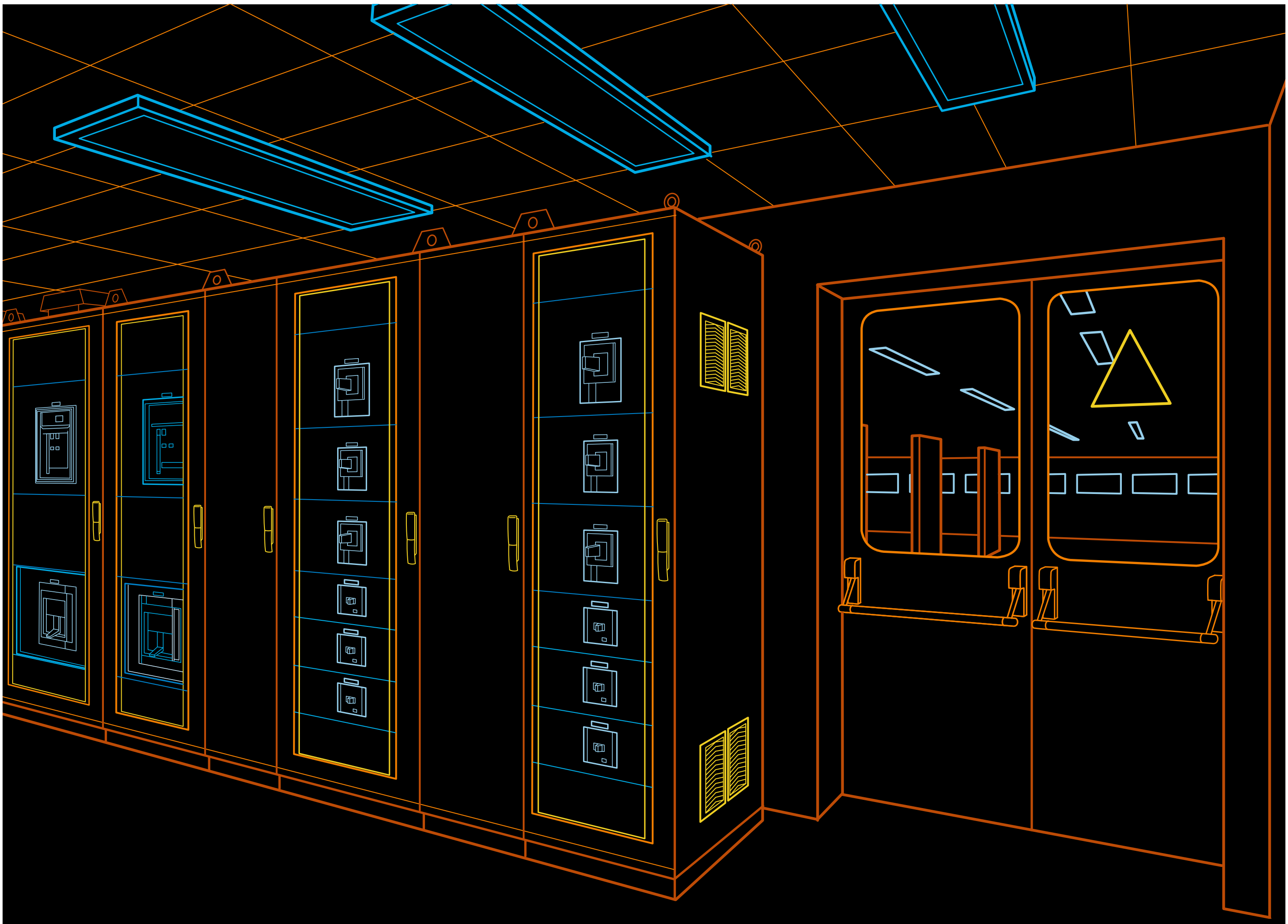

Technical Application Papers No.11
Guidelines to the construction of a low-voltage assembly complying with the Standards IEC 61439 Part 1 and Part 2

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Guidelines to the construction of a low-voltage assembly complying with the Standards IEC 61439 Part 1 and Part 2

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Introduction

An electrical assembly is a combination of more protection and switching devices, grouped together in one or more adjacent cases (columns).
In an assembly the following parts can be distinguished: a case, called enclosure by the Standards, (it has the function of support and mechanical protection of the housed components), and the electrical equipment, formed by the internal connections and by the incoming and outgoing terminals for the connections to the plant.
As all components of an electrical system, also assemblies shall comply with the relevant product standard.

In this regard, there has been an evolution which has resulted in the replacement of the previous Standard IEC 60439 with the present Standard IEC 61439. In particular, at international level, the Standards IEC 61439-1 Edition 2.0 2011-08 and IEC 61439-2 Edition 2.0 2011-08 are in force. These Standards apply to all low voltage switchgear and controlgear assemblies for which the rated voltage does not exceed 1000 V in case of alternating current and 1500 V in case of direct current.

This Technical Application Paper has the purpose of:
1) describing the main innovations and changes introduced in the new Standard as regards structure, definitions and contents (e.g.: methods of verification of assemblies and relevant applicability conditions), with particular attention to the performance verifications as regards: temperature-rise limits, short-circuit withstand strength and dielectric properties;
2) giving a document that includes useful information for the realization and certification of LV assemblies in compliance with the Standards IEC 61439.

This document is divided into seven main parts:
- introduction and description of the new IEC 61439;
- definition of the rated electrical characteristics, of IP and IK degrees and of the forms of internal separation for an assembly;
- standard prescriptions as regards: temperature-rise, short-circuit withstand strength and dielectric properties (clearance or creepage distances);
- prescriptions for the protection against direct and indirect contact;
- instructions for construction, handling, transport and final installation of assemblies;
- properties and performances (design verifications) of assemblies and a guide for the carrying out of routine verifications (assembly type-approval);
- an example of choice of products (circuit-breakers, conductors, distribution system, busbars and structure) for the construction of a System pro *E* power assembly.

1 Standards on low voltage assemblies and applicability

The recent publication of the new Standard IEC 61439 has imposed an evolution and a refinement of the concept of switchgear and controlgear assembly, which has remained actually unchanged since 1990 when the "Factory Assembled Boards" concept was replaced by TTA (Type-Tested Assemblies) and PTTA (Partially-Type-Tested Assemblies) definitions.
The new Standard still considers an assembly as a standard component of the plant, such as a circuit-breaker or a plug-and-socket, although it consists of the assembling of more apparatus, grouped together in one or more adjacent units (columns).
In an assembly the following parts can be distinguished: the case, called enclosure by the Standards, (it has the function of support and mechanical protection of the housed components), and the electrical equipment, formed by the internal connections and by the incoming and outgoing terminals for the connections to the plant). Such system shall be assembled in order to meet the safety requirements and satisfy as much as possible the functions for which it has been designed.

From this point of view, in Italy, the Law 46/90 and now the Ministerial Decree 37/08 oblige manufacturers to undersign a declaration of conformity to the "rule of the art" for each action carried out on a plant excepted for ordinary maintenance. In the mandatory enclosures to this Declaration, in the list of the materials installed or changed, the assembly that has undergone actions is frequently mentioned.
As you know, to comply with the Article 2 of the Italian Law 186 dated 1st March 1968, the equipment and plants realized in compliance with CEI EN Standards are considered in accordance with the "rule of the art". Therefore, as all the components of an electrical plant, also the assembly shall comply with the relevant product Standard. In this regard, at international level, the Standards in force are IEC 61439-1 Edition 2.0 2011-08 and IEC 61439-2 Edition 2.0 2011-08.
These Standards apply to the low voltage assemblies for which the rated voltage does not exceed 1000 V in case of a.c. or 1500 V in case of d.c.).
IEC 61439-1 is the general part for the different types of LV assemblies, whereas the other parts (specific product Standards) which shall be published step by step, refer to specific types of assembly and must be interpreted together with the general rules.

The envisaged parts are the following ones:

- IEC 61439-2: "Power switchgear and controlgear assemblies" (in force; superseding the former IEC 60439-1 as specific product Standard for power assemblies);
- IEC 61439-3: "Distribution boards intended to be operated by ordinary persons (DBO)" (in force; superseding the former IEC 60439-3 concerning ASD);
- IEC 61439-4: "Assemblies for construction sites" (in force; superseding IEC 60439-4 about ASC);
- IEC 61439-5: Assemblies for power distribution in public networks" (in force; superseding the former IEC 60439-5);
- IEC 61439-6: "Busbar trunking systems (busways)" (in force; superseding the former IEC 60439-2);
- IEC TS 61439-7: 2014 "Low-voltage switchgear and controlgear assemblies - Part 7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicles charging stations".

Three other documents published by IEC about swithchgear and controlgear assemblies are still available:

- IEC 60890, which represents a method to determine temperature rise by verification (in particular by calculation). For further details, see Chapter 7 of this Technical Application Paper.
- IEC/TR 61117, which represents a method to determine the short-circuit withstand strength of a busbar structure by comparison with a tested reference design and by calculation.The content of this guide has been integrated in the new Annex P of IEC 61439-1 Edition 2.0 2011-08 "Verification of the short-circuit withstand strength of busbar structures by comparison with a tested reference design by calculation". For deeper analysis, see clause 8.4 of this Technical Application Paper.
- IEC TR 61439-0, which is a support for the specification of the switchgear assemblies according to the installation, environmental and performance requirements, and a great help in using the Standard IEC 61439.

1.1 The Standard IEC 61439-1

As already said, the new set of Standards identified by IEC with code number 61439 consists of the basic Standard 61439-1 and of the specific Standards (product Standards) regarding the particular typology of assembly.
The first Standard (Part 1) deals with rules, definitions, manufacturing and verification prescriptions, technical characteristics and performances which are common to the different types of LV assembly, taken into consideration in the relevant product Standards.
At present, the new IEC 61439 series is structured as follows:

1) IEC 61439-1: "Low voltage switchgear and controlgear assemblies - Part 1: "General rules" (in force);
2) IEC 61439-2: "Power switchgear and controlgear assemblies" (in force);
3) IEC 61439-3: "Distribution boards intended to be operated by ordinary persons (DBO)" (in force);
4) IEC 61439-4: "Assemblies for construction sites" (in force);
5) IEC 61439-5: "Assemblies for power distribution in public networks" (in force);
6) IEC 61439-6: "Busbar trunking systems (busways)" (in force).
7) IEC 61439-7: "Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicles charging stations".

IEC 61439-1 cannot be used alone to specify an assembly or to determine its compliance with the Standard.
As regards the declaration of conformity, each specific type of assembly must be declared in compliance with the relevant product Standard (e.g.: power switchgear and controlgear assemblies shall be declared to comply with IEC 61439-2; distribution boards shall be declared to comply with IEC 61439-3).

The "old" IEC 60439-1 has been superseded by the new IEC 61439-1and 2 for PSC_assemblies (acronym for the English "Power Switchgear Controlgear) and also as normative reference of "general rules" for the part still to be completed.
The new PSC-assemblies are to be declared in compliance with the new IEC 61439-2 only.
The basic Standard establishes the requirements for the construction, safety and maintenance of the assemblies by identifying ratings, service conditions, mechanical and electrical requirements and prescriptions relevant to performances.
The former Standard dated 1990 divided the assemblies into two types, defining them TTA (type-tested assemblies) and PTTA (partially type-tested assemblies), according to their total or partial compliance with the laboratory type tests. The new Standard completely abolishes this dualism and simply replaces it with the concept of "conforming" assembly that is any assembly that complies with the design verifications[1] prescribed by the Standard.
To this purpose the Standard accepts three different but equivalent methods to verify the conformity of an assembly:
1) verification by laboratory testing (formerly called type tests and now called verification tests);
2) verification by comparison with a tested reference design (structured comparison with a proposed design for an assembly, or parts of an assembly, with the reference design verified by test);
3) verification assessment (verification of the design through defined rules, including the use of suitable safety margins, or calculations applied to a sample of an assembly or to parts of assemblies to show that the design meets the requirements of the relevant assembly Standard).

The different characteristics (temperature-rise limits, short-circuit withstand strength, properties of insulating materials, resistance to corrosion etc.) may be verified following one of these three methods; following one way or the other is irrelevant to the purpose of guaranteeing conformity of assemblies.
Since it is not always possible to choose one of these three procedures, Table D.1 "List of design verifications to be performed" in Annex D of the Standard (see Table 1.1) shows for each characteristic to be verified which verification option can be used.

