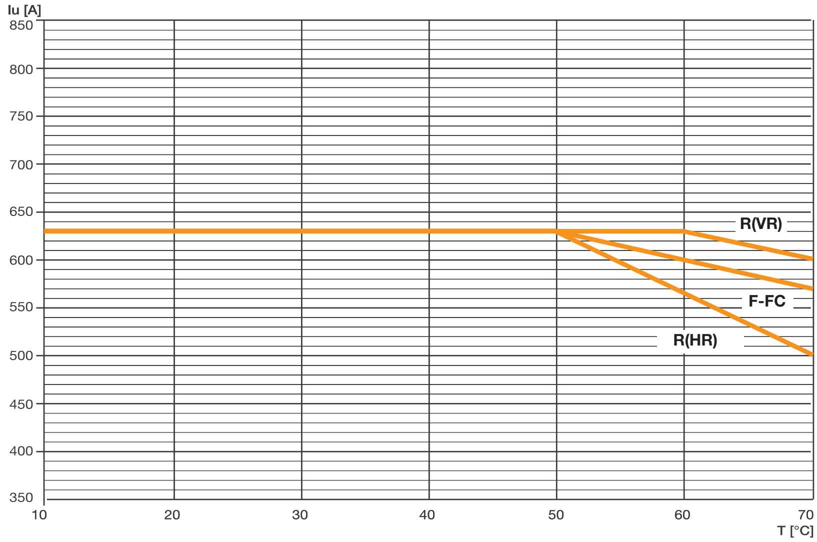
Plug-in / Withdrawable



EF = Front extended terminals HR = Rear flat horizontal terminals VR = Rear flat vertical terminals

T6 630

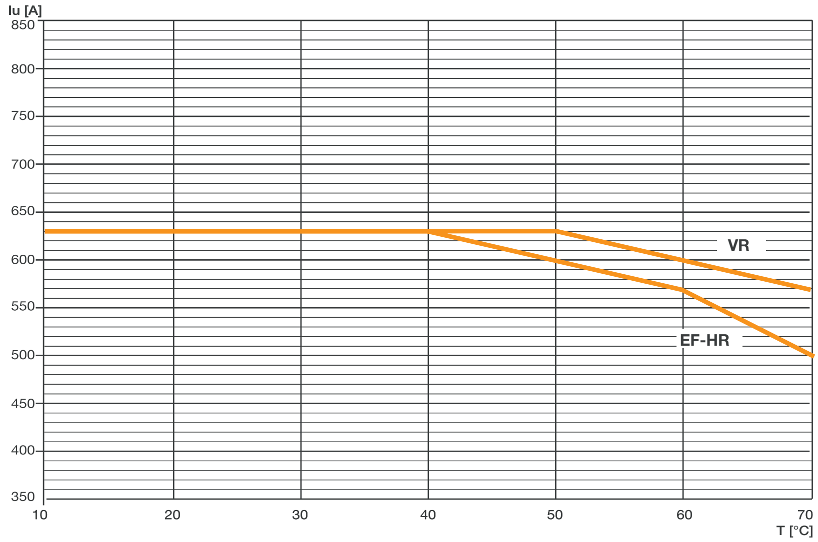
Fixed



F = Front flat terminals FC = Front terminals for cables R(VR)=Rear(vertical)terminals R(HR) = Rear(horiz.)terminals

T6 630

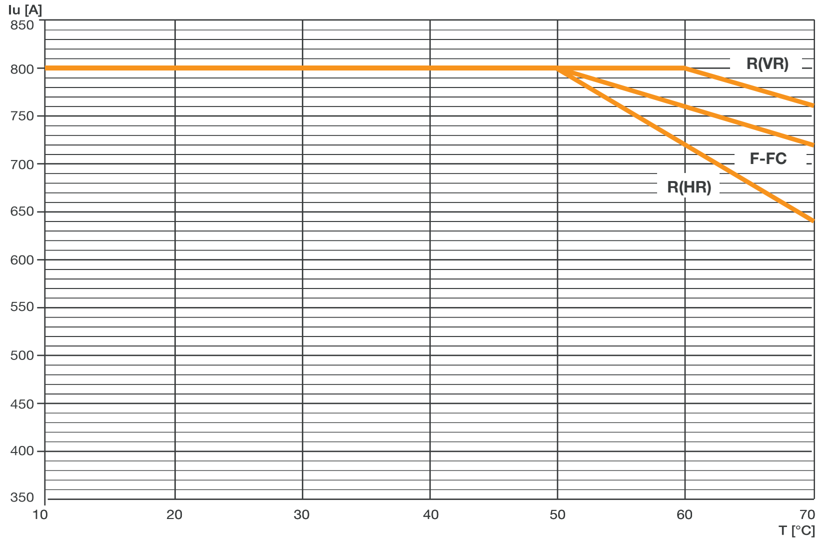
Withdrawable



EF = Front extended terminals HR = Rear flat horizontal terminals VR = Rear flat vertical terminals

T6 800

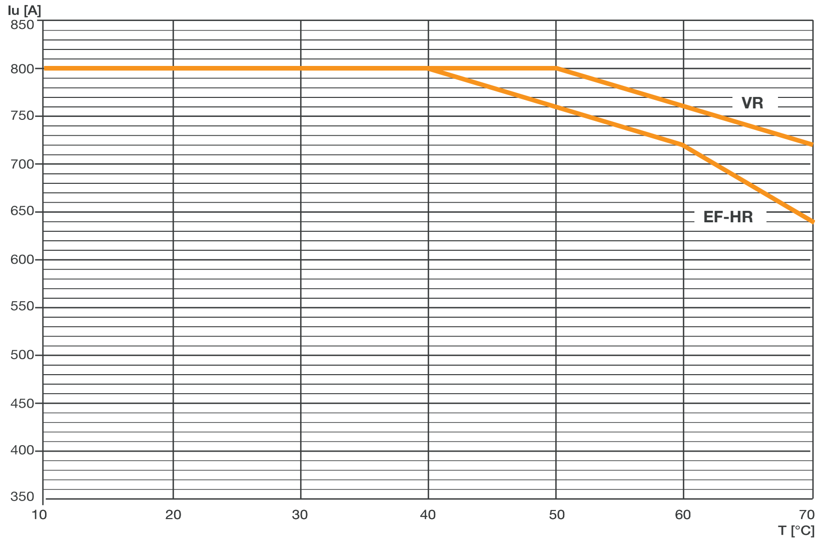
Fixed



F = Front flat terminals FC = Front terminals for cables R(VR)=Rear(vertical)terminals R(HR) = Rear(horiz.)terminals

T6 800

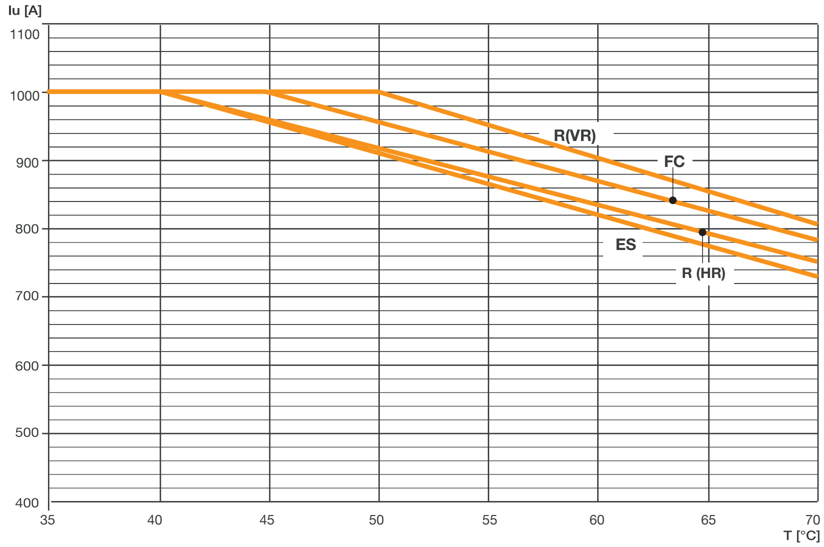
Withdrawable



EF = Front extended terminals HR = Rear flat horizontal terminals VR = Rear flat vertical terminals

T6 1000

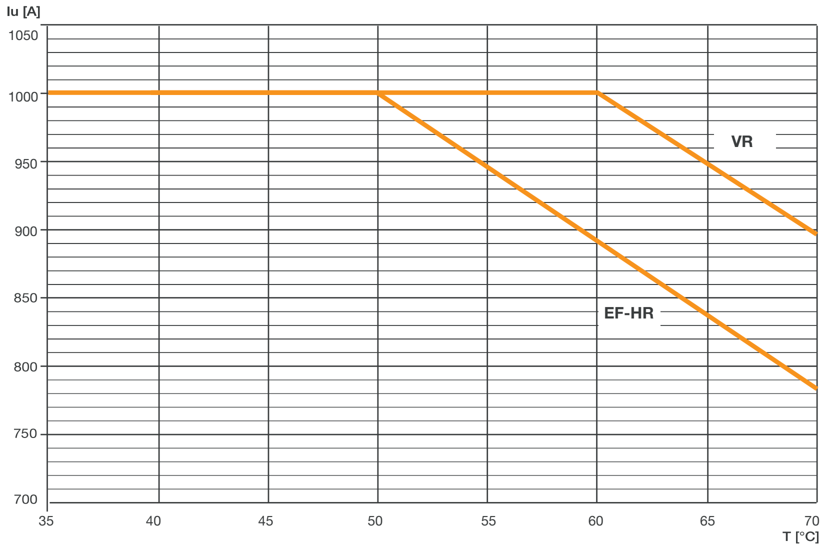
Fixed



FC = Front terminals for cables   R (HR) = Rear flat horizontal terminals   R (VR) = Rear flat vertical terminals
ES = Front extended spread terminals

T7 V 1000

Fixed

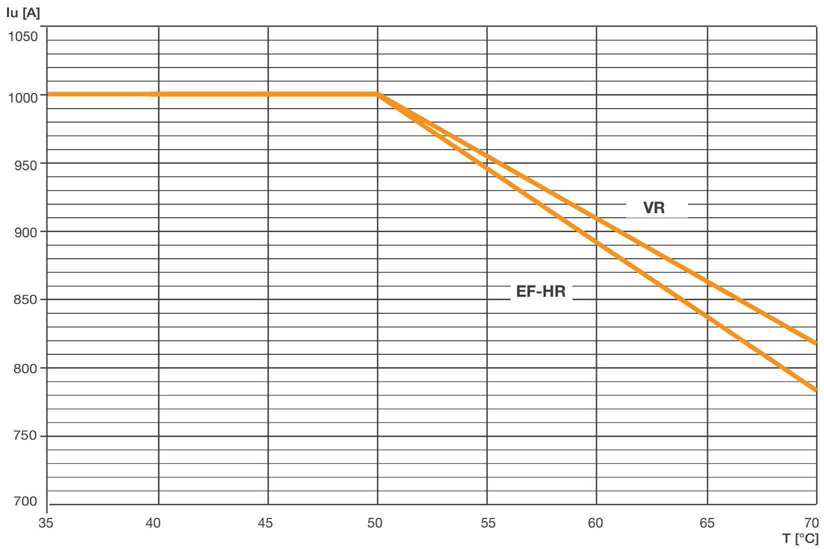


EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

Note: For ratings below 1000 A Tmax T7 does not undergo any thermal derating.