[1] *Design verification is a verification made on a sample of an assembly or on parts of assemblies to show that the design meets the requirements of the relevant assembly Standard.*

Table 1.1

No.	Characteristic to be verified	Clauses or subclauses	Verification options available: Testing	Comparison with a reference design	Assessment
1	Strength of material and parts:	10.2			
	Resistance to corrosion	10.2.2	YES	NO	NO
	Properties of insulating materials:	10.2.3			
	Thermal stability	10.2.3.1	YES	NO	NO
	Resistance to abnormal heat and fire due to internal electric effects	10.2.3.2	YES	NO	YES
	Resistance to ultra-violet (UV) radiation	10.2.4	YES	NO	YES
	Lifting	10.2.5	YES	NO	NO
	Mechanical impact	10.2.6	YES	NO	NO
	Marking	10.2.7	YES	NO	NO
2	Degree of protection of enclosures	10.3	YES	NO	YES
3	Clearances	10.4	YES	NO	NO
4	Creepage distances	10.4	YES	NO	NO
5	Protection against electric shock and integrity of protective circuits:	10.5			
	Effective continuity between the exposed conductive parts of the ASSEMBLY and the protective circuit	10.5.2	YES	NO	NO
	Short-circuit withstand strength of the protective circuit	10.5.3	YES	YES	NO
6	Incorporation of switching devices and components	10.6	NO	NO	YES
7	Internal electrical circuits and connections	10.7	NO	NO	YES
8	Terminals for external conductors	10.8	NO	NO	YES
9	Dielectric properties:	10.9			
	Power-frequency withstand voltage	10.9.2	YES	NO	NO
	Impulse withstand voltage	10.9.3	YES	NO	YES
10	Temperature-rise limits	10.10	YES	YES	YES
11	Short-circuit withstand strength	10.11	YES	YES	NO
12	Electromagnetic compatibility (EMC)	10.12	YES	NO	YES
13	Mechanical operation	10.13	YES	NO	NO

As can be noticed, for some characteristics such as resistance to corrosion or mechanical impact, only laboratory testing is allowed; for other characteristics, such as for example short-circuit withstand strength, testing and comparison with a tested reference design are allowed. Instead, for other characteristics such as temperature-rise, all three verification options are accepted indifferently: testing, comparison with a reference design or assessment.
Another important change in the new Standard is a better specification of the manufacturer. In particular, two roles are defined for the manufacturer: the "original" manufacturer and the "assembly" manufacturer.
The first one is the organization that has carried out the original design, built and verified (through design verifications) the prototype of the assembly (the assembly or the assembly series) in compliance with the relevant product Standard (e.g. IEC 61439-2 for "Power switchgear and controlgear assemblies").
The original manufacturer is essentially the organization that produces the assembly system[2].
It is evident that the higher and more performing the layouts that the original manufacturer is able to "standardize" and then to propose, the greater his chances to have his assemblies constructed and to make good profits.
The second one is the organization that takes the responsibility for the completed assembly and puts its name on the nameplate of the assembly. The assembly manufacturer is who really builds the assembly, that is who gets the different elements and components and assembles them following the instructions of the original manufacturer, thus carrying out the completed assembly, mounted and wired, exploiting one of the design opportunity already mentioned, ready to use, offered by the original manufacturer.
The Standard still accepts that some phases of the fitting out of assemblies are carried out not at the manufacturer's laboratory or workshop (on site or machine board), provided that the instructions of the original manufacturer are complied with.

From an operational point of view, installer and panel builders when considered as end manufacturers can employ, as usual, products sold in kits and included in the catalogues of the original manufacturers, to assemble them according to the arrangement they need.
To summarize, the original manufacturer shall:
- design the assembly or the assembly series;
- perform tests on prototypes;
- pass the tests to demonstrate compliance of the assembly with the Standard (product Standard);
- derive from the tests other configurations by carrying out verification assessment or verification by comparison with a reference design (tested);
- add other configurations obtained without testing but through other verification methods;
- provide technical documentation (e.g.: catalogues or assembling guidelines) with the instructions for the choice of components and assembly.

The list of the design verifications prescribed by the Standard and to be carried out by the original manufacturer (in compliance with Table 1.1 he shall decide how to perform them) comprises:
Verification of the characteristics relevant to construction:
- Strength of materials and of the parts of the assembly;
- Degree of protection of enclosures;
- Clearances and creepage distances;
- Protection against electric shock and integrity of protective circuits;
- Incorporation of switching devices and components;
- Internal electrical circuits and connections;
- Terminals for external conductors.

Verification of the characteristics relevant to performance:
- Dielectric properties;
- Temperature rise;
- Short-circuit withstand capability;
- Electromagnetic compatibility (EMC);
- Mechanical operation.

[2] Assembly system: full range of mechanical and electrical components (enclosures, busbars, functional units, etc.), as defined by the original manufacturer, which can be assembled in accordance with the original manufacturer's instructions in order to produce various assemblies

The assembly manufacturer shall be responsible for:

- constructing the assembly according to the instructions given by the original manufacturer;
- carrying out the routine verifications on each completed assembly;
- drawing up the CE declaration of conformity of the assembly (to be attached and filed with the technical documentation).

The list of the routine verifications (final testing) prescribed by the Standard and to be carried out by the assembly manufacturer comprises:

Characteristics relevant to construction
- Degree of protection of enclosures;
- Clearances and creepage distances;
- Protection against electric shock and integrity of protective circuits;
- Installation of components;
- Internal electrical circuits and connections;
- Terminals for external conductors;
- Mechanical operation.

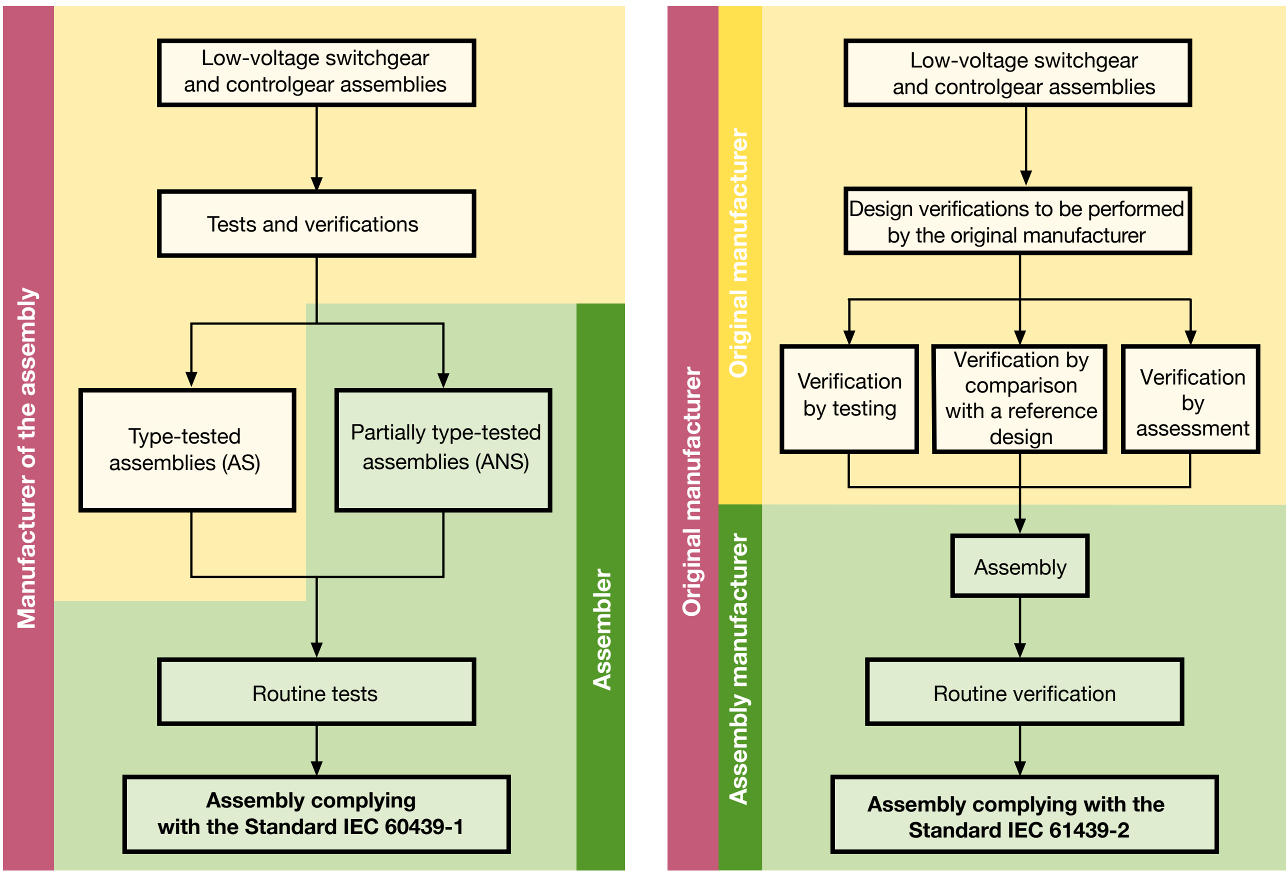
Characteristics relevant to performance:
- Dielectric properties;
- Wiring, operational performance and function

These verifications can be carried out in any sequence. The fact that the routine verifications are carried out by the assembly manufacturer does not exempt the panel builder from verifying them after the transport and erection of the assembly.

The main amendments and changes introduced by the IEC 61439 with respect to the former IEC 60439 can be summarized by the diagrams in Figure 1.1:

Figure 1.1

Standard IEC 60439-1 **Standard IEC 61439-1-2**



2 Rated electrical characteristics of an assembly

Rated voltage (U_n)
Highest nominal value of the a.c. (r.m.s) or d.c. voltage, declared by the assembly manufacturer, to which the main circuit(s) of the assembly is (are) designed to be connected. In three-phase circuits, it is the voltage between phases.

Rated operational voltage (U_e)
it is the rated voltage of a circuit of an assembly which combined with the rated current of this circuit determines its application. For three-phase circuits such voltage corresponds to the voltage between phases.
In an assembly there are usually a main circuit with its own rated voltage and one or more auxiliary circuits with their own rated voltages.
The manufacturer of the assembly shall state the limits of voltage necessary for correct functioning of the circuits inside the assembly.

Rated insulation voltage (U_i)
it is the voltage value of a circuit of an assembly to which test voltages (power frequency withstand voltage) and the creepage distances are referred.
The rated voltage of each circuit shall not exceed its rated insulation voltage.

Rated impulse withstand voltage (U_{imp})
It is the peak value of the impulse of prescribed form and polarity withstood by the main circuit of the assembly under specified testing conditions; clearances are related to the Uimp. This value shall be equal to or higher than the values stated for the transient overvoltages occurring in the system in which the equipment is installed.
In this regard the Standard IEC 61439-1 provides two tables:
- Table G.1 (see Table 2.1) gives the preferred values of rated impulse withstand voltage at the different points of the plant as a function of the nominal voltage of the supply system and of the maximum value of rated operational voltage to earth;
- Table 10 (see Table 2.2) gives the value of the testing voltage appropriate to the impulse withstand voltage as a function of altitudes during test.

Table 2.1

Correspondence between the rated voltage of the supply system and the rated withstand voltage, in case of protection against overvoltages with surge-protective devices complying with the Standard IEC 60099-1

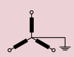
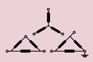
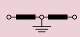
Maximum value of rated operational voltage to earth a.c. (r.m.s. value) or d.c	Nominal voltage of the supply system (≤ rated insulation voltage of the equipment) V				Preferred values of rated withstand voltage (1.2/50 µs) at 2000 m kV			
					Overvoltage category			
V					IV	III	II	I
	a.c. r.m.s. value	a.c. r.m.s. value	a.c. r.m.s. value or d.c	a.c. r.m.s. value or d.c	Origin of installation (service entrance) level	Distribution circuit level	Load (appliance equipment) level	Specially protected level
50	-	-	12.5, 24, 25, 30, 42, 48	-	1.5	0.8	0.5	0.33
100	66/115	66	60	-	2.5	1.5	0.8	0.5
150	120/208 127/220	115, 120 127	110, 120	220-110, 240-120	4	2.5	1.5	0.8
300	220/380 230/400 240/415 260/440 277/480	220, 230 240, 260 277	220	440-220	6	4	2.5	1.5
600	347/600 380/660 400/690 415/720 480/830	347, 380, 400 415, 440, 480 500. 577, 600	480	960-480	8	6	4	2.5
1000	-	660 690, 720 830, 1000	1000	-	12	8	6	4

Table 2.2

Rated impulse withstand voltage U_{imp} kV	Impulse withstand voltages									
	U1,2/50, a.c. peak and d.c. kV					R.m.s. value a.c. kV				
	Sea level	200 m	500 m	1000 m	2000 m	Sea level	200 m	500 m	1000 m	2000 m
2.5	2.95	2.8	2.8	2.7	2.5	2.1	2	2	1.9	1.8
4	4.8	4.8	4.7	4.4	4	3.4	3.4	3.3	3.1	2.8
6	7.3	7.2	7	6.7	6	5.1	5.1	5	4.7	4.2
8	9.8	9.6	9.3	9	8	6.9	6.8	6.6	6.4	5.7
12	14.8	14.5	14	13.3	12	10.5	10.3	9.9	9.4	8.5

Rated current of the assembly (I_{nA})
It is a new characteristic introduced by the Standard IEC 61439 and normally indicates the maximum incoming permanent and allowable load current or the maximum current which an assembly is capable of withstanding. The rated current shall be withstood in any case, provided that the temperature-rise limits stated by the Standard are complied with.

Rated current of a circuit (I_{nC})
It is the current value to be carried out by a circuit without the temperature-rise of the various parts of the assembly exceeding the limits specified according to the testing conditions of Clause 7.

Rated short-time withstand current (I_{cw})
It is the r.m.s. value of short-time current, declared by the assembly manufacturer, that can be withstood by the assembly with no damages under specified conditions defined in terms of current and time. Different values of I_{cw} for different durations (e.g. 0.2 s; 1 s; 3 s) may be assigned to an assembly.

Rated peak withstand current (I_{pk})
it is the peak value of the short-circuit current, declared by the manufacturer of the assembly, which the assembly is capable of withstanding under the specified conditions.

Rated conditional short-circuit current (I_{cc})
it is the r.m.s. 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 specified test conditions.

Rated diversity factor (RDF)
It is the per unit value of the rated current, assigned by the assembly manufacturer, to which the outgoing circuits of an assembly can be continuously and simultaneously loaded taking into account the mutual thermal influences.
The rated diversity factor can be stated:
- for groups of circuits;
- for the whole assembly

The rated diversity factor is: $\frac{\sum Ib}{\sum In}$

The rated diversity factor multiplied by the rated current of the circuits (Inc) shall be equal to or higher than the assumed loading of the outgoing circuits (Ib).
The rated diversity factor is applicable to the outgoing circuits with the assembly operating at rated current InA.
When a rated diversity factor is assigned to the assembly, such value must be used for the temperature-rise test.
In the absence of an agreement between the assembly manufacturer and the user concerning the actual load currents, the assumed loading of the outgoing circuits or group of outgoing circuits may be based on the values of rated diversity factor shown in Table 101 of IEC 61439-2 (see below):

Type of load	Assumed loading factor
Distribution - 2 and 3 circuits	0.9
Distribution - 4 and 5 circuits	0.8
Distribution - 6 to 9 circuits	0.7
Distribution - 10 or more circuits	0.6
Electric actuator	0.2
Motors ≤ 100 kW	0.8
Motors > 100 kW	1.0

Rated frequency
It is the value of frequency to which the operating conditions are referred; ± 2% variations are accepted. Where the circuits of an assembly are designed for different values of frequency, the rated frequency of each circuit shall be given.

3 Classification of assemblies

Assemblies may be classified according to different factors:
by the constructional typology, by the external design, by the installation conditions, by the function carried out.

3.1 Open-type and enclosed assemblies

According to the constructional typology the Standard IEC 61439-1 distinguishes between open-type and enclosed assemblies.

- **Enclosed assembly**
  An assembly is enclosed when there are protected panels on all its sides so as to provide a degree of protection against direct contact not lower than IPXXB (see Chapter 4). Assemblies intended to be installed in common environments shall be of enclosed type.

- **Open-type assembly**
  An assembly, with or without front covering, in which the live parts of the electrical equipment are accessible. Such assemblies can be used only in places where skilled persons have access for their use.

3.2 External design

From the point of view of the external design, assemblies are classified in:

- **Cubicle-type (column)**
  Used for large distribution and control equipment; mechanically joined multi-cubicle-type assemblies are obtained by combining side by side more cubicle-type assemblies.

- **Desk-type**
  Used to control complex machines or plants in mechanical engineering, iron and steel and chemical industries.

- **Box-type**
  Intended to be mounted on a vertical plane, both jutting out as well as built-in; such assemblies are used mainly for department or area distribution in industrial or service sector environments.

- **Multi-box-type**
  A combination of boxes, generally of protected type and with fixing flanges, each housing a functional unit which may be an automatic circuit-breaker, a starter, a socket completed with a blocking or protective circuit-breaker. Thus, a combination of box-compartments is obtained; these are mechanically joined together with or without a common supporting frame; the electrical connections between two adjacent boxes pass through openings in the adjoining faces.

3.3 Installation conditions

According to the conditions of installation, assemblies can be divided into:

- **Assembly for indoor installation**
  Assembly designed for use in locations where the normal service conditions for indoor use as specified in IEC 61439-1 are fulfilled, that is:

Environmental conditions for indoor installation

Table 3.1

Relative humidity	Ambient air temperature	Altitude
50% (at a maximum temperature of 40° C) 90% (at a maximum temperature of 20° C)	Maximum temperature ≤40° C	Not higher than 2000 m
	Maximum temperature average over a period of 24 h ≤35° C	
	Minimum temperature ≥-5° C	

- **Assembly for outdoor installation**
  Assembly designed for use in locations where the normal service conditions for outdoor use as specified in the Standard IEC 61439-1 are fulfilled, that is:

Environmental conditions for outdoor installation

Tabella 3.2

Relative humidity	Ambient air temperature	Altitude
100% temporarily (at the maximum temperature of 25° C))	Maximum temperature ≤40° C	Not higher than 2000 m
	Maximum temperature average over a period of 24 h ≤35° C	
	Minimum temperature ≥-25° C	

- **Stationary assembly**
  Assembly designed to be fixed at its place of installation, for instance to the floor or to a wall, and to be used at that place.

- **Movable assembly**
  Assembly designed so that it can readily be moved from one place of use to another.

3.4 Functional classification

According to the functions for which assemblies are intended for, they can be classified into the following typologies:

- **Primary distribution switchgear assemblies**
  Primary distribution switchgear assemblies, also called Power Centers (PC), are usually installed directly on the load side of MV/LV transformers or generators. These assemblies includes one or more incoming units, bus ties and a relatively limited number of outgoing units.

- **Secondary distribution switchgear assemblies**
  Secondary distribution assemblies include a large category of assemblies intended for power distribution and are usually provided with one incoming unit and many outgoing units.

- **Motor control switchgear assemblies**
  Motor control switchgear assemblies are intended for the control and centralized protection of motors; consequently they include the relevant switching and protection equipment and the auxiliary control and signaling equipment. They are also called Motor Control Centers (MCC).

- **Control, measurement and protection assemblies**
  Control, measurement and protection assemblies usually consist of banks containing mainly equipment intended for the control, switching and measurement of industrial installations and processes.

- **Machine-mounted switchgear assemblies**
  Machine-mounted assemblies are operationally similar to the above mentioned ones; they are intended to allow machine interface with the electric power source and with the operator. Further requirements for assemblies being an integral part of the machine are established by IEC 60204 series.

- **Assemblies for construction sites**
  Assemblies for construction sites have different dimensions, ranging from the simple socket-outlet units to distribution boards in metal enclosure or insulating material.
  These assemblies are usually mobile or however transportable.

4 Degree of protection IP of an assembly

The IP code indicates the degree of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects and ingress of water. The code IP represents the identification system of the degrees of protection in compliance with the prescriptions of IEC 60529.
The Table below shows, in details, the meaning of the different numerals and letters

Figure 4.1

IP 6 5 C H

Code letters	International protection
First characteristic numeral	Numerals 0 to 6, or letter X
Second characteristic numeral	Numerals 0 to 8, or letter X
Additional letter (optional)	Letters A, B, C, D
Supplementary letter (optional)	Letters H, M, S, W

Table 4.1

	Protection of equipment	Against access to hazardous part with
First characteristic numeral (access of solid foreign objects)	**0**	non-protected
	1 ≥ 50 mm diameter	back of hand
	2 ≥ 12.5 mm diameter	finger
	3 ≥ 2.5 mm diameter	tool
	4 ≥ 1 mm diameter	wire
	5 dust-protected	wire
	6 dust-tight	wire
Second characteristic numeral (ingress of water)	**0** non-protected	
	1 vertically dripping	
	2 dripping (15 tilted)	
	3 spraying	
	4 splashing	
	5 jetting	
	6 powerful jetting	
	7 temporary immersion	
	8 continuous immersion	
Additional letter (optional)	**A**	back of hand
	B	finger
	C	tool
	D	wire
Supplementary letter (optional)	**H** High-voltage apparatus	
	M Motion during water test	
	S Stationary during water test	
	W Weather conditions	

The additional letter indicates the degree of protection of persons against access to hazardous parts.
The additional letters are used only:
- if the actual protection against access to hazardous parts is higher than that indicated by the first characteristic numeral;
- or, if only the protection against access to hazardous parts is indicated, the first characteristic numeral shall be replaced by the letter X.

For example, this higher protection could be provided by barriers, openings of suitable shape or distances inside the enclosure.
The degree of protection shall be verified in compliance with IEC 60529. The test can be performed on a representative assembly equipped under conditions stated by the original manufacturer.
The tests on the degree of protection IP shall be carried out:
- with all the lids, covers and doors properly positioned and closed as in the ordinary use;
- without live parts (no voltage), unless otherwise specified by the original manufacturer.

When an empty enclosure is used in compliance with the Standard IEC 62208, a verification by assessment must be carried out to make sure that no external modification may have caused a decrease in the degree of protection. In this case, no additional test is required. Practically, if the enclosure already complies with the IEC 62208, it is not necessary to perform further constructional verifications provided that no significant modifications have been carried out on the enclosure.

4.1 Degree of protection IP in ABB assemblies

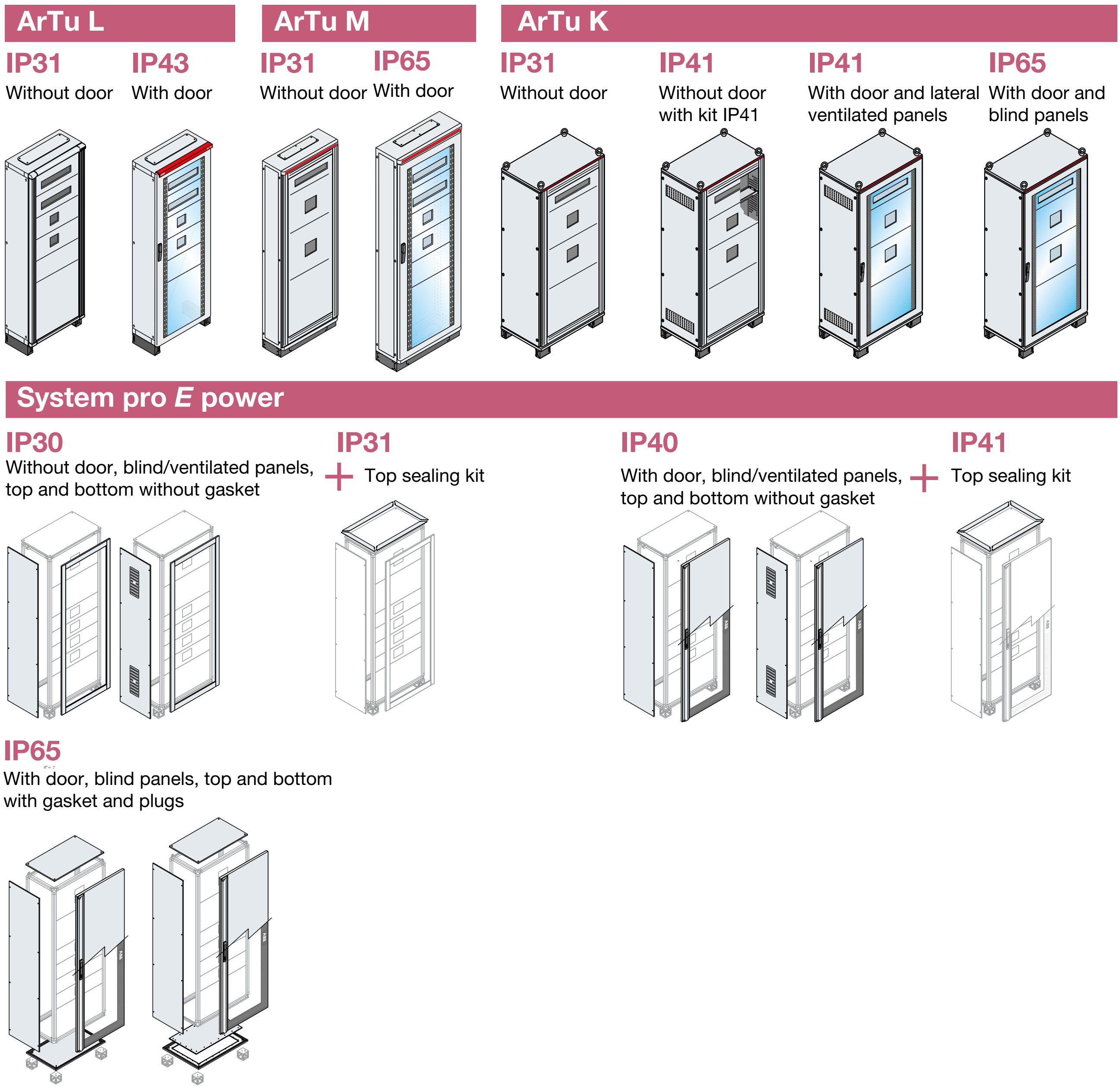
As regards assemblies, when not otherwise specified by the manufacturer, the degree of protection is valid for the whole assembly, mounted and installed as in ordinary use (with closed door).
The manufacturer can also indicate the degrees of protection relevant to special configurations that may be present in service, such as the degree of protection with doors open and the one with apparatus removed or racked out.