T7 V 1000

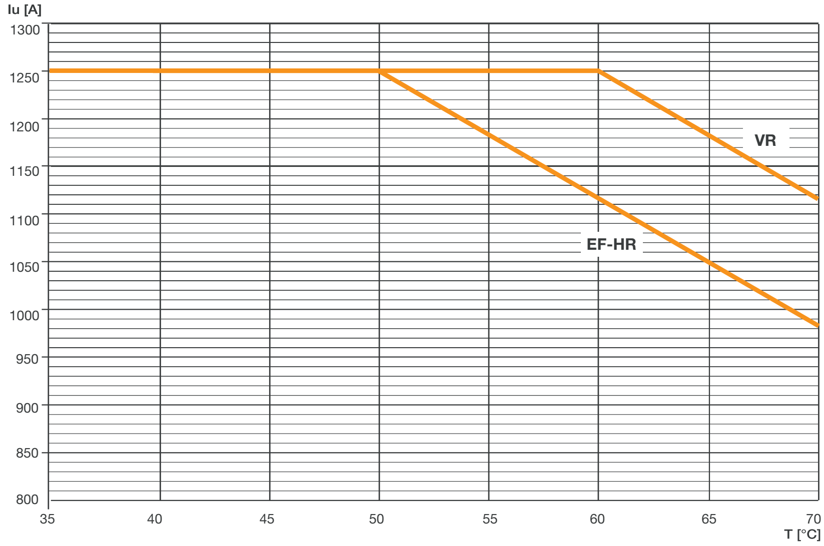
Withdrawable



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

T7 S,H,L, 1250

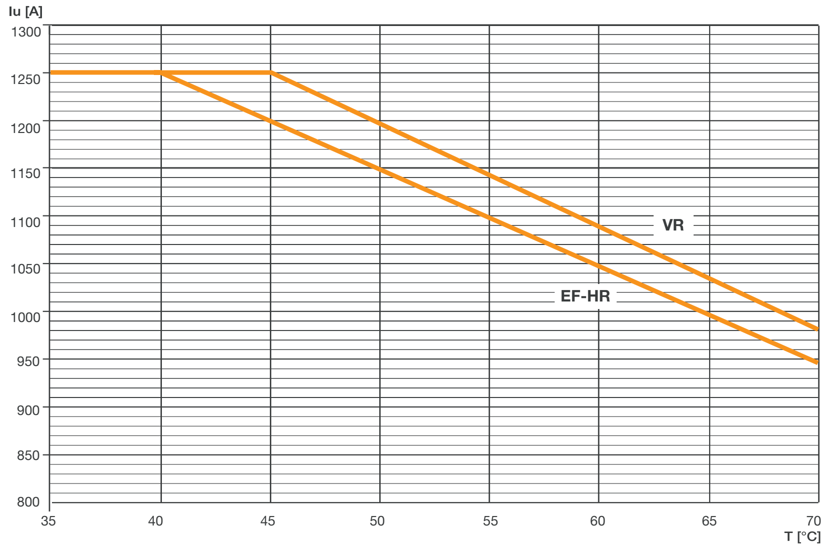
Fixed



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

T7 V 1250

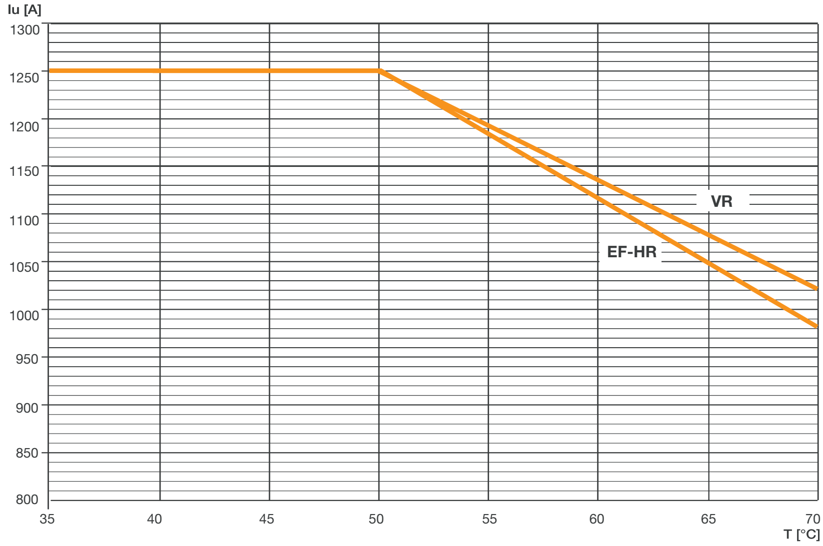
Fixed



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

T7 S,H,L, 1250

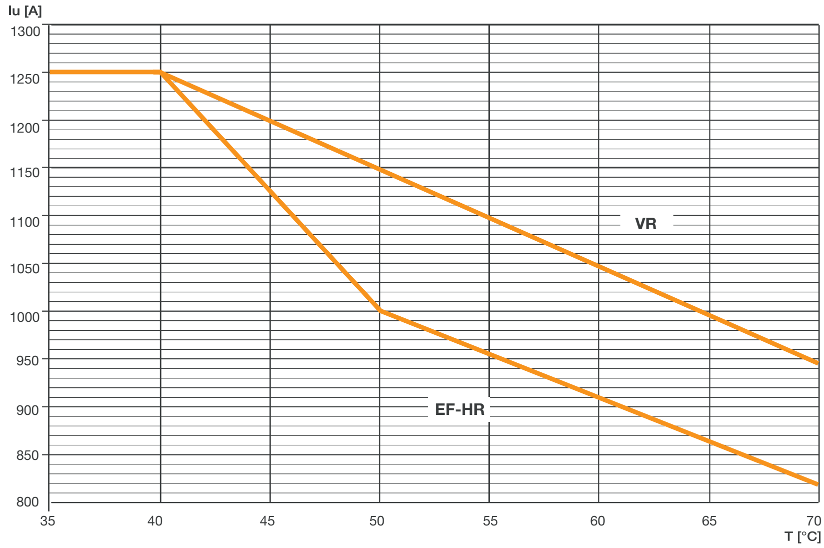
Withdrawable



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

T7 V 1250

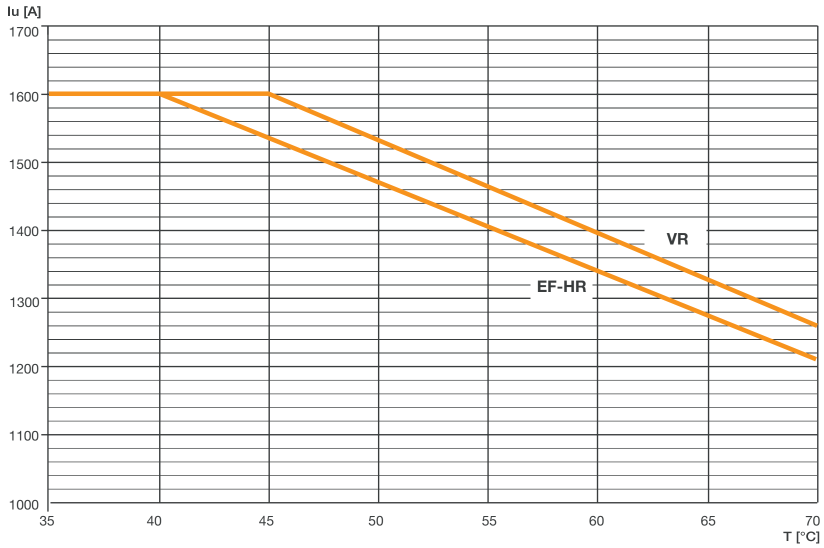
Withdrawable



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

T7 S,H,L, 1600

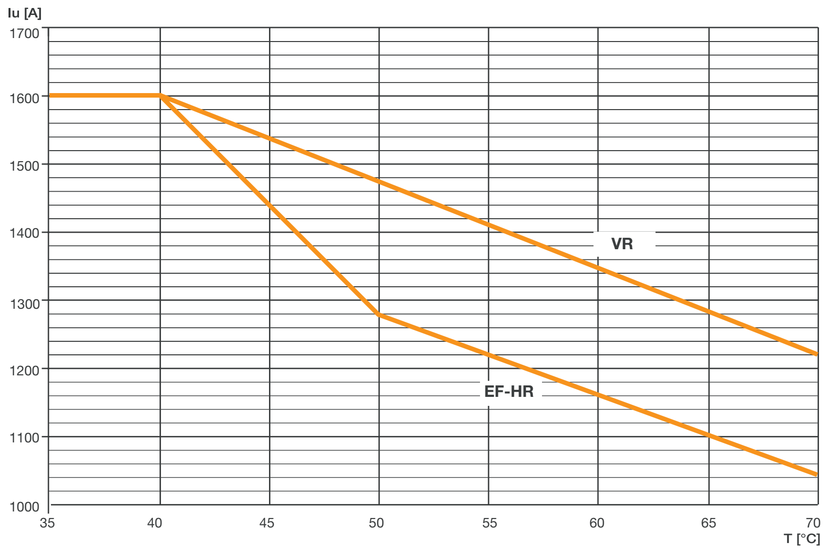
Fixed



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

T7 S,H,L, 1600

Withdrawable



EF = Extended front terminals VR = Rear flat vertical terminals HR = Rear flat horizontal terminals

Table 18

Tmax T1 and T1 1P (*)

In [A]	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
16	13	18	12	18	12	17	11	16	11	15	10	14	9	13
20	16	23	15	22	15	21	14	20	13	19	12	18	11	16
25	20	29	19	28	18	26	18	25	16	23	15	22	14	20
32	26	37	25	35	24	34	22	32	21	30	20	28	18	26
40	32	46	31	44	29	42	28	40	26	38	25	35	23	33
50	40	58	39	55	37	53	35	50	33	47	31	44	28	41
63	51	72	49	69	46	66	44	63	41	59	39	55	36	51
80	64	92	62	88	59	84	56	80	53	75	49	70	46	65
100	81	115	77	110	74	105	70	100	66	94	61	88	57	81
125	101	144	96	138	92	131	88	125	82	117	77	109	71	102
160	129	184	123	176	118	168	112	160	105	150	98	140	91	130

(*) For T1 1P circuit-breakers (fitted with TMF themomagnetic trip unit) consider only the column corresponding to the maximum adjustament of the TMD trip units.

Tmax T2

In [A]	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1,6	1,3	1,8	1,2	1,8	1,2	1,7	1,1	1,6	1	1,5	1	1,4	0,9	1,3
2	1,6	2,3	1,5	2,2	1,5	2,1	1,4	2	1,3	1,9	1,2	1,7	1,1	1,6
2,5	2	2,9	1,9	2,8	1,8	2,6	1,8	2,5	1,6	2,3	1,5	2,2	1,4	2
3,2	2,6	3,7	2,5	3,5	2,4	3,4	2,2	3,2	2,1	3	1,9	2,8	1,8	2,6
4	3,2	4,6	3,1	4,4	2,9	4,2	2,8	4	2,6	3,7	2,4	3,5	2,3	3,2
5	4	5,7	3,9	5,5	3,7	5,3	3,5	5	3,3	4,7	3	4,3	2,8	4
6,3	5,1	7,2	4,9	6,9	4,6	6,6	4,4	6,3	4,1	5,9	3,8	5,5	3,6	5,1
8	6,4	9,2	6,2	8,8	5,9	8,4	5,6	8	5,2	7,5	4,9	7	4,5	6,5
10	8	11,5	7,7	11	7,4	10,5	7	10	6,5	9,3	6,1	8,7	5,6	8,1
12,5	10,1	14,4	9,6	13,8	9,2	13,2	8,8	12,5	8,2	11,7	7,6	10,9	7,1	10,1
16	13	18	12	18	12	17	11	16	10	15	10	14	9	13
20	16	23	15	22	15	21	14	20	13	19	12	17	11	16
25	20	29	19	28	18	26	18	25	16	23	15	22	14	20
32	26	37	25	35	24	34	22	32	21	30	19	28	18	26
40	32	46	31	44	29	42	28	40	26	37	24	35	23	32
50	40	57	39	55	37	53	35	50	33	47	30	43	28	40
63	51	72	49	69	46	66	44	63	41	59	38	55	36	51
80	64	92	62	88	59	84	56	80	52	75	49	70	45	65
100	80	115	77	110	74	105	70	100	65	93	61	87	56	81
125	101	144	96	138	92	132	88	125	82	117	76	109	71	101
160	129	184	123	178	118	168	112	160	105	150	97	139	90	129

(*) For plug-in circuit-breakers, a derating of 10% is to be considered.

Tmax T3

In [A]	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
63	51	72	49	69	46	66	44	63	41	59	38	55	35	51
80	64	92	62	88	59	84	56	80	52	75	48	69	45	64
100	80	115	77	110	74	105	70	100	65	93	61	87	56	80
125	101	144	96	138	92	132	88	125	82	116	76	108	70	100
160	129	184	123	176	118	168	112	160	104	149	97	139	90	129
200	161	230	154	220	147	211	140	200	130	186	121	173	112	161
250	201	287	193	278	184	263	175	250	163	233	152	216	141	201

(*) For plug-in circuit-breakers, a derating of 10% is to be considered.

Tmax T4

In [A]	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
20	19	27	18	24	16	23	14	20	12	17	10	15	8	13
32	26	43	24	39	22	36	19	32	16	27	14	24	11	21
50	37	62	35	58	33	54	30	50	27	46	25	42	22	39
80	59	98	55	92	52	86	48	80	44	74	40	66	32	58
100	83	118	80	113	74	106	70	100	66	95	59	85	49	75
125	103	145	100	140	94	134	88	125	80	115	73	105	63	95
160	130	185	124	176	118	168	112	160	106	150	100	104	90	130
200	162	230	155	220	147	210	140	200	133	190	122	175	107	160
250	200	285	193	275	183	262	175	250	168	240	160	230	150	220

Tmax T5

In [A]	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
320	260	368	245	350	234	335	224	320	212	305	200	285	182	263
400	325	465	310	442	295	420	280	400	265	380	250	355	230	325
500	435	620	405	580	380	540	350	500	315	450	280	400	240	345

Tmax T6

In [A]	10 °C		20 °C		30 °C		40 °C		50 °C		60 °C		70 °C	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
630	520	740	493	705	462	660	441	630	405	580	380	540	350	500
800	685	965	640	905	605	855	560	800	520	740	470	670	420	610

Table 19

X1 withdrawable – rear horizontal terminals

Temperature [°C]	X1 630		X1 1800		X1 1000		X1 1250		X1 1600	
	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]
10	100	630	100	800	100	1000	100	1250	100	1600
20	100	630	100	800	100	1000	100	1250	100	1600
30	100	630	100	800	100	1000	100	1250	100	1600
40	100	630	100	800	100	1000	100	1250	100	1600
45	100	630	100	800	100	1000	100	1250	100	1600
50	100	630	100	800	100	1000	100	1250	97	1550
55	100	630	100	800	100	1000	100	1250	94	1500
60	100	630	100	800	100	1000	100	1250	93	1480

X1 withdrawable – rear vertical terminals

Temperature [°C]	X1 630		X1 1800		X1 1000		X1 1250		X1 1600	
	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]
10	100	630	100	800	100	1000	100	1250	100	1600
20	100	630	100	800	100	1000	100	1250	100	1600
30	100	630	100	800	100	1000	100	1250	100	1600
40	100	630	100	800	100	1000	100	1250	100	1600
45	100	630	100	800	100	1000	100	1250	100	1600
50	100	630	100	800	100	1000	100	1250	100	1600
55	100	630	100	800	100	1000	100	1250	98	1570
60	100	630	100	800	100	1000	100	1250	95	1520

SACE Emax E1

Temperature [°C]	E1 800		E1 1000		E1 1250		E1 1600	
	%	[A]	%	[A]	%	[A]	%	[A]
10	100	800	100	1000	100	1250	100	1600
20	100	800	100	1000	100	1250	100	1600
30	100	800	100	1000	100	1250	100	1600
40	100	800	100	1000	100	1250	100	1600
45	100	800	100	1000	100	1250	98	1570
50	100	800	100	1000	100	1250	96	1530
55	100	800	100	1000	100	1250	94	1500
60	100	800	100	1000	100	1250	92	1470
65	100	800	100	1000	99	1240	89	1430
70	100	800	100	1000	98	1230	87	1400

SACE Emax E2

Temperature [°C]	E2 800		E2 1000		E2 1250		E2 1600		E2 2000	
	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]
10	100	800	100	1000	100	1250	100	1600	100	2000
20	100	800	100	1000	100	1250	100	1600	100	2000
30	100	800	100	1000	100	1250	100	1600	100	2000
40	100	800	100	1000	100	1250	100	1600	100	2000
45	100	800	100	1000	100	1250	100	1600	100	2000
50	100	800	100	1000	100	1250	100	1600	97	1945
55	100	800	100	1000	100	1250	100	1600	94	1885
60	100	800	100	1000	100	1250	98	1570	91	1825
65	100	800	100	1000	100	1250	96	1538	88	1765
70	100	800	100	1000	100	1250	94	1510	85	1705

SACE Emax E3

Temperature [°C]	E3 800		E3 1000		E3 1250		E3 1600		E3 2000		E3 2500		E3 3200	
	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]	%	[A]
10	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	100	3200
20	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	100	3200
30	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	100	3200
40	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	100	3200
45	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	100	3200
50	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	97	3090
55	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	93	2975
60	100	800	100	1000	100	1250	100	1600	100	2000	100	2500	89	2860
65	100	800	100	1000	100	1250	100	1600	100	2000	97	2425	86	2745
70	100	800	100	1000	100	1250	100	1600	100	2000	94	2350	82	2630

SACE Emax E4

Temperature [°C]	E4 3200		E4 4000	
	%	[A]	%	[A]
10	100	3200	100	4000
20	100	3200	100	4000
30	100	3200	100	4000
40	100	3200	100	4000
45	100	3200	100	4000
50	100	3200	98	3900
55	100	3200	95	3790
60	100	3200	92	3680
65	98	3120	89	3570
70	95	3040	87	3460

SACE Emax E6

Temperature [°C]	E6 3200		E6 4000		E6 5000		E6 6300	
	%	[A]	%	[A]	%	[A]	%	[A]
10	100	3200	100	4000	100	5000	100	6300
20	100	3200	100	4000	100	5000	100	6300
30	100	3200	100	4000	100	5000	100	6300
40	100	3200	100	4000	100	5000	100	6300
45	100	3200	100	4000	100	5000	100	6300
50	100	3200	100	4000	100	5000	100	6300
55	100	3200	100	4000	100	5000	98	6190
60	100	3200	100	4000	98	4910	96	6070
65	100	3200	100	4000	96	4815	94	5850
70	100	3200	100	4000	94	4720	92	5600

As regards small-size molded-case circuit-breakers there is no remarkable difference among the various terminal typologies, whereas for big-size molded-case circuit-breakers (starting from T4), the rear vertical terminals are to be preferred to the other terminal typologies when the circuit-breaker is installed in vertical position. In general, however, the fixed version is suggested instead of the withdrawable and the plug-in ones. If the circuit-breaker were installed in horizontal position, to determine its current carrying capacity reference should be taken to the lowest curve in the graphics.
As regards the air circuit-breakers of Emax series, the behaviour of the rear horizontal terminals is analogous to that of the front ones.

The greater heat dissipation capacity is definitely that of the rear vertical terminals.

In the same way, as an example, Table 20 shows the different current carrying capacity given by the Std. DIN 43671 for copper conductors of rectangular cross-section in indoor installations, where the radiation coefficient is assumed to be equal to 0.4 for not painted bars and 0.9 for painted bars.

As it can be observed from the table, under the same conditions in the busbar system, passing from bare busbars to painted busbars there is an increase in the current carrying capacity which can reach also 15%.