For the assemblies intended for indoor installation, in environments where no risk of ingress of water exists, the Standard requires at least the following degrees of protection: IP 00, IP 2X, IP 3X, IP 4X, IP 5X, IP 6X.

As regards the enclosed assemblies, the degree of protection IP must be ≥2X after the installation, in compliance with the instructions given by the assembly manufacturer. The IP degree for the front and the rear part must be at least equal to IP XXB.
As regards the assemblies intended for outdoor installation and without additional protection (for example a shed), the second of the characteristic numeral of the code IP shall be at least equal to 3.

Hereunder are the degrees of protection that can be obtained with ABB SACE ArTu and System pro *E* power assemblies.

Figure 4.2



4.2 Degree of protection IP and installation environment

At present there are no Standards that correlate the degree of protection IP with the installation environment of assemblies, except for special environments with explosion risk (CEI 64-2).

As an indication, the following table derived from the Guide UTE C 15-103 shows the relation between the environments and the degrees of protection of ABB SACE assemblies ArTu and System pro *E* power.

It should be kept in mind that ArTu and System pro *E* power assemblies manufactured by ABB SACE are for indoor installation.

Table 4.2

Industrial factories	IP30	IP31	IP40	IP65
accumulators (fabrication)			•	
acids (fabrication and storage)			•	
alcoholic liquids (storage)	•			
alcohol (fabrication and storage)			•	
aluminum (fabrication and storage)				•
animals (breeding)				•
asphalt bitumen (storage)				•
breweries	•			
lime (furnaces)				•
coal (warehouses)				•
fuels (fabrication and storage)				•
paper (storage)		•		
paper (fabrication)			•	
paper (preparation of paste)			•	
cardboard (fabrication)			•	
bottling lines			•	
tar (treatment)			•	
quarries				•
cellulose (fabrication of objects)	•			
cellulose (fabrication)			•	
cement works				•
chlorine (fabrication and storage)			•	
coking plants				•
glues (fabrication)			•	
combustible liquids (stores)		•		
tanneries			•	
fertilizers (fabrication and storage)				•
chromium plating (factories for)			•	
pickling				•
detergents (fabrication)				•
distilleries			•	
electrolysis	•			
explosives (fabrication and storage)				•
joineries				•
ironmongery (fabrication)	•			
iron (fabrication and treatment)				•
spinning mills				•
cheese factories	•			
gas (factories and storage)		•		
gypsum (fabrication and storage)				•
foam rubber (fabrication, transformation)	•			
cereals (factories and storage)				•
fats (treatment of fatty bodies)				•
hydrocarbons (extraction)			•	
inks (fabrication)	•			

Industrial factories	IP30	IP31	IP40	IP65
metal engraving			•	
wool (carding of)				•
dairies	•			
laundries	•			
public wash-houses	•			
wood (working of)				•
halogen liquids (use)	•			
flammable liquids (storage and use)	•			
spirits (fabrication)	•			
machines (machine rooms)		•		
butchers	•			
magnesium (fabrication, processing, and storage)		•		
plastic materials (fabrication)				•
slaughter houses				•
bricks (factory for)				•
metals (treatment for metals)		•		
thermal motors (tests)	•			
ammunition (deposits)			•	
nickel (treatment of the minerals)			•	
oil (extraction)		•		
leather (fabrication and storage)		•		
furs (scutching)				•
paint (fabrication and storage)			•	
powder factory				•
chemicals (fabrication)	•			
perfumes (fabrication and storage)		•		
oil refineries			•	
copper (treatment of the minerals)		•		
rubbish (treatment)				•
welding				•
cured meat factories	•			
soap (fabrication)		•		
sawmills				•
silk and hair (preparation)				•
grain or sugar silos				•
soda (fabrication and storage)			•	
fabrics (fabrication)				•
dyeing factories	•			
printing works	•			
paints (fabrication and use)			•	
clothes (deposits)	•			
glassworks			•	
zinc (zinc processing)		•		
sulphur (treatment)				•
sugar refineries				•

4.3 Degree of protection IP and temperature-rise

The degree of protection of an assembly affects the capacity of dissipating heat: the higher the degree of protection is, the less the assembly manages to dissipate heat. For this reason, it is advisable to use a degree of protection suitable for the installation environment.
For example, by using an assembly series System pro *E* power with door and back panel without gaskets and ventilated side panels, a degree of protection equal to IP40 is guaranteed, whereas when blind door, blind rear and blind side panels are used the degree becomes IP65.

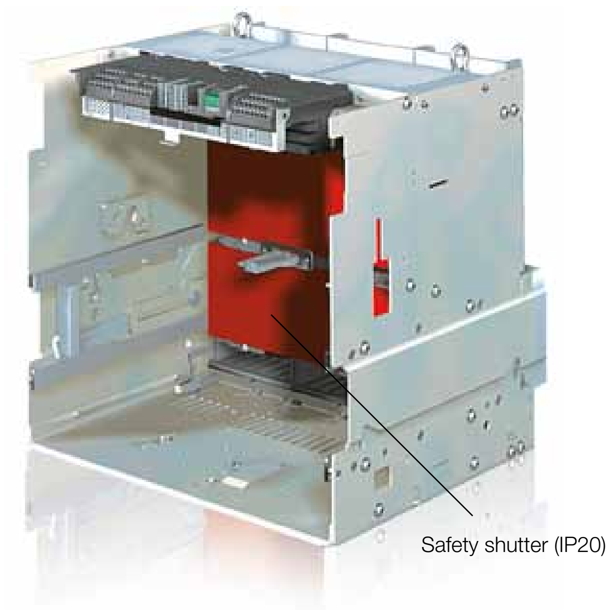
Both assemblies guarantee the inaccessibility to the circuit-breakers through the front door; however, the assembly with ventilated side panels guarantees better ventilation than the assembly with blind side panels. As a consequence, it is preferable to use the former where the installation environment allows it.

4.4 Degree of protection IP of removable parts

The removal of movable parts in an installed assembly can be carried out in two different situations:
1) the withdrawal of the removable part of a component (e.g.: withdrawable circuit-breaker, withdrawable switch-disconnector, fuse holders) for fixing, control or maintenance;
2) the removal of a fixed part, such as flanges, panels, covers or base strips, to carry out electric works, such as the realization of new incoming or outgoing lines or the replacement of existing cables.
In the first case, the same degree IP as before the removal shall be maintained, which generally is IP2X; the safety shutters, positioned on the fixed part of withdrawable air circuit-breakers, allow to comply with this specification (see Figure 4.3). If the degree IP were higher (e.g.: IP44, IP55 or other), the movable part would be inside the enclosure which, once reclosed, should restore such condition.

In the case of electrical works, if after the removal of a fixed part by using a tool the original degree of protection were not maintained, suitable measures - as prescribed by EN 50110-1 and the relevant national Standards - shall be taken in order to guarantee an adequate safety level for the operators.

Figure 4.3



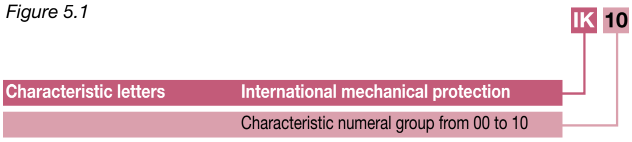
5 Degree of protection IK of enclosures

The degree of protection IK indicates the protection level provided by the enclosure of the assembly against harmful mechanical impacts and it is verified when required by the relevant Standard of assemblies through tests to be performed in compliance with IEC 62262.

The code IK is the coding system indicating the degree of protection against harmful mechanical impacts provided by an enclosure in compliance with the prescriptions of the Standard IEC 62262 dated 2008.

The degree of protection of the enclosure against impacts is indicated by the code IK as follows:

Figure 5.1



Each characteristic numerical group represents an impact energy value as shown in the table 5.1.

Usually the degree of protection is applied to the whole enclosure. If parts of the enclosure have different degrees of protection, these shall be indicated separately.

It is not mandatory to define and declare the degree of protection IK for power assemblies. When carrying out mechanical impact tests on power assemblies, clause 9.6 of the IEC 62208:2002 must be complied with.

5.1 Degree of protection IK of ArTu and System pro *E* power assemblies

As regards ArTu and System pro *E* power assemblies, the degree of protection IK is valid for the whole assembly, mounted and installed as in ordinary use (with door closed).
The degrees of protection against external mechanical impacts (IK code) of ArTu and System pro *E* power series are given below.

Figure 5.2

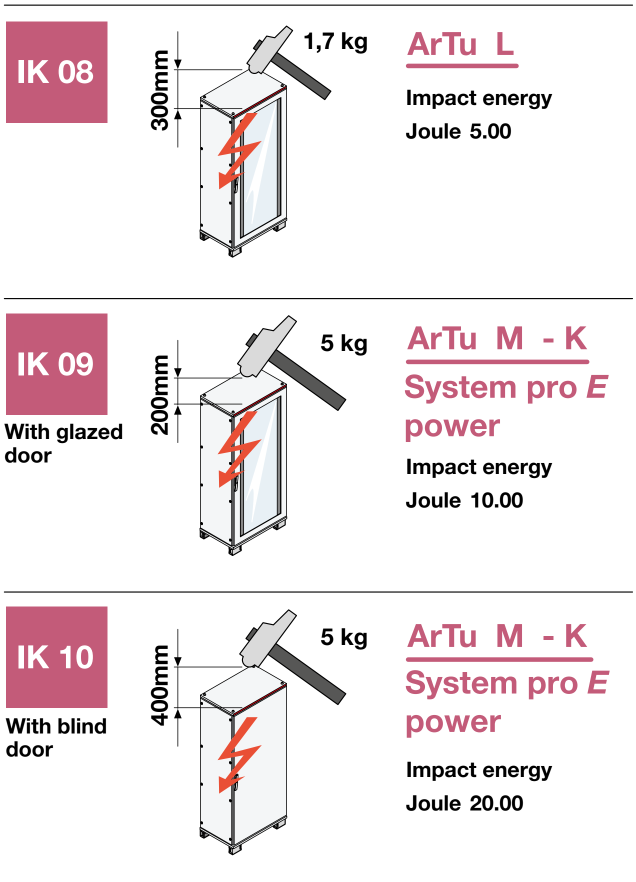


Table 5.1

Relationship between the degree of protection IK and the impact energy

IK code	IK00	IK01	IK02	IK03	IK04	IK05	IK06	IK07	IK08	IK09	IK10
Impact Energy in joule	(*)	0.14	0.2	0.35	0.5	0.7	1	2	5	10	20