Table 20

Width x Thickness	Carrying capacity in A a.c. up to 60Hz for bare copper conductors				Carrying capacity in A up to 60Hz for painted copper conductors			
[mm] x [mm]	I	II	III	II II*	I	II	III	II II*
50 x 5	583	994	1240	1920	679	1140	1330	2010
50 x 10	852	1510	2040	2600	1020	1720	2320	2950
60 x 5	688	1150	1440	2210	826	1330	1510	2310
60 x 10	985	1720	2300	2900	1180	1960	2610	3290
80 x 5	885	1450	1750	2720	1070	1680	1830	2830
80 x 10	1240	2110	2790	3450	1500	2410	3170	3930
100 x 5	1080	1730	2050	3190	1300	2010	2150	3300
100 x 10	1490	2480	3260	3980	1810	2850	3720	4530

Validity condition of the table: ambient temperature 35°C, conductor temperature 65°C, conductor width vertical, clearance between conductors in parallel equal to conductor thickness.
(*) minimum clearance between the central conductors: 50mm.

3 Problems concerning short-circuit

In this chapter the problems regarding short-circuit are analyzed, making specific reference to the interaction between the protection circuit-breaker installed in the switchboard and the switchboard itself. After a short introduction defining the main electrical parameters related to short-circuit, an analysis shall be carried out to illustrate the prescriptions regarding the electrical circuits of switchboards and the modalities aimed at reducing the possibility of occurrence of a short-circuit on the circuits inside the switchboards and to reduce its effects.

3.1 Main definitions of the parameters characterizing a switchboard under short-circuit conditions

As far as the short-circuit withstand strength of a switchboard is concerned, the main parameters characterizing a switchboard are:
- rated short-time withstand current;
- rated peak withstand current;
- rated conditional short-circuit current.

The Std. IEC 60439-1 about low voltage controlgear and switchgear define the above parameters as follows :

Rated short-time withstand current "Icw"
The rated short-time withstand current of a circuit of a switchboard is the r.m.s. value of short-time current assigned to that circuit by the manufacturer which that circuit can carry without damage under the test conditions specified by the Standard. Unless otherwise stated by the manufacturer, the reference time is 1s. To this short-time current a determined peak value "I_{pk}" is associated and it is assumed that the maximum current value which can occur and which can be withstand by the switchboard does not exceed the peak value, related to the Icw by a coefficient "n".

Rated peak withstand current "I_{pk}"
The rated peak withstand current of a switchboard circuit is the value of peak current assigned to that circuit by the manufacturer which that circuit can withstand satisfactorily under the test conditions specified by the Standard. The peak current value, which is used to determine electro-dynamic stresses, is obtained by multiplying the short-time current by the coefficient "n". The values normalized by the multiplying factor "n" are reported in Table 21.

Table 21

RMS value of short-circuit current kA	Values normalized by coefficient "n" Coφ	n
I ≤ 5	0.7	1.5
5 < I ≤ 10	0.5	1.7
10 < I ≤ 20	0.3	2
20 < I ≤ 50	0.25	2.1
50 < I	0.2	2.2

Rated conditional short-circuit current "Icc"
The rated conditional short-circuit current characterizing the circuit of a switchboard is the value of prospective short-circuit current, stated by the manufacturer, which that circuit, protected by a short-circuit protective device specified by the manufacturer, can withstand satisfactorily for the operating time of the device under the test conditions specified.

With reference to these definitions, it is possible to say that the circuit of a switchboard for which a specific Icw has been defined, can withstand the electro-dynamic stresses due to the initial peak value which can reach a maximum value equal to "Icw x n" and a specific thermal energy due to the current and equal to Icw^2 x t (with t=1s).
On the other hand, the circuit of a switchboard protected by a suitable device shall have a rated conditional short-circuit current if it can withstand the electro-dynamic stresses due to the peak current limited by the protective device and a specific thermal energy let through by the protective device in correspondence with the prospective short-circuit current Ik.

3.1.1 General prescriptions and information about short-circuit withstand strength

As regards the short-circuit withstand strength of an assembly, the Std. IEC 60439-1 prescribes that the user of the switchboard shall give the manufacturer the data relevant to the short-circuit currents at the installation point so that the assembly is protected against short-circuit by protective devices – for example automatic circuit-breakers positioned inside or outside the switchboard – and so that it is manufactured to withstand the thermal and dynamic stresses occurring under short-circuit conditions. The information concerning the short-circuit withstand strength of the switchboard are given by the manufacturer according to the presence or not of the protective device.

For assemblies with an automatic circuit-breaker incorporated in the incoming unit, the manufacturer shall indicate the maximum allowable value of short-circuit current, expressed as:

- rated conditional short-circuit current Icc, when the protective device is a circuit-breaker having remarkable current limiting characteristics;
- allowable short-time withstand current Icw, when the protective device is a circuit-breaker having a high Icw value.

For assemblies where a protective circuit-breaker is not incorporated in the incoming unit, the manufacturer may indicate:

- a rated conditional short-circuit current (Icc), specifying the characteristics of the external device which protects the switchboard (rated current, breaking capacity, limited current, specific let-through energy);
- an allowable value of short-time withstand current (Icw).

If the duration of the current is not specified, the current is understood to be equal to 1sec; if the initial peak value is not specified, this is understood to be linked to the assigned conditional short-circuit withstand current through the factor "n".

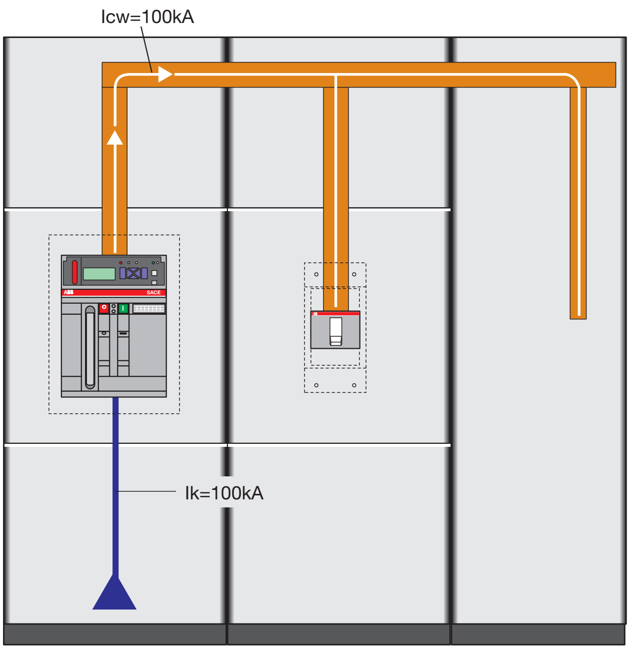
3.2 Prescriptions concerning the electrical circuits of a switchboard

In addition to the previous general prescriptions concerning the indication of the short-circuit withstand strength of a switchboard, the Standard prescribes how the electrical circuits inside the assembly must be dimensioned in order to reduce the possibility that a fault occurs.
The main prescriptions are given with reference to the internal busbar system, which shall be designed so that the likelihood of a short-circuit on the busbars is remote.
As regards busbar dimensioning in relation to the short-circuit withstand strength, different prescriptions must be complied with if reference is made to a main busbar system rather than to circuits derived from the busbars.

3.2.1 Main busbar systems

The main busbars (bare or insulated) shall be arranged in such a manner that an internal short-circuit is not to be expected under normal operating conditions. Unless otherwise specified, the busbars shall be rated in accordance with the information concerning the short-circuit withstand strength and designed to withstand the short-circuit stresses limited by the protective devices installed on the supply side of the busbars.
In practice, if the limiting characteristics of the protective device upstream the busbar system are not remarkable (or if they are not known in advance), the busbar system shall be rated so that the Icw is higher than the short-circuit current value at the installation point.
Here is an application example to illustrate this concept:

Figure 24



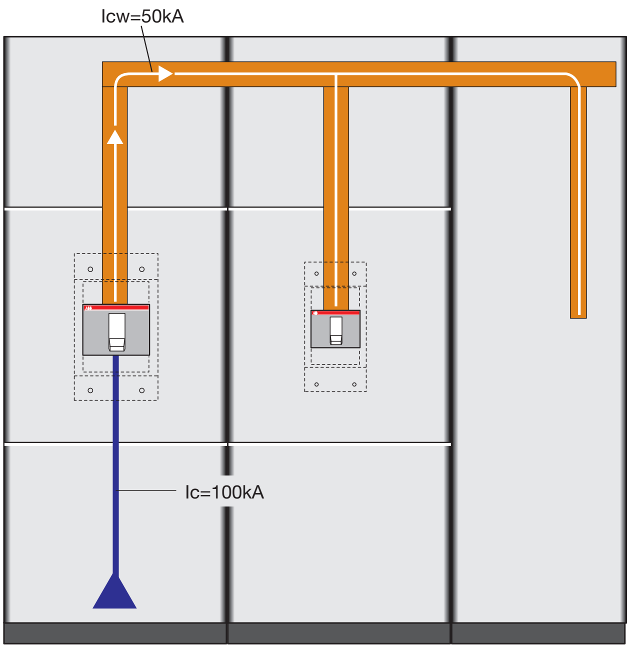
In the switchboard of Figure 24, the circuit-breaker protecting the main busbar system is an Emax E4H with Icw = 100kA.
If also the busbar system has an Icw value equal to 100kA or higher, the circuit formed by the circuit-breaker and by the busbar system shall be considered to have Icw = 100kA.
On the other hand, if the device protecting the main busbar system is an automatic circuit-breaker with current limiting characteristics, the busbar system may be dimensioned to withstand the stresses due to the limited peak current and to the specific let-through energy limited by the circuit-breaker.

The switchboard of Figure 25 to be installed in a plant with a prospective short-circuit current Ik equal to 100kA at 400V is now taken as example. A Tmax T6L1000 is chosen as incoming circuit-breaker.

In correspondence with the Ik values, downstream the incoming apparatus, the following parameters are verified:
- specific let-through energy lower than 20MA²s
- limited peak current lower than 80kA

The presence of a current limiting apparatus inside the switchboard allows a busbar system with an Icw value < 100kA (short-circuit current in the plant) to be installed on the load side of this apparatus, to which, however, a peak current value and a specific let-through energy exceeding those measured on the load side of the circuit-breaker shall correspond.

Figure 25



For example, a busbar system characterized by an Icw value equal to 50kA can withstand the following parameters:
- specific let-through energy
  50kA x 50kA x 1s = 2500MA²s
- peak current
  50kA x 2.1 = 105kA

As a consequence it is quite easy to verify that the busbar system (Icw = 50kA, Ipk = 105kA, I²t = 2500MA²s) can withstand greater stresses than those ones generated on the load side of T6L circuit-breaker. To conclude: it is possible to install a busbar system with an Icw value equal to 50kA on the load side of the circuit-breaker type T6L; in this case, the circuit formed by the busbars and by the circuit-breaker shall have Icc = 100kA and therefore it is suitable for the prospective short-circuit current of the plant.