(*) Not protected according to the Standard

6 Forms of internal separations

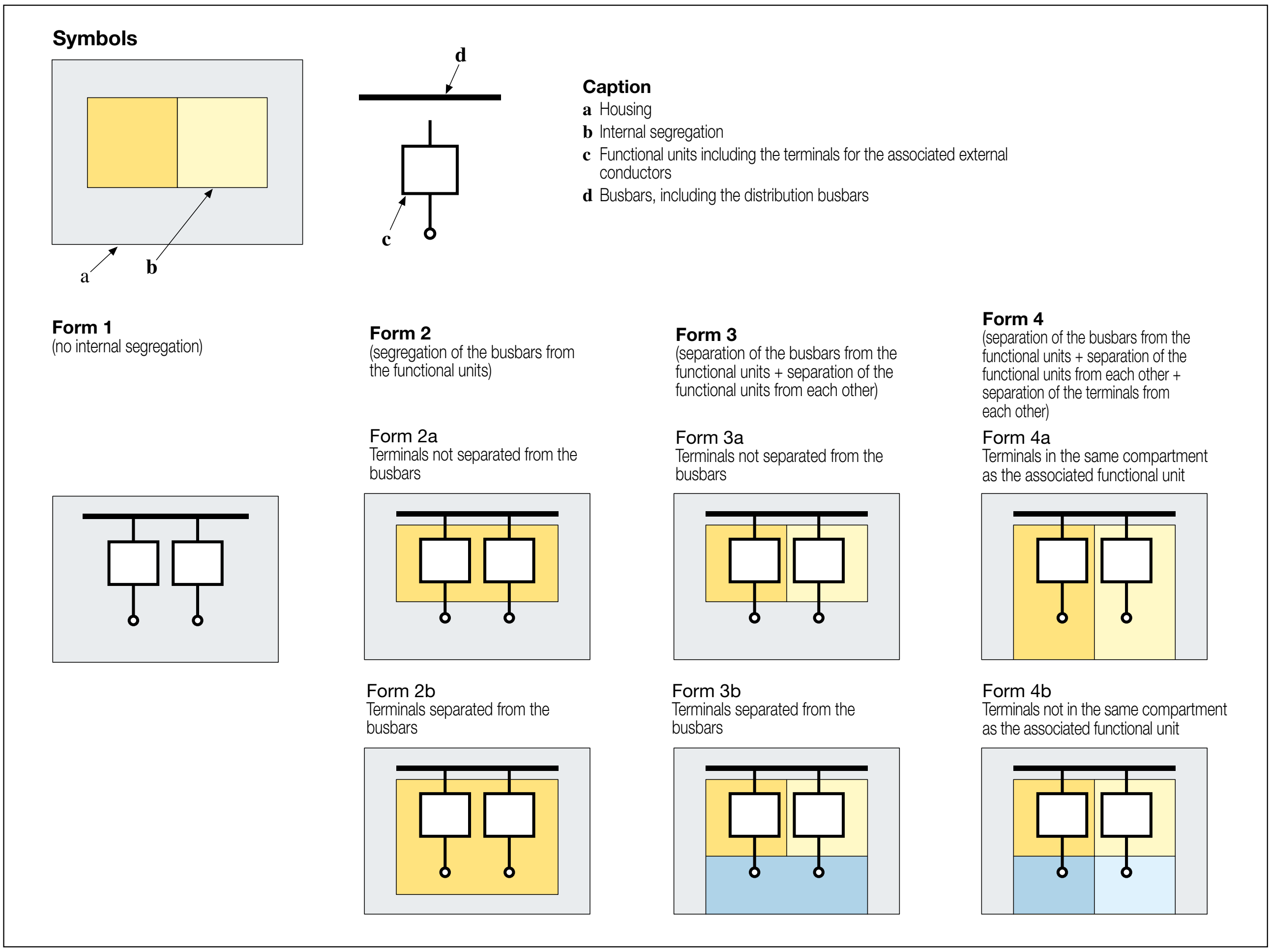
By form of separation the type of subdivision provided inside the assembly is intended.
Separation by means of barriers or partitions (metallic or non metallic materials) is aimed at:

- ensuring protection against direct contact (at least IPXXB), in case of access to a part of the assembly cut off from the power supply, as to the rest of the assembly still supplied;
- reducing the probability of striking and propagation of an internal arc;
- preventing the passage of solid foreign bodies between different parts of the assembly (at least degree of protection IP2X).

By partition, the separating element between two compartments is intended, whereas the barrier protects the operator from direct contacts and from the effects of the arc of the breakers in the normal access direction.

The following table given in IEC 61439-2 highlights the typical separation forms that can be obtained by using barriers or partitions:

Table 6.1



By means of a suitable kit, ABB SACE switchgear assemblies can realize the following forms of separation:

Form 1: no internal separation with ArTu and System pro *E* power series
Form 2: covers form 2a, of the Standard with ArTu and System pro *E* power series and form 2b of the Standard with System pro *E* power series
Form 3: covers form 3a and 3b of the Standard with ArTu and System pro *E* power series
Form 4: covers form 4b of the Standard with ArTu and System pro *E* power series

7 Verification of the temperature-rise limits inside assemblies

7.1 Introduction

The verification of the temperature-rise limits imposed by the Standard IEC 61439-1 can be carried out according to one or more of the following methods:

- tests with current (at laboratory);
- derivation of ratings from a tested design/assembly for similar variants/ assemblies;
- calculation for single-compartment assemblies with rated current not higher than 630 A or for assemblies with rated current not exceeding 1600 A.

The Standard IEC 61439-1 imposes the compliance of the same temperature-rise limits as the former version; the limits must not be exceeded during the temperature-rise test. These temperature-rise limits apply for a mean ambient air temperature up to 35°C.

The temperature rise of an element or part is the difference between the temperature of this element or part and the mean ambient air temperature outside the assembly. For example, if the mean ambient air temperature is higher than 35°C, then the temperature-rise limits have to be adapted for this special service condition so that the sum of the ambient temperature and of the individual temperature-rise limit (of an element or a part) remains the same[3].

If the mean ambient air temperature is lower than 35 °C the same adaptation of the temperature-rise limits is allowed subject to agreement between the user and the assembly manufacturer.

Table 7.1 shows the parts of assemblies and the temperature-rise limits given by the Standard.

[3] If the temperature-rise limits have been changed to cover a different ambient temperature, then the rated current of all busbars, functional units etc. may need to be changed accordingly. The original manufacturer should state the measures to be taken, if any, to ensure compliance with the temperature limits. For ambient temperatures up to 50 °C this can be done by calculation, assuming that the over temperature of each component or device is proportional to the power loss generated in this component. There are devices (e.g.: low voltage moulded-case and air circuit-breakers) where the power loss is substantially proportional to I^2 and others that have substantially fixed losses.

Table 7.1

Parts of assemblies	Temperature-rise K
Built-in components [a]	[(*)] In accordance with the relevant product standard requirements for the individual components or, in accordance with the component manufacturer's instructions [f], taking into consideration the temperature in the ASSEMBLY
Terminals for external insulated conductors	70 [b]
Busbars and conductors	Limited by [f]: – mechanical strength of conducting material [g]; – possible effect on adjacent equipment; – permissible temperature limit of the insulating materials in contact with the conductor; – 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
Manual operating means:	
- of metal	15 [c]
- of insulating materials	25 [c]
Accessible external enclosures and covers:	
- metal surfaces	30 [d]
- insulating surfaces	40 [d]
Discrete arrangements of plug and socket-type connections	Determined by the limit for those components of the related equipment of which they form part [e]

NOTE 1 The 105 K relates to the temperature above which annealing of copper is likely to occur. Other materials may have a different maximum temperature rise.

NOTE 2 The temperature rise limits given in this table apply for a mean ambient air temperature up to 35 °C under service conditions (see 7.1). During verification a different ambient air temperature is permissible (see 10.10.2.3.4).

a The term "built-in components" means:
– conventional switchgear and controlgear;
– electronic sub-assemblies (e.g. rectifier bridge, printed circuit);
– parts of the equipment (e.g. regulator, stabilized power supply unit, operational amplifier).

b The temperature-rise limit of 70 K is a value based on the conventional test of 10.10. 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. Where the terminals of the built-in component are also the terminals for external insulated conductors, the lower of the corresponding temperature-rise limits shall be applied. The temperature rise limit is the lower of the maximum temperature rise specified by the component manufacturer and 70 K. In the absence of manufacturer's instructions it is the limit specified by the built-in component product standard but not exceeding 70 K.

c Manual operating means within ASSEMBLIES which are only accessible after the ASSEMBLY has been opened, for example draw-out handles which are operated infrequently, are allowed to assume a 25 K increase on these temperature-rise limits.

d Unless otherwise specified, in the case of covers and enclosures, which are accessible but need not be touched during normal operation, a 10 K increase on these temperature-rise limits is permissible. External surfaces and parts over 2 m from the base of the ASSEMBLY are considered inaccessible.

e This allows a degree of flexibility in respect of equipment (e.g. electronic devices) which is subject to temperature-rise limits different from those normally associated with switchgear and controlgear.

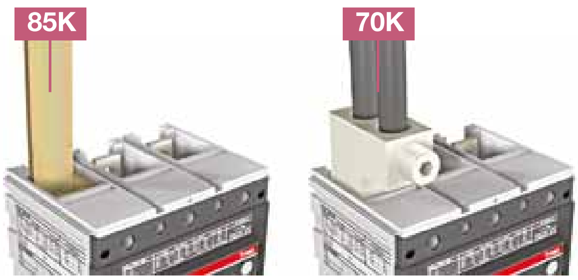
f For temperature-rise tests according to 10.10, the temperature-rise limits have to be specified by the original manufacturer taking into account any additional measuring points and limits imposed by the component manufacturer

g Assuming all other criteria listed are met a maximum temperature rise of 105 K for bare copper busbars and conductors shall not be exceeded.

(*) As far as circuit-breakers inside assemblies are concerned, the temperature-rise limits are the following ones:
- 70 K if an insulated conductor is connected to the terminal;
- 85 K for the terminals of ABB circuit-breakers, if they are not directly connected to insulated conductors (the temperature-rise 85 K is always referred to an ambient temperature outside the assembly of 35°C).

Figure 7.1

Connection with busbar — **Connection with PVC-insulated cable**



7.2 Thermal verification of the assembly

The purpose of this document is to provide a support permitting the verification of the temperature-rise inside the assemblies according to the criteria in compliance with the IEC 61439-1/2.
Verification shall be made by one or more of the following methods[4]:

1) Verification tests[5] (formerly defined type tests) in which the two following situations are verified:
- each type of circuit, loaded alone, is capable of carrying its rated current (when it is incorporated in the assembly);
- when subject to the maximum current (rated current) of the incoming circuit, the outgoing circuits (any possible combination) can be simultaneously and continuously loaded to their rated current multiplied by the rated diversity factor for the assembly.

For example, take the verification of the completed assembly (in accordance with clause 10.10.2.3.5 of the IEC 61439-1) prescribing to load the outgoing and incoming circuits of the assembly to their rated current and to consider a rated diversity factor equal to 1. This method is a rapid and conservative approach to verify particular configurations of the assembly.
For example, take into consideration an assembly with a rated current of the incoming circuit (InA) insufficient to supply simultaneously all the outgoing circuits (consisting of different functional units) loaded to their rated current; in such case, two or more tests shall be necessary to verify at their rated current all the outgoing circuits, which will be divided into two or more groups.
In each test, the incoming circuit and the busbars are loaded to their rated current and as many outgoing circuits in a group are loaded to their rated current as necessary to distribute the incoming current.
In each test, for each group, the most severe combination of currents, which causes the highest possible temperature-rise inside the assembly, shall be verified in the outgoing circuits.
The assembly (prototype) is subject to the temperature-rise test with mean air ambient temperature ≤ 35°C.
Once the temperature has stabilized (when the variation of temperature at all measured points does not exceed 1K/h), the constant temperature-rise values are measured at defined points in the assembly (see Table 7.1); then these values are compared with the admissible ones (shown in Table 7.1).
When the measured values are lower than or equal to the admissible ones, the test is considered as passed for those currents, that rated diversity factor and under those defined conditions (ambient temperature, humidity, etc.) around the assembly.
When the temperature rise verification is carried out through tests, the choice of the conductors to be used inside the assembly and of their cross-sectional area is the original manufacturer's responsibility.
The tests performed at 50Hz, are valid also at 60Hz up to 800 A currents. When such value is exceeded, the currents must be reduced by 5%. As an alternative, no derating factor must be applied to currents for service at 60Hz, if the test at 50Hz gives temperature rise values not exceeding 90% of the admissible ones.