3.2.2 Distribution busbars and conductors derived by the main busbars

Within a section of an assembly, the conductors and the distribution busbars positioned between the main busbars and the supply side of functional units, as well as the components included in these units, may be rated on the basis of the reduced short-circuit stresses occurring on the load side of the respective short-circuit device, provided that these conductors are arranged so that under normal operating conditions, an internal short-circuit between phases and/or between phases and earth is only a remote possibility. Such conductors are preferably of solid rigid manufacture.
The economical and dimensional advantages which result from this prescription of the Standard are evident, above all when there are many circuits derived by a single main busbar system.

Figure 26

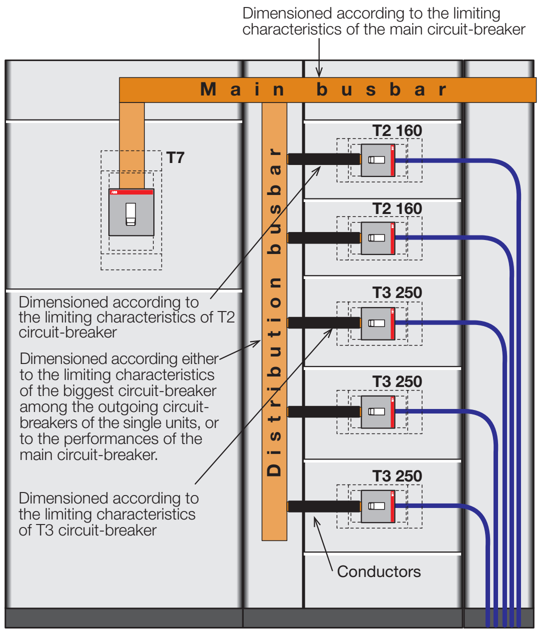


Figure 26 represents a switchboard where the vertical distribution busbar, constituted by a bare bar of solid manufacture and provided with spacers, is derived from the main busbar, so that the possibility that a short-circuit occurs can be considered as remote.
From this busbar, different horizontally-arranged conductors (in cable) depart, supplying the main circuit-breakers of the different outgoing feeders.
For a correct dimensioning of the vertical distribution busbar, it is possible to consider the outgoing device having the lowest current limiting performances. Thus, also in the event of a fault on the load side of the circuit-

breaker with lower limiting characteristics, the busbar shall undergo acceptable stresses.

Dimensioning of the distribution busbar carried out according to the above corresponds to the Standard prescriptions; in spite of this, the usual procedure for many switchboard manufacturers is dimensioning distribution busbars making reference to the performances of the circuit-breaker on the incoming of the switchboard, in terms of let-through energy and limited peak current value.
On the contrary, the different cables which feed the individual circuit-breakers shall be dimensioned according to the limiting characteristics of the relevant device they supply.

3.3 Reduction of the possibility of short-circuit events and of the relevant effects

As regards the prescriptions aimed at making unlikely the occurrence of a short-circuit in live conductors, the Std. IEC 60439-1 suggests a series of measures which depend on the conductor typology. As an example here are the prescriptions intended for:

- bare conductors, or single-core conductors, with basic insulation, e.g. cables complying with IEC 60227-3, for which mutual contact or contact with conductive parts shall be avoided, for example by use of spacers;
- single-core conductors with basic insulation and a maximum permissible conductor-operating temperature above 90° C, for example cables complying with IEC 60245-3, or heating resistant PVC insulated cables according to IEC 60227-3, for which mutual contact or contact with conductive parts is permitted where there is no applied external pressure. Contact with sharp edges must be avoided. There must be no risk of mechanical damage. These conductors may only be loaded such that an operating temperature of 70° C is not exceeded:
- conductors with basic insulation (cables complying with IEC 60227-3), having additional secondary insulation, for example individual covered cables with shrink sleeving or individually run cables in plastic conduits, or conductors insulated with a very high mechanical strength material (FTFE insulation), for which there are no additional requirements if there is no risk of mechanical damage.

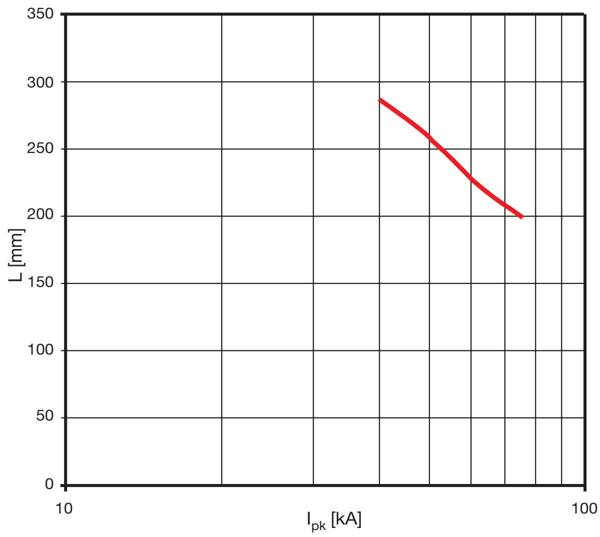
3.3.1 Minimum anchor distances for conductors

One of the main problems which regard short-circuit and which is to be faced directly by panel builders is the maximum anchor distances of the conductors connected to the circuit-breakers from the circuit-breaker terminals.
As known, inside the switchboards it is necessary that cables and busbars are fastened to the frame.
In fact, during a short-circuit, the dynamic stresses on the conductors could affect also the circuit-breaker terminals causing damages. Figure 27 shows some diagrams relevant to Tmax and Emax series circuit-breakers allowing to determine, as a function of the maximum peak current under short-circuit conditions and of the circuit-breaker typology, the maximum distances from the circuit-breaker terminals to the first anchor element of the conductors.
The term conductor is used for busbars when the current exceeds or is equal to 400A, whereas cables are referred to when the current is lower than this value. This distinction is made complying with the Tables 8 and 9 of the Std. IEC 60439-1.
When specific requirements demand or prescribe the use of busbars also for currents lower than 400A, the distances which can be obtained by the diagrams shall not undergo any variations, whereas the distances referred to the use of busbars are not valid when using cables.

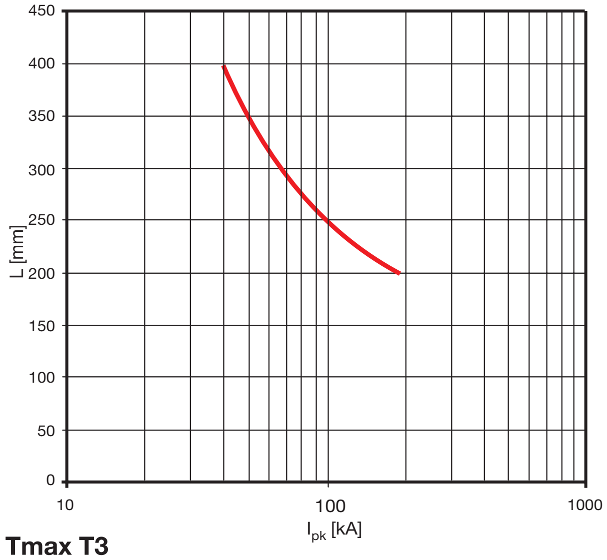
Figure 27

Distance suggested for the first anchor element of busbars as a function of the maximum prospective short-circuit current peak.

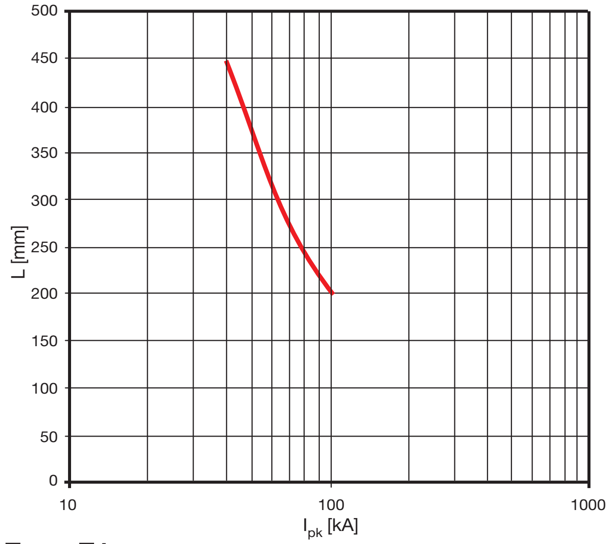
Tmax T1



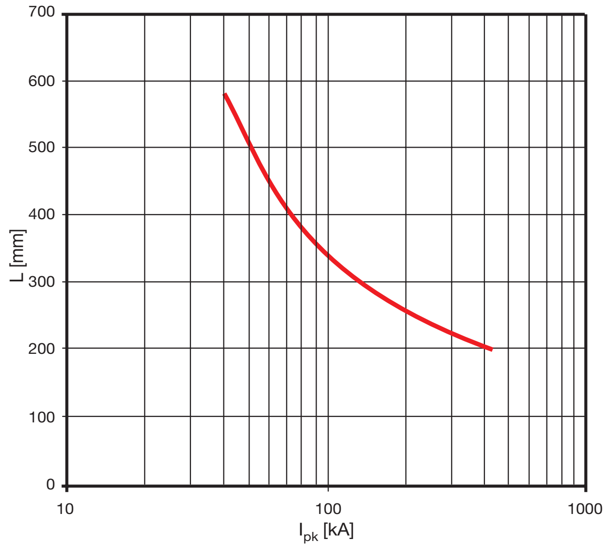
Tmax T2



Tmax T3

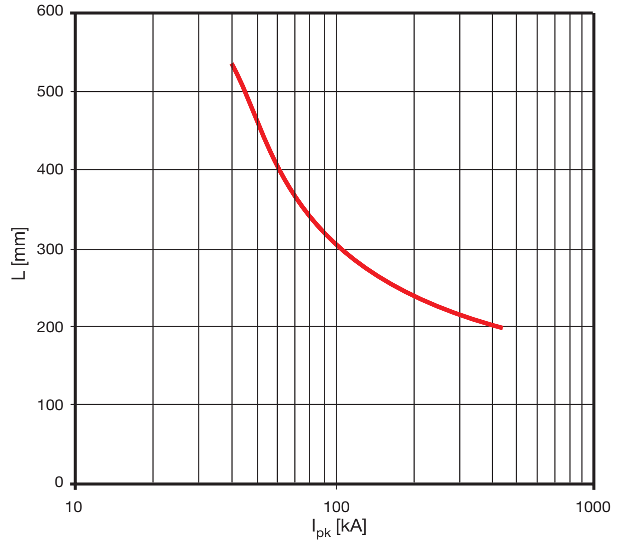


Tmax T4



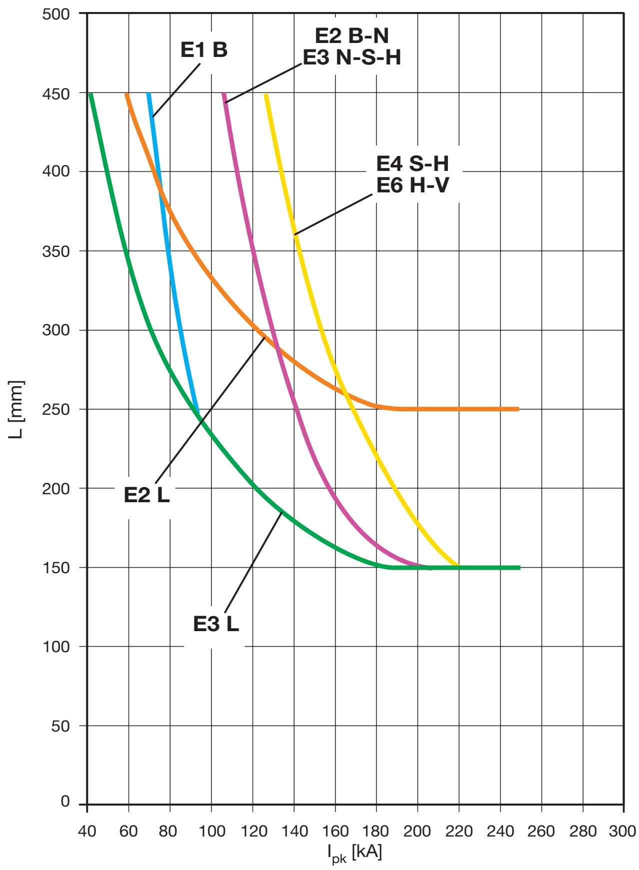
Tmax T5

Valid for:
- front and rear terminals
- connection by means of rigid busbars



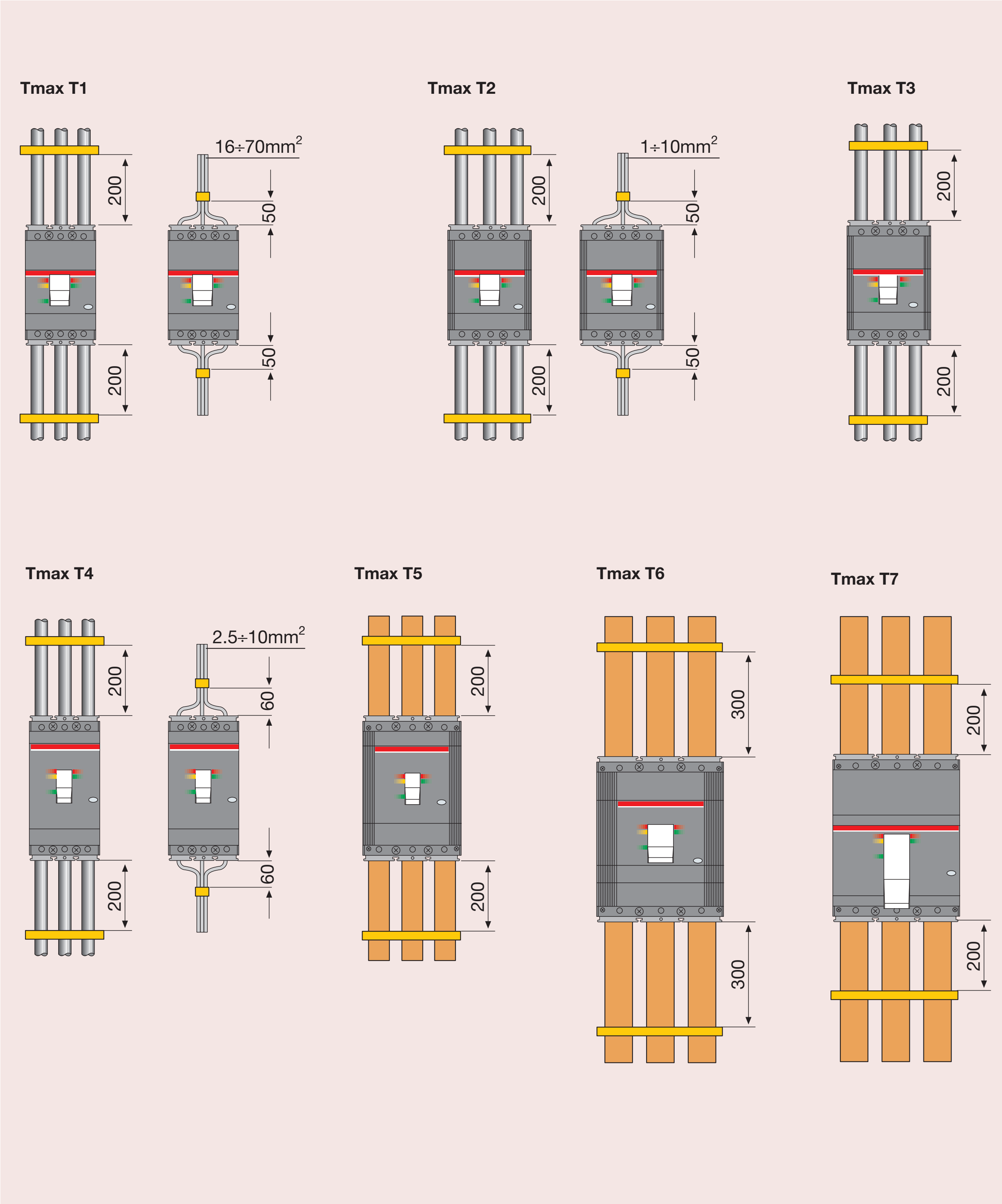
Distance suggested for the first anchor element of busbars as a function of the maximum prospective short-circuit current peak. Circuit-breaker with horizontal and vertical terminals..

Emax



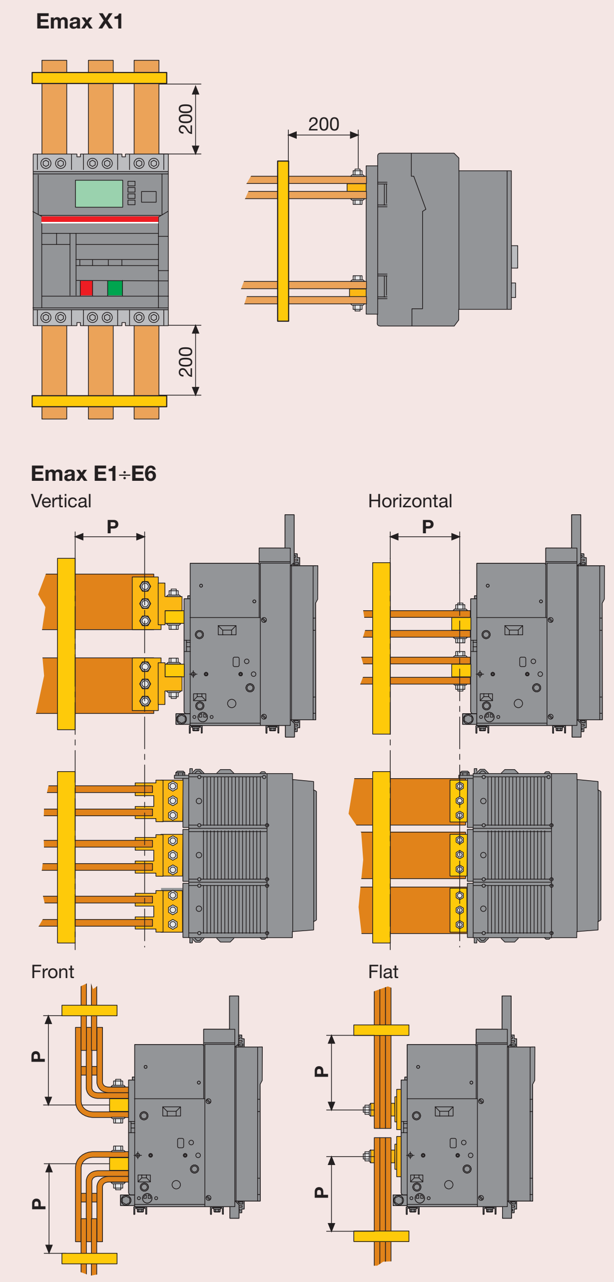
As regards Tmax molded-case circuit-breakers, Figure 28 gives an example of the maximum distance (in mm) suggested for the positioning of the nearest anchor support, in relation to the maximum peak current admitted for the circuit-breaker.

Figure 28



As regards Emax air circuit-breakers, Figure 29 gives an example of the maximum distance (in mm) suggested for the positioning of the nearest anchor support for the busbars connecting to the circuit-breaker according to the different types of terminals available and for the highest peak values, as derived from the curves of Figure 28.

Figure 29



Emax	Horizontal P [mm]	Vertical P [mm]	Front P [mm]	Flat P [mm]
E1-E2	250	250	-	-
E3-E4-E6	150	150	-	-
E1-E6	-	-	250	250

3.3.2 Verification of the short-circuit withstand strength and of the current limiting characteristics of circuit-breakers

In some cases, the Std. IEC 60439-1 allows that the short-circuit withstand strength of assemblies is not verified.

In particular, the following switchgear and controlgear assemblies are free from verification:

- those having rated short-time withstand currents or rated conditional short-circuit currents lower than 10kA;
- those protected by current limiting devices with a limited peak current not exceeding 17kA in correspondence with the maximum prospective short-circuit current measured at the terminals of the incoming circuit of the assembly.

As known, the limiting characteristics of a circuit-breaker are a function of the working voltage of the circuit-breaker itself.

Table 22 below gives - for the different protective circuit-breakers and the most common voltages of the plant – the values which approximately represent the maximum prospective short-circuit current in [kA] which guarantee a limited peak current not exceeding 17kA, so that the short-circuit withstand test for the switchboard is not to be carried out.

Table 22

Circuit-breaker		Rated voltage of the plant			
Type	Rated current In [A]	230Vac	415Vac	500Vac	690Vac
S200	≤63	20	10	-	-
S200M	≤63	25	15	-	-
S200P	≤25	40	25	-	-
S200P	32-63	25	15	-	-
S800	≤125	50	50	15(In≤80A) 10(In≥80A)	6(In≤80A) 4.5(In≥80A)
S290	≤125	25	15	-	-
T1	<160	50	35	15	6
T1	160	37	33	15	6
T2	≤32	120	85	50	10
T2	≤50	120	85	39	10
T2	≤63	120	65	30	10
T2	80 -160	120	50	29	10
T3	63	37	20	18	8
T3	80	27	18	17	8
T3	100	21	16	15	8
T3	125-160	18	15	14	8
T3	200-250	16	14	13	8
T4	20	200	200	150	80
T4	32-50	200	200	150	55
T4	80	200	100	48	32
T4	100-320	200	24	21	19
T5 T6 T7	320-1600	10	10	10	10

The short-circuit current value reported in the table above must be compared with the breaking capacity of the circuit-breaker for the different versions available.