2) Derivation of ratings from a tested design/assembly for similar variants/assemblies.
This procedure allows an assembly obtained by derivation from similar tested assemblies to be verified.
An assembly which derives from a similar one already tested for temperature-rise is verified without further testing, when the following conditions are fulfilled:
- the functional units shall belong to the same group of the functional units tested (e.g.: same function and same basic wiring diagram of the main circuit; same rated values; devices of the same size; same physical arrangement of the devices; same type of mounting structure; same type and arrangement of conductors; conductors of the same cross sectional area as the tested ones);
- the two assemblies shall have the same type of construction (the same manufacturer);
- the overall dimensions of the assembly to be verified shall be the same or increased as used for the test;
- the cooling conditions of the assembly to be verified shall be the same or increased as those of the tested one (forced or natural convection, same or larger ventilation openings);
- the internal separation of the assembly to be verified shall be the same or reduced as the tested one;
- the power loss inside the assembly to be verified is the same as or lower than that of the tested assembly.

3) Verification by assessment.
The Standard IEC 61439-1 provides two calculation methods to determine the approximate air temperature rise inside the enclosure caused by the power loss of all the circuits and of the internal components and compare this temperature with the limits for the operation (functioning) of the installed equipment.
These methods are:

[4] *For further details see clause 10.10 and Annex O of the IEC 61439-1: Edition 2.0 2011-08.*
[5] *For further details see clause 10.10.2 and O.3 (Annex O) of the IEC 61439-1: Edition 2.0 2011-08.*

[6] *The assembly consists of a single compartment without horizontal partitions, that is the single cell coincides with the assembly compartment.*

a) calculation of the power losses for single-compartment[6] assemblies with InA ≤ 630 A and f ≤ 60 Hz.
This procedure is used to verify that the power loss inside the compartment, dissipated by the built-in components and by the conductors, is lower than the power dissipated by the enclosure.
This method can be applied if all the following conditions are fulfilled:
- the power loss data for each built-in components is made available from the component manufacturer;
- there is an approximately even distribution of power losses inside the enclosure;
- the rated current of the circuits of the assembly (Inc) to be verified shall not exceed 80% of the rated conventional free air thermal current (Ith), if any, or the rated current (In) of the switching devices and electrical components installed in the circuit[7];
- the mechanical parts and the installed equipment are so arranged that air circulation is not significantly impeded;
- the conductors carrying a current exceeding 200 A and the adjacent structural parts are so arranged that the eddy currents and hysteresis losses are minimized;
- all conductors shall have a minimum cross-sectional area based on 125% of the permitted current rating of the associated circuit. Selection of cables shall be in accordance with IEC 60364-5-52[8]. The cross-section of bars shall be as tested or as given in Annex N of IEC 61439-1 Edition 2.0 2011-08. Where the device manufacturer specifies a conductor with a larger cross-sectional area this shall be used;
- the temperature-rise depending on the power loss in the enclosure for the different installation methods (e.g.: wall- or floor-mounted assembly) is given either by the enclosure manufacturer or is determined as follows:
Heating inside the empty assembly is simulated by means of heating resistors installed inside the enclosure. Once a constant temperature has been reached, the air temperature-rise shall be measured in the top part of the enclosure and after verifying that the temperature-rise of the external surfaces of the enclosure does not exceed the fixed values (see Table 7.1), the maximum power loss capability of the enclosure is determined.

b) calculation algorithm of IEC 60890 for assemblies with InA ≤ 1600 A and f ≤ 60 Hz.
In this case, algebraic calculation procedures are carried out without using experimental data.

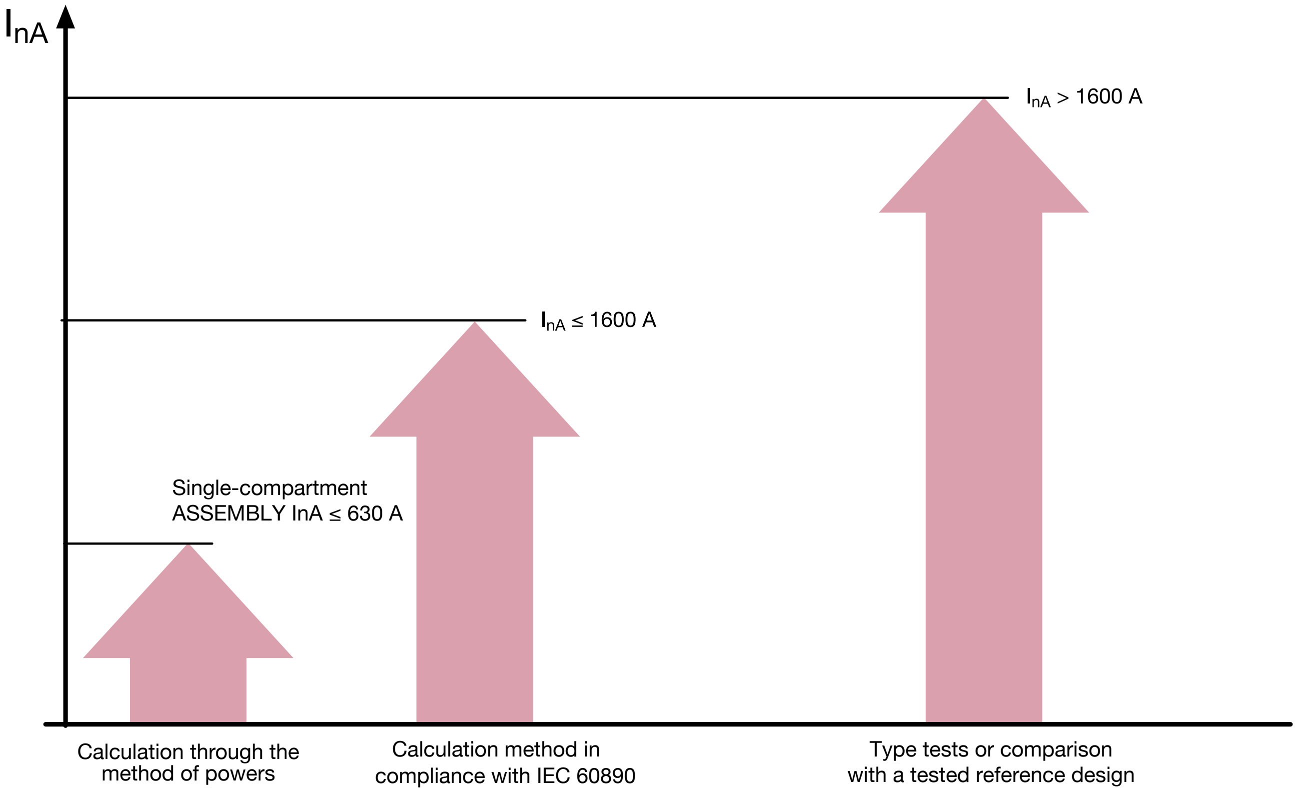
This method is based on the calculation of the air temperature-rise inside the enclosure in accordance with the procedure prescribed by the Standard IEC 60890.
It is a calculation procedure that leads to the tracing, from bottom to top, of the thermal map of the assembly under steady state conditions, according to temperature values on linear growth reaching their maximum values at the top of the enclosure. Thus, through the total power loss, it is possible to assess the temperature rise inside the assembly at different heights, from bottom to top.
According to the Standard IEC 61439-1, this calculation method is applicable only if the following conditions are satisfied:

- the power loss for all built-in components is stated by the component manufacturer;
- there is an approximately even distribution of power losses inside the enclosure;
- the rated current of the circuits of the assembly (Inc) to be verified shall not exceed 80 % of the rated conventional free air thermal current (Ith), if any, or the rated current (In) of the switching devices and of the electrical components included in the circuit[9];
- the mechanical parts and the installed equipment are so arranged that air circulation is not significantly impeded;
- the conductors carrying a current exceeding 200 A and the adjacent structural parts are so arranged that the eddy currents and hysteresis losses are minimized;
- all conductors shall have a minimum cross-sectional area based on 125% of the permitted current rating of the associated circuit. Selection of cables shall be in accordance with IEC 60364-5-52[10]. The cross-section of bars shall be as tested or as given in Annex N of IEC 61439-1 Edition 2.0 2011-08. Where the device manufacturer specifies a conductor with a larger cross-sectional area this shall be used;
- for enclosures with natural ventilation, 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 a section of an assembly;
- for enclosures with compartments and natural ventilation the cross-section of the ventilating openings in each horizontal partition is at least 50% of the horizontal cross section of the compartment.

[7] With moulded-case circuit-breakers Tmax T and SACE Tmax XT and air circuit-breakers series Emax and Emax X1 it must be: Inc ≤ 80%In.
[8] See Annex H of IEC 61439-1 (Edition 2.0 2011-08) for:
-some examples of how you can correlate the Standard with the conditions inside the enclosure
-the relationship between the operating current of copper conductors and the power loss under ideal conditions inside the enclosure.

[9] With moulded-case circuit-breakers Tmax T and SACE Tmax XT and air circuit-breakers series Emax and Emax X1 it must be: Inc ≤ 80%In.
[10] See Annex H of IEC 61439-1 (Edition 2.0 2011-08) for:
-some examples of how you can correlate the Standard with the conditions inside the enclosure
-the relationship between the operating current of copper conductors and the power loss under ideal conditions inside the enclosure.

Figure 7.2



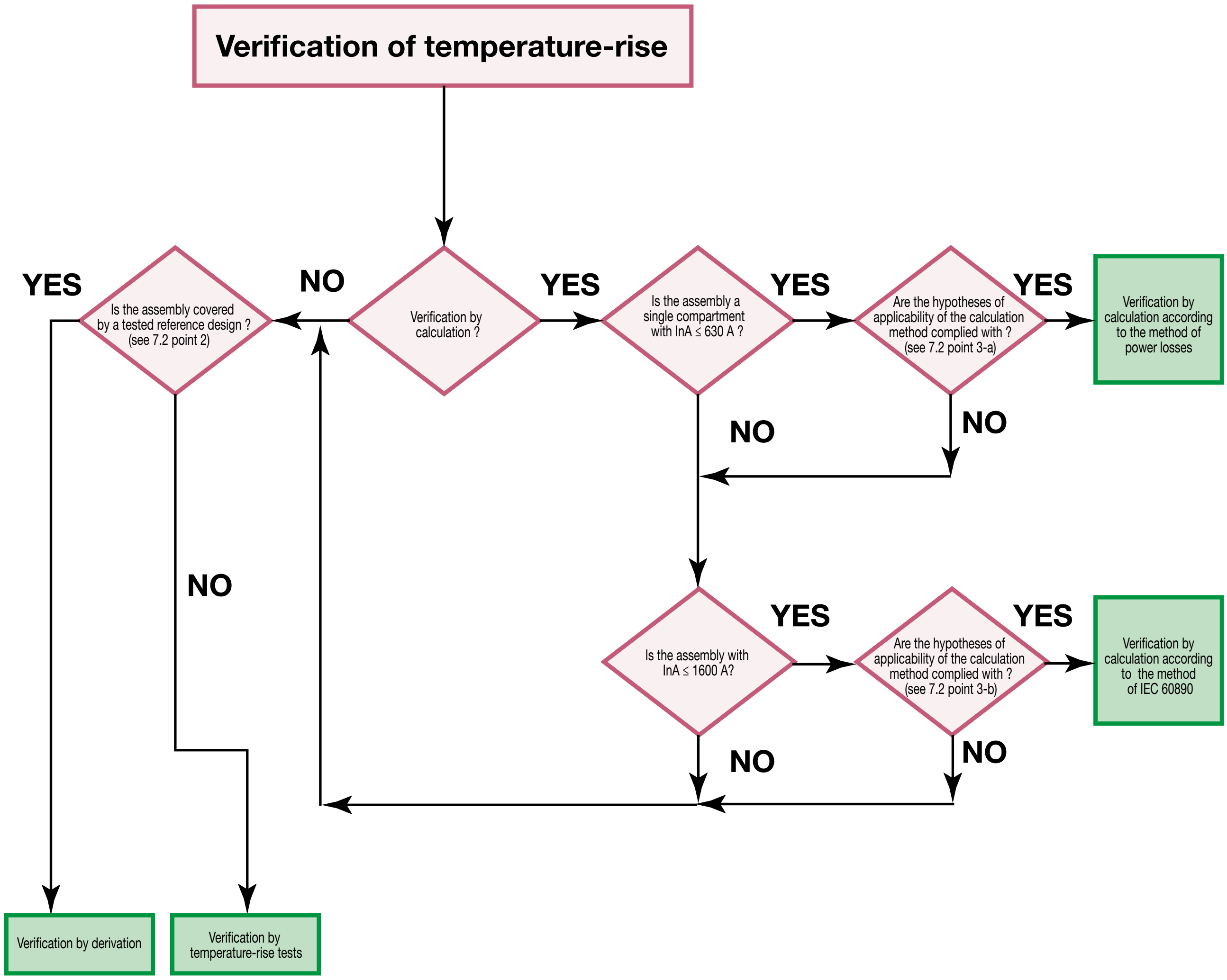
By using calculation methods, it is possible to verify the compliance with the temperature-rise limits of:

- single-compartment assemblies with rated currents not exceeding 630 A, by power method
- assemblies with rated current not exceeding 1600A, through the IEC TR 60890.