3.3.3 Problems concerning the installation distances

The Std. IEC 60439-1 assigns the circuit-breaker manufacturers the task of defining the prescriptions for the installation of these devices inside switchboards.

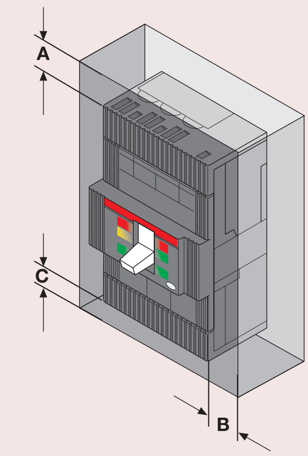
Hereunder, Figures 30 and 31 give, for ABB SACE circuit-breakers series Tmax and Emax respectively, the indications relevant to the distances to be complied with in the plants up to 690 Va.c.; such distances are already specified in the circuit-breaker technical catalogues and installation manuals.

Figure 30

Insulation distances for installation in metallic cubicle

	A [mm]	B [mm]	C [mm]
T1	25	20	20
T2	25	20	20
T3	50	25	20
T4	30(*)	25	25(*)
T5	30(*)	25	25(*)
T6	35(*)	25	20
T7	50(*)	20	10

(*) For Un ≥ 440V and T6L all versions: distances A 100 mm
Note: For the insulation distances of the 1000 V circuit-breakers, please ask ABB SACE.



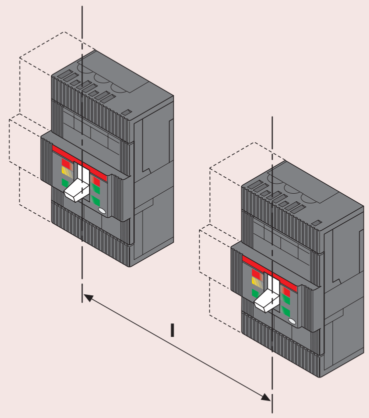
Distances between two circuit-breakers side by side or superimposed

For assembly side by side or superimposed, check that the connection busbars or cables do not reduce the air insulation distance

Minimum centre distance for two circuit-breakers side by side

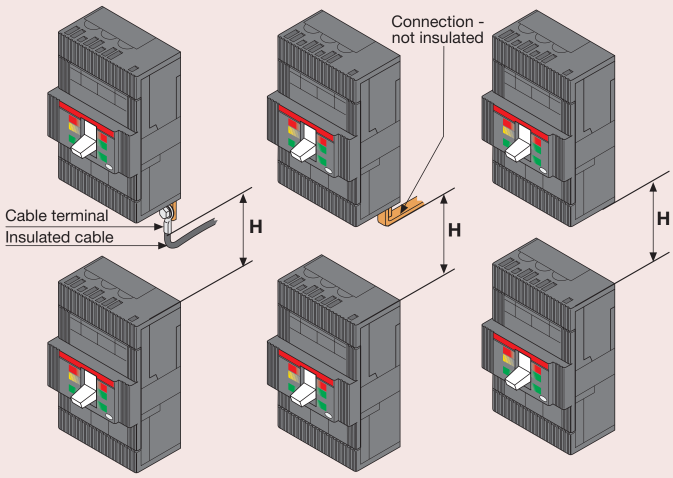
	Circuit-breaker width (mm)		Centre distance I [mm]	
	3 poles	**4 poles**	**3 poles**	**4 poles**
T1	76	102	76	102
T2	90	120	90	120
T3	105	140	105	140
T4	105	140	105	140
T5	140	184	140(*)	184(*)
T6	210	280	210	280
T7	210	280	210	280

(*) For Un ≥ 500 V minimum centre I (mm) 3 poles 180, minimum centre I (mm) 4 poles 224



Minimum distance between two superimposed circuit-breakers

	H [mm]
T1	60
T2	90
T3	140
T4	160
T5	160
T6	180
T7	180



Note: The dimensions shown apply for operating voltage Un up to 690 V. The dimensions to be respected must be added to the maximum dimensions of the various different versions of the circuit-breakers, including the terminals. For 1000 V versions, please ask ABB SACE.

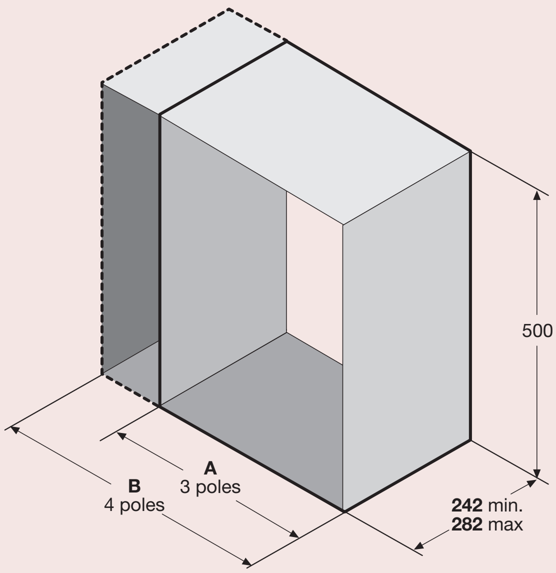
Figure 31

Compartment dimensions

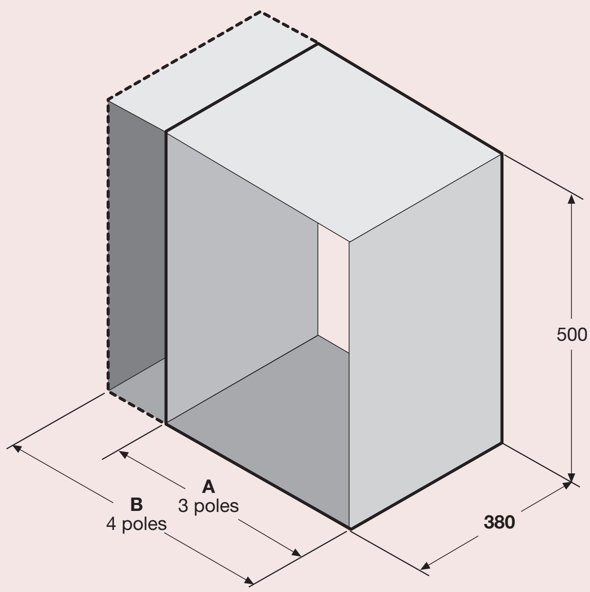
Emax	A [mm]	B [mm]
E1	400	490
E2	400	490
E3	500	630
E4	700	790
E4f	-	880
E6	1000	1130
E6f	-	1260

Nota: For Emax X1 CB, please consider the same indications of Figure 30 referred to the insulation distance of Tmax T7 CB

Emax – fixed version



Emax – withdrawable version



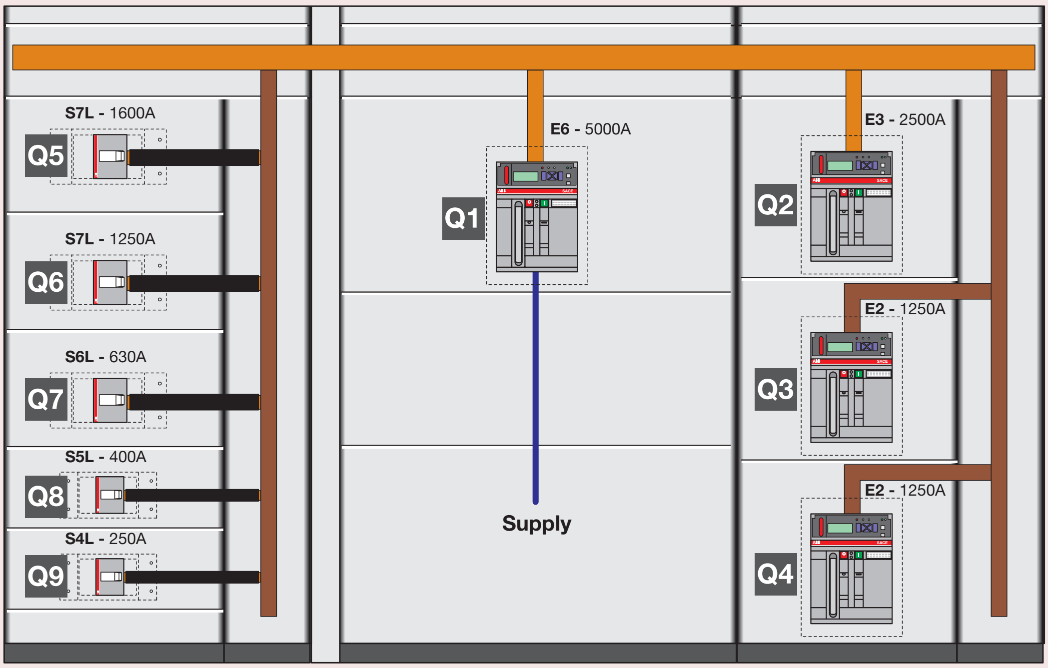
Annex A

Example of electrical switchboards with ABB circuit-breakers

This Annex contains considerations about two different typologies of switchboards with ABB circuit-breakers.