Verification of the temperature-rise can be carried out through type test or by comparison with a tested reference design, with no limits as regards the rated current of the assembly.

The choice of the calculation method for the verification of the temperature-rise, as an alternative to heat test or to verification by derivation, can be summarized through the following flow chart:

Figure 7.3



7.3 Calculation of the temperature rises in compliance with the Standard IEC TR 60890

Figure 7.4 shows the different methods of installation taken into consideration in IEC TR 60890.

Calculation of the powers generated by the different components and dissipated inside the assembly
The calculation of the power losses reported in the configurations shown is carried out by taking into account the effective powers dissipated by the different components.

Circuit-breakers

Given the power losses at the rated current (In) shown in the following tables and the current that actually flows through the circuit-breakers (Ib), it is possible to calculate the effective power losses of the equipment:

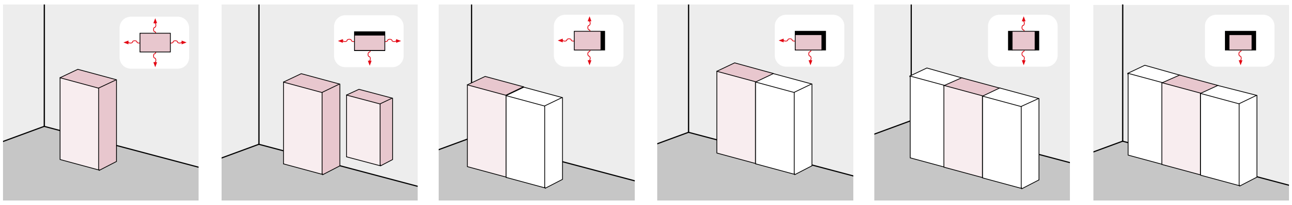
$$P(I_b) = P(I_n)\left(\frac{I_b}{I_n}\right)^2$$

The values thus obtained must be increased by a factor depending on the circuit-breaker type.
This coefficient is used to take into account the connections that carry the current to the circuit-breakers.

Table 7.2

Type of circuit-breaker	Air and large moulded-case circuit-breakers (T7)	Moulded-case circuit-breakers	Miniature circuit-breakers
Coefficient of increase (C)	1,3	1,5	2

Figure 7.4



Separate enclosure exposed on all sides — Separate enclosure wall-mounted assembly — First or last enclosure exposed — First or last enclosure wall-mounted assembly — Central enclosure exposed — Central enclosure wall-mounted assembly

Power losses – Air circuit-breakers

SACE Emax 2 E1.2÷E6.2

Table 7.3

Total power loss (3/4poles) [W]

	E1.2B/C/N		E2.2B/N/S/H		E4.2N/N/S/H/V		E6.2H/V/X	
Iu [A]	F	W	F	W	F	W	F	W
630	31	62						
800	50	100	34	72				
1000	78	156	53	113				
1250	122	244	83	176				
1600	201	400	136	288				
2000			212	450				
2500			267	550				
3200					425	743		
4000					465	900	309	544
5000							483	850
6300							767	1550

F: fixed - W: withdrawable
The power losses are measured according to IEC 60947 product Standard. The values given in the table refer to the total power for 3- and 4-pole circuit-breakers with balanced load and a current flow equal to the rated uninterrupted power "Iu" at 50/60Hz.

Emax E1÷E6, X1

Table 7.4

Total power loss (3/4poles) [W]

	X1B-N		X1L		E1B-N		E2B-N-S		E2L		E3N-S-H-V		E3L		E4S-H-V		E6H-V	
Iu [A]	F	W	F	W	F	W	F	W	F	W	F	W	F	W	F	W	F	W
In=630	31	60	61	90														
In=800	51	104	99	145	65	95	29	53			22	36						
In=1000	79	162	155	227	96	147	45	83			38	58						
In=1250	124	253	242	354	150	230	70	130	105	165	60	90						
In=1600	203	415			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

The values shown in the Tables refer to balanced loads, with phase currents equal to In, and are valid for both three- as well four-pole circuit-breakers and switch-disconnectors. For the latter the current in the neutral is null by definition.

Table 7.5

Power losses – Molded-case circuit-breakers

SACE Tmax XT

Total power loss (3/4 poles) [W]

Trip unit	In [A]	XT1		XT2		XT3		XT4	
		F	P	F	P/W	F	P	F	P/W
TMD TMA TMG MF MA	1.6			6.00	7.2				
	2			7.2	8.4				
	2.5			7.5	8.4				
	3			8.4	9.6				
	4			7.5	8.4				
	6.3			9.9	11.7				
	8			7.8	9				
	10			8.7	10.2				
	12.5			3	3.6				
	16	4.5	4.8	3.9	4.5				
	20	5.4	6	4.8	5.7				
	25	6	8.4	6	7.5				
	32	6.3	9.6	7.8	9			7.5	7.8
	40	7.8	13.8	11.1	13.2			7.8	8.1
	50	11.1	15	12.3	14.1			8.1	8.4
	63	12.9	18	14.4	17.1	12.9	15.3	15.9	17.1
	80	14.4	21.6	17.4	20.4	14.4	17.4	16.5	18.3
	100	21	30	24.3	28.5	16.8	20.4	18.6	21.6
	125	32.1	44.1	34.2	42	19.8	23.7	22.2	27
	160	45		48.3	57	23.7	28.5	26.7	32.4
	200					39.6	47.4	35.7	44.7
	250					53.4	64.2	49.2	63.3
Ekip LS/I Ekip I Ekip LSI Ekip LSIG Ekip E-LSIG Ekip M-LRIU Ekip M-LIU Ekip N-LS/I Ekip G-LS/I	10			0.3	0.3				
	25			2.4	2.7				
	40							1.8	2.1
	63			5.1	6.3			4.2	5.4
	100			12.6	15.6			10.5	13.5
	160			32.4	40.2			26.7	34.5
	250							49.2	68.1

F: fixed - W: withdrawable - P: plug-in

Table 7.6

Tmax

Total power loss (3/4 poles) [W]

Trip unit	In [A]	T11P	T1	T2		T3		T4		T5		T6		T7 S,H,L		T7 V		T7X
		F	F	F	P	F	P	F	P/W	F	P/W	F	W	F	W	F	W	F
TMF TMD TMA MA MF	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													
	20	1.8	5.4	5.1	6			10.8	10.8									
	25	2	6	6.9	8.4													
	32	2.1	6.3	8.1	9.6			11.1	11.1									
	40	2.6	7.8	11.7	13.8													
	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											92.8	117					
	800											93	118.8					
PR221 PR222 PR223 PR231 PR232 PR331 PR332	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							
	400									49.5	84			15	27	24	36	
	630									123	160.8	90	115.5	36	66	60	90	
	800											96	124.9	57.9	105.9	96	144	105
	1000											150		90	165	150	225	
	1250													141	258	234.9	351.9	
	1600													231	423			

F: fixed - W: withdrawable - P: plug-in

Distribution busbars
The busbars present in the column under examination must be considered when calculating the power loss. The length may be obtained approximately by checking the switchboard front.

The power dissipated by the busbars may be obtained by the following relation:

$$P(I_b) = P(I_n)\left(\frac{I_b}{I_n}\right)^2 \cdot L_{tratto} \cdot 3$$

where:
- $P(I_n)$ is the power loss per unit of length at the rated current and its value can be obtained either from the Table B.3 of the IEC TR 60890 Edition 2.0 reported below or from the manufacturer's catalogue
- ($L_{section} \cdot 3$) is the length of the bar section which pass through the column being considered, multiplied by 3 since the circuit is three-phase.

Table B.3 - Operating current and power loss of bare copper bars with rectangular cross-section, run horizontally and arranged with their largest face vertical (ambient temperature inside the enclosure: 55 °C, temperature of the conductor 70 °C)

Table 7.7

Height x thickness of bars	Cross-sectional area of bar	One bar per phase (I)					Two bars per phase (spacing = thickness of bars) (II)				
		50 Hz to 60 Hz AC			DC and AC up to 16 2/3 Hz		50 Hz to 60 Hz AC			DC and AC up to 16 2/3 Hz	
		k_3	Operating current	Power losses per phase conductor P_v	Operating current	Power losses per phase conductor P_v	k_3	Operating current	Power losses per phase conductor P_v	Operating current	Power losses per phase conductor P_v
mm × mm	mm²		A	W/m	A	W/m		A	W/m	A	W/m
12 × 2	23,5	1,00	70	4,5	70	4,5	1,01	118	6,4	118	6,4
15 × 2	29,5	1,00	83	5,0	83	5,0	1,01	138	7,0	138	6,9
15 × 3	44,5	1,01	105	5,4	105	5,3	1,02	183	8,3	183	8,1
20 × 2	39,5	1,01	105	6,1	105	6,0	1,01	172	8,1	173	8,1
20 × 3	59,5	1,01	133	6,4	133	6,3	1,02	226	9,4	226	9,2
20 × 5	99,1	1,02	178	7,0	178	6,9	1,04	325	11,9	326	11,5
20 × 10	199	1,03	278	8,5	278	8,3	1,07	536	16,6	541	15,7
25 × 5	124	1,02	213	8,0	213	7,8	1,05	381	13,2	384	12,7
30 × 5	149	1,03	246	9,0	247	8,8	1,06	437	14,5	439	13,9
30 × 10	299	1,05	372	10,4	376	10,2	1,11	689	18,9	702	17,7
40 × 5	199	1,03	313	10,9	315	10,7	1,07	543	17,0	551	16,4
40 × 10	399	1,07	465	12,4	473	12,0	1,15	839	21,7	878	20,7
50 × 5	249	1,04	379	12,9	382	12,6	1,09	646	19,6	663	18,9
50 × 10	499	1,08	554	14,2	569	13,9	1,18	982	24,4	1 047	23,5
60 × 5	299	1,05	447	15,0	452	14,7	1,10	748	22,0	774	21,4
60 × 10	599	1,10	640	16,1	663	15,7	1,21	1 118	27,1	1 216	26,4
80 × 5	399	1,07	575	19,0	586	18,5	1,13	943	27,0	995	26,6
80 × 10	799	1,13	806	19,7	852	19,4	1,27	1 372	32,0	1 547	32,1
100 × 5	499	1,10	702	23,3	722	22,4	1,17	1 125	31,8	1 177	29,7
100 × 10	999	1,17	969	23,5	1 040	23,2	1,33	1 612	37,1	1 879	37,8
120 × 10	1 200	1,21	1 131	27,6	1 229	27,0	1,41	1 859	43,5	2 204	43,4

For power losses at other temperatures inside the ENCLOSURE, and/or with a temperature of 90 °C on conductors, see Annex B and Table B.4 of IEC TR 60890, Edition 2.0.

Incoming and outgoing assembly cables

The power loss of the cable section which enter the assembly must be calculated separately.
The variability in length of these section causes their power to be negligible in some cases, or decisive in others for the correct calculation of the power loss inside the assembly.
Their power loss can be determined by the following relation:

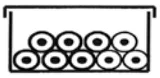
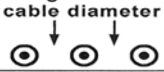
$$P\,(I_b) = P\,(I_n)\left(\frac{I_b}{I_n}\right)^2 \cdot L_{tratto} \cdot 3$$

where:

- $P\,(I_n)$ is the power loss per unit of length at the rated current and its value can be taken either from the Table B.1 of IEC TR 60890 Edition 2.0 (see Table 7.7) or from the catalogue of the manufacturer
- $(L_{section} \cdot 3)$ is the length of the cable section inside the assembly or inside the column under consideration multiplied by 3 since the circuit is three-phase; this length may be approximately determined by inspection of the switchboard front.