First example

Configuration of the switchboard front



Switchboard characteristics

Switchboard dimensions	Heigth: 2300 mm	Width: 2900 mm	Depth: 1100 mm
Degree of protection IP3X	Form of separation 4B		

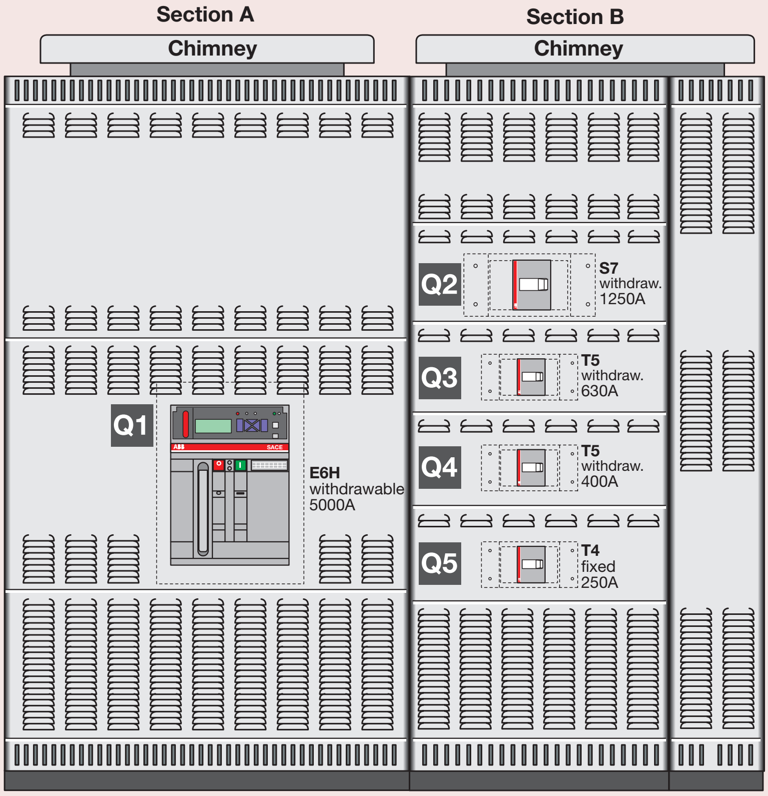
Data table

Circuit	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Circuit-breaker	E6H	E3H	E2L	E2L	S7L	S7L	S6L	S5L	S4L
Rated current In [A]	5000	2500	1250	1250	1600	1250	630	400	250
Rated diversity factor	0.9	0.8	0.9	0.9	0.85	0.85	0.85	0.85	0.85
Test current [A]	4500	2000	1125	1125	1360	1062.5	535.5	340	212.5
Rated short-time current Icw [kA]	100	100	-	-	-	-	-	-	-
Rated peak current Ipk [kA]	220	220	-	-	-	-	-	-	-
Rated conditional short-circuit current Icc [kA]	-	-	100	100	100	100	100	100	100

The table above reports the data concerning the circuit-breakers installed in the switchboard and the relevant effective current carrying capacities obtained by the tests carried out in compliance with IEC 60439-1.
From these results it is evident that, if the switchboard has been designed according to a correct layout and with suitable forms of separation, by positioning the apparatuses properly and with conductors and busbars rated in compliance with cross-sectional areas and minimum length prescribed by the Standard, the current carrying capacities of the circuit-breakers inside the switchboard shall be very near to the rated ones.
From this table it results also how the main distribution circuit (orange trace), which is provided with a non-current-limiting circuit-breaker, shall be rated to withstand the conditioned current for 1 second and its relevant peak; on the other hand, the distribution circuits (brown trace), which are equipped with a current limiting circuit-breaker, shall be dimensioned according to the conditioned short-circuit current: thus, for the section C, the circuit-breakers shall be rated to withstand the peak and specific energy let-through by E2L, whereas, for the section A, they shall be sized according to the peak and specific energy let-through by S7L. Dimensioning carried out in compliance with this criterion is valid only if it can guarantee that the possibility that a fault occurs on the distribution busbar is null. If not, the distribution busbar too shall be dimensioned as the main busbar.

Second example

Configuration of the switchboard front



Switchboard characteristics

Switchboard dimensions	Heigth: 2320 mm	Width: 1800 mm	Depth: 1240 mm
Degree of protection IP30	Form of separation 4		

Data table

Circuit	Q1	Q2	Q3	Q4	Q5
Circuit-breaker	E6H	S7H	T5H	T5H	T4H
Rated current In [A]	5000	1250	630	400	250
Rated diversity factor	1	1	1	1	1
Test current [A]	5000	1250	630	400	250
Rated short-time current Icw [kA]	100	-	-	-	-
Rated peak current Ipk [kA]	220	-	-	-	-
Rated conditional short-circuit current Icc [kA]		100	100	100	100

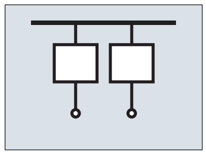
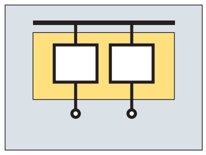
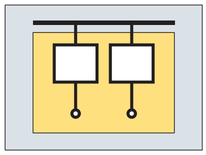
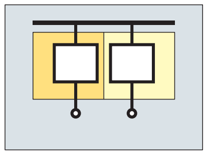
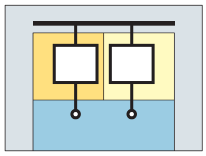
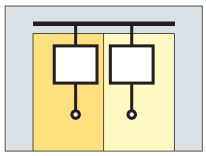
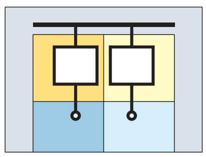
The conductors and busbars used for the realization of the circuits of this switchboard are of bigger cross-sections than those suggested by the Standard. Under these conditions, as it results from an analysis of the data reported in the table, the effective current carrying capacities of the circuits inside the switchboard turn out to coincide with the rated carrying capacities of the circuit-breakers.
The same remarks of the previous case are valid also for the verification of the busbar protection.

Annex B

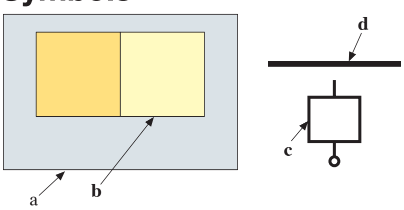
Forms of internal separation

By dividing assemblies by means of barriers or partitions (metallic or non-metallic) into separate compartments or enclosed protected spaces, protection against contact with hazardous live parts belonging to the adjacent functional units and protection against the passage of solid foreign bodies from one unit of the assembly to an adjacent one can be attained.

The following are typical forms of separation by barriers or partitions:

Form 1 No internal separation		
Form 2 Separation of busbars from the functional units	**Form 2a** Terminals for external conductors not separated from busbars	
	Form 2b Terminals for external conductors separated from busbars	
Form 3 Separation of busbars from the functional units and separation of all functional units from one another. Separation of terminals for external conductors from the functional units, but not from those of other functional units	**Form 3a** Terminals for external conductors not separated from busbars	
	Form 3b Terminals for external conductors separated from busbars	
Form 4 Separation of busbars from all functional units and separation of all functional units from one another. Separation of terminals for external conductors associated with a functional unit from those of any other functional unit and the busbars	**Form 4a** Terminals for external conductors in the same compartment as the associated functional unit	
	Form 4b Terminals for external conductors not in the same compartment as the associated functional unit, but in individual, separate, enclosed protected spaces or compartments	

Symbols



Caption
a Enclosure
b Internal separation
c Functional units including terminals for associated external conductors
d Busbars, including distribution busbars

Annex C

Degrees of protection (IP code)

As example, the table below reports the minimum degrees of protection for a switchgear and controlgear assembly to be installed in the specified environments in compliance with the above mentioned Standards.
The degree of protection prescribed for an apparatus against access to hazardous live parts and against ingress of solid foreign objects and liquids is indicated by the Code IP... in accordance with the Std. IEC 60529.

A brief description of the IP Code elements is given hereunder. For full details reference shall be made to the Std. IEC 60529.

Code letters (International Protection)	IP
First characteristic numeral (numerals 0 to 6, or letter X)	Against ingress of solid foreign objects
Second characteristic numeral (numerals 0 to 8, or letter X)	Against ingress of water with harmful effects
Additional letter (optional) (letters A, B, C, D):	Against access to hazardous parts
Supplementary letter (optional) (letters H, M, S, W):	Supplementary information

When a characteristic numeral is not required to be specified, it shall be replaced by the letter “X” (“XX” if both numerals are omitted).

Type of assemblies / Type of environment	Standards and sub-clause	Minimum degree of protection
Switchgear and controlgear assembly: enclosed switchboard	IEC 60439-1 sub-clause 2.3.3	Not defined
Assemblies for outdoor installation	IEC 60439-1 sub-clause 7.2.1.3	IPX3
Assemblies with protection by total insulation	IEC 60439-1 sub-clause 7.4.3.2.2	IP2XC
Installations in normal environments		
Live parts which are not be touched intentionally	IEC 60364-4 sub-clause 412.2.1	IPXXB (IP2X)
Live parts which are readily accessible (horizontal top)	IEC 60364-4 sub-clause 412.2.2	IPXXD (IP4X)
Installations in locations containing a bath tube or shower basin		
Zones 1 and 2	IEC 60364-7 sub-clause 701.512.2	IPX4
Zone 3	IEC 60364-7 sub-clause 701.512.2	IPX1
Zones 1–2–3 public baths where water jets are used for cleaning purposes	IEC 60364-7 sub-clause 701.512.2	IPX5
Installations for swimming-pools		
Zone 0	IEC 60364-7 sub-clause 702.512.2	IPX8
Zone 1	IEC 60364-7 sub-clause 702.512.2	IPX5
Zone 2 for indoor locations	IEC 60364-7 sub-clause 702.512.2	IPX2
Zone 2 for outdoor location	IEC 60364-7 sub-clause 702.512.2	IPX4
Zone 2 where water jets are used for cleaning purposes	IEC 60364-7 sub-clause 702.512.2	IPX5
Installations for rooms and cabins containing sauna heaters	IEC 60364-7 sub-clause 703.512.2	IP24
Assemblies for construction sites (ACS)	IEC 60439-4 sub-clause 7.2.1.1	IP44

Glossary

fn	rated diversity factor
In_c	rated current of the circuit
I2test, I3test....	test current of the circuit "2", test current of the circuit "3", etc.
T_T	absolute temperature [°C]
T_A	air ambient temperature [°C]
ΔT	temperature-rise [K]
LV	low voltage
PTTA	partially type-tested low-voltage switchgear and controlgear assembly
d.c.	direct current
a.c.	alternating current
Ib	full load current
P_{CB}	power loss of the circuit-breaker at Ib
Pn_{CB}	power loss of the circuit-breaker at In_{CB}
In_{CB}	rated current of the circuit-breaker
P_{SB}	power loss of the busbar at Ib
Pn_{SB}	power loss of the busbar at In_{SB}
In_{SB}	busbar rated current
L_{SB}	busbar length
P_{TQ}	total power dissipated inside the switchboard
A_E	effective cooling surface
b	surface factor
A_0	sum of the individual surface areas
d	temperature coefficient
IP	degree of protection
Icw	rated short-time current
I_{pk}	rated peak withstand current
Icc	rated conditional short-circuit current
Ik	prospective short-circuit current
n	peak factor

Due to possible developments of standards as well as of materials, the characteristics and dimensions specified in this document may only be considered binding after confirmation by ABB SACE.

1SDC007103G0201 December '06
Printed in Italy
4.000 - CAL

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