Operating current and power loss of single-core copper cables with a permissible conductor temperature of 70 °C (ambient temperature inside the enclosure: 55 °C)

Table 7.8

Conductor arrangement		 Single-core cables in a cable trunking on a wall, run horizontally or vertically. 6 of the cables (2 three-phase circuits) continuously loaded		 Single-core cables, touching free in air or on a perforated tray. 6 cables (2 three-phase circuits) continuously loaded		Spacing at least one cable diameter  Single-core cables, spaced horizontally in free air	
Cross-sectional area of conductor mm²	Resistance of conductor at 20 °C, R_{20} [a] mΩ/m	Max. operating current I_{max} [b] A	Power losses per conductor P_v W/m	Max. operating current I_{max} [c] A	Power losses per conductor P_v W/m	Max. operating current I_{max} [d] A	Power losses per conductor P_v W/m
0,50	36,0	3,7	0,6	-	-	-	-
0,75	24,5	4,8	0,7	-	-	-	-
1	18,1	5,8	0,7	-	-	-	-
1,5	12,1	7,6	0,8	9,6	1,3	15	3,2
2,5	7,41	10	0,9	13	1,6	21	3,7
4	4,61	14	1,0	18	1,9	28	4,2
6	3,08	18	1,1	24	2,1	36	4,7
10	1,83	24	1,3	33	2,5	50	5,4
16	1,15	33	1,5	45	2,9	67	6,2
25	0,727	43	1,6	61	3,3	89	6,9
35	0,524	54	1,8	76	3,6	110	7,7
50	0,387	65	2,0	93	4,0	134	8,3
70	0,268	83	2,2	120	4,6	171	9,4
95	0,193	101	2,4	147	5,0	208	10,0
120	0,153	117	2,5	171	5,4	242	10,7
150	0,124	-	-	198	5,8	278	11,5
185	0,099 1	-	-	227	6,1	318	12,0
240	0,075 4	-	-	269	6,6	375	12,7
300	0,060 1	-	-	311	7,0	432	13,5

[a] Values from IEC 60228:2004, Table 2 (stranded, plain copper conductors).

[b] Current carrying capacity I_{30} for one three-phase circuit from IEC 60364-5-52:2009, Table B.52.4, col. 4 (Reference method of installation: item B1 in Table B.52.1). Values for cross-sections less than 1,5 mm² calculated following Annex D of IEC 60364-5-52:2009.

k_2 = 0,8 (item 1 in Table B.52.17 of IEC 60364-5-52:2009, two circuits).

[c] Current carrying capacity I_{30} for one three-phase circuit from IEC 60364-5-52:2009, Table B.52.10, col. 5

(Reference method of installation: Item F in Table B.52.1). Values for cross-sections less than 25 mm² calculated following Annex D of IEC 60364-5-52:2009, k_2 = 0,91 (Table B.52.21 of IEC 60364-5-52:2009, vertical perforated cable tray systems; Method of installation: 31; number of trays or ladders: 1; number of three-phase circuits per tray or ladder: two circuits).

[d] Current carrying capacity I_{30} for one three-phase circuit from IEC 60364-5-52:2009, Table B.52.10, col. 7 (Reference method of installation: item G in Table B.52.1 of IEC 60364-5-52:2009). Values for cross-sections less than 25 mm² calculated following Annex D of IEC 60364-5-52:2009.

k_2=1

For power losses at other air temperatures inside the ENCLOSURE, see Annex B and Table B.2 of IEC TR 60890, Edition 2.0.

Calculation of temperature rise

The temperature rise value inside the assembly can be calculated by means of ABB SACE software tools such as e-Design.

The parameters required by the software are the following:

- linear dimensions of the assembly (height, length and width);
- methods of installation (exposed separate, separate, wall-mounted, ...);
- air inlet surface; (the Standard IEC TR 60890 prescribes an air outlet with a surface at least 1.1 times the inlet area; otherwise the inlet area must be reduced of 10% in comparison with the present one)
- ambient temperature;
- number of horizontal partitions;
- total power loss.

Besides, the air temperature at mid height and at the top of the assembly to be constructed is calculated by using the same method or tool.

At this point, once the thermal map of the inside of the assembly, from bottom to top, has been drawn, if the temperature of each built-in device at the fixing point remains equal to or lower than the admissible one, which is declared by the manufacturer, the whole assembly shall be considered as successfully verified.

Moreover, for the switching devices or the electrical components of the main circuits, and in particular for ABB LV moulded-case and air circuit-breakers, the following condition must be satisfied:

Inc ≤ 80%In

where:

I_{nc}: rated current of the circuit of the assembly to be verified;

I_n: free air rated current of the LV circuit-breaker.

Note

From the compliance of an assembly to IEC TR 60890 other arrangements can be derived by means of analyses and physical deductions of conservative type. Such arrangements can be accepted if:

- they use a structure with bigger linear dimensions;
- they are positioned in an air-conditioned environment with ambient temperature ≤ 35 °C average value;
- they use a method of installation allowing greater ventilation of the assembly;
- they use a device for the forced ventilation of the assembly.

If required, these parameters can be inserted in the temperature-rise calculation so that a precise thermal map of the assembly can be defined.

On the other hand, the different degrees of protection and the different forms of separation cannot be taken into account to obtain lower temperature values.

8 Verification of performances under short-circuit conditions

The assembly shall be built so as to withstand the thermal and dynamic stresses due to the short-circuit current up to the assigned values. Besides, the assembly may be protected against short-circuit currents by means of automatic circuit-breakers or fuses that may be installed either in the assembly or on its supply side.

When placing the order, the user shall specify the short-circuit conditions at the point of installation.

This chapter takes into consideration the following aspects:

- whether a verification of the short-circuit withstand strength is required;
- the suitability of an assembly for a plant on the basis of the prospective short-circuit current in the plant and of the short-circuit characteristics of the assembly;
- the suitability of a busbar system on the basis of the short-circuit current and of the protective devices;
- verification of short-circuit withstand strength in compliance with IEC 61439-1.

8.1 Verification of short-circuit withstand strength

Verification of short-circuit withstand strength is dealt with in the new edition of the Standards IEC 61439-1 and 2; in particular, these Standards specify when the verification must be carried out and the different types.

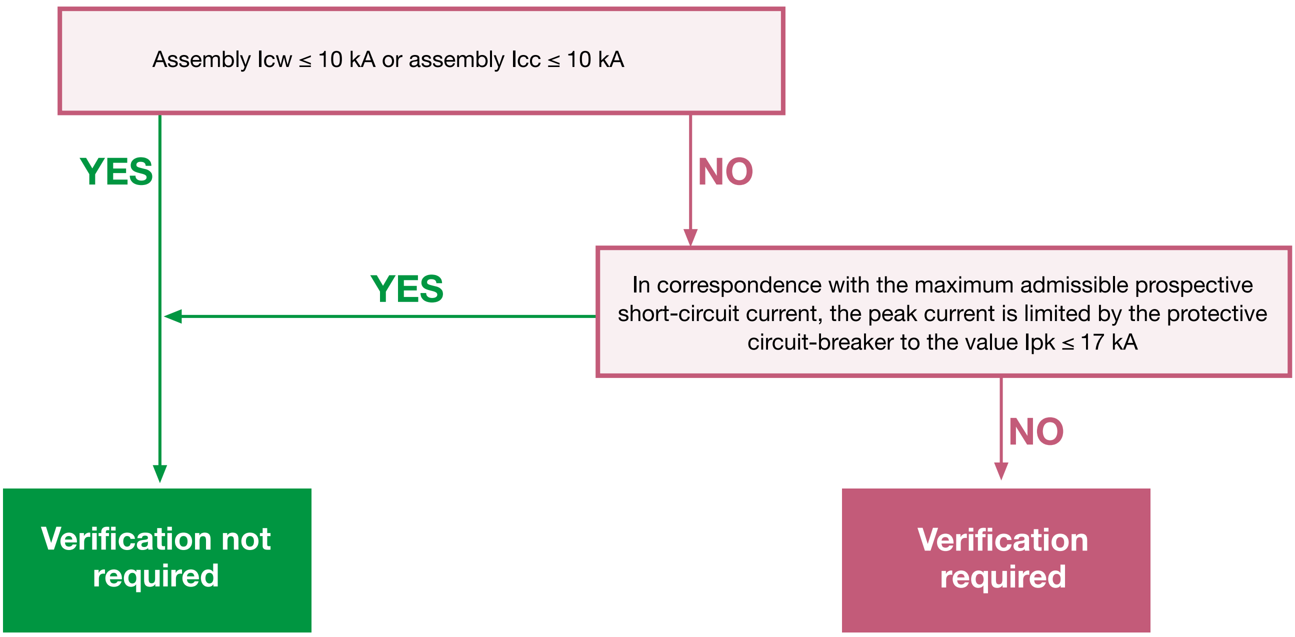
A verification of short-circuit withstand strength is not required in the following cases:

- assemblies having a rated short-time withstand current or a rated conditional short-circuit current not exceeding 10 kA r.m.s;
- assemblies, or circuits of assemblies, protected by current-limiting devices having a cut-off current not exceeding 17 kA, in correspondence with the maximum allowable prospective short-circuit current at the terminals of the incoming circuit of the assembly;
- auxiliary circuits of assemblies intended to be connected to transformers whose rated power does not exceed 10 kVA for a rated secondary voltage of not less than 110 V, or 1.6 kVA for a rated secondary voltage of not less than 110 V, and whose short-circuit impedance in both cases is not less than 4%.

All other circuits shall be verified.

The need to verify short-circuit withstand strength can be summarized as follows:

Figure 8.1



As regards the details about the performance of the short-circuit test, reference should be made directly to the Standard IEC 61439-1.

The following Table shows for the different protective devices and for the most common plant voltages the values that approximately represent the maximum prospective short circuit-current in [kA], such that the limited peak does not exceed 17 kA, so that the short-circuit withstand test must not be carried out.

Table 8.1

Circuit-breaker		Rated voltage of the plant			
Typology	Rated current In [A]	230Vca	415Vca	500Vca	690Vca
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
XT1	16-32	100	70	50 (In ≤ 20 A) 30 (25 A ≤ In ≤ 32 A)	10
XT1	40-50	65	60	24	10
XT1	63-160	40	36	24	10
XT2	1.6-50	200 (In ≤ 32 A) 50 (40 ≤ In ≤ 50)	150 (In ≤ 20 A) 100 (In = 25 A) 40 (32 ≤ In ≤ 50)	70 (In ≤ 25 A) 50 (32 ≤ In ≤ 50)	20
XT2	63	50	30	36	20
XT2	80-160	33	30	36	20
XT3	63	85	25	22	6
XT3	80	50	25	22	6
XT3	100	30	22	20	6
XT3	125-160	25	20 (In=125 A) 18 (In=160 A)	18	6
XT3	200-250	22	18	17 (In=200 A) 16 (In= 250A)	6
XT4	16-32	200	150 (In ≤ 25A) 90 (In=32A)	70 (In ≤ 25A) 36 (In=32A)	25
XT4	40-50	50	30	20	25
XT4	63-80	30	22	20	20
XT4	100-160	22	20	20	20
XT4	200-250	22	20	18	20

The short-circuit value shown in the Table above shall be compared with the breaking capacity of the circuit-breaker for the different versions available.

8.2 Short-circuit current and suitability of the assembly to the plant

The verification of the short-circuit current withstand is mainly based on two parameters of the assembly, which are:

- admissible rated short-time withstand current I_{cw};
- rated conditional short-circuit current I_{cc}.

According to one of these two values it is possible to establish whether the assembly is suitable for being installed in a determined point of the plant.

It must be verified (if necessary through back-up) that the breaking capacities of the equipment inside the assembly are compatible with the short-circuit current values of the plant.

The rated short-time withstand current I_{cw} is the r.m.s. value of the current applied for the short-circuit test for 1 s without tripping of the protective devices, declared by the assembly manufacturer, that can be withstood by the assembly without damages under specified conditions, defined in terms of a current and time. Different values of Icw for different durations (e.g. 0.2 s; 1 s; 3 s) may be assigned to an assembly.

From the test (if passed) which allows to define the I_{cw} value it is possible to obtain the specific let-through energy (I^2t) withstood by the assembly (this relation is valid by hypothesizing an adiabatic phenomenon which cannot exceed 3 seconds):

$$I^2t = I_{cw}^2 \cdot t \text{ (generically } t = 1\text{s).}$$

The Standard defines also the admissible rated peak current I_{pk} as the short-circuit peak current value, declared by the assembly manufacturer, that can be carried by the assembly itself under specified conditions. The value of current peak to determine the electrodynamic stresses shall be obtained by multiplying the short-time current by the factor "n" according to Table 7 of IEC 61439-1. The values for the factor "n" are given in Table 8.2.

$$I_{pk} = I_{cw} \cdot n$$

Table 8.2

R.m.s. value of the short-circuit (in kA)	cosφ	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

The values in this Table take into account the majority of applications. In particular areas, e.g. near transformers or generators, the power factor can take lower values and consequently, in these cases, the maximum peak value of the prospective current may become the limiting factor, instead of the r.m.s. value of the short-circuit current.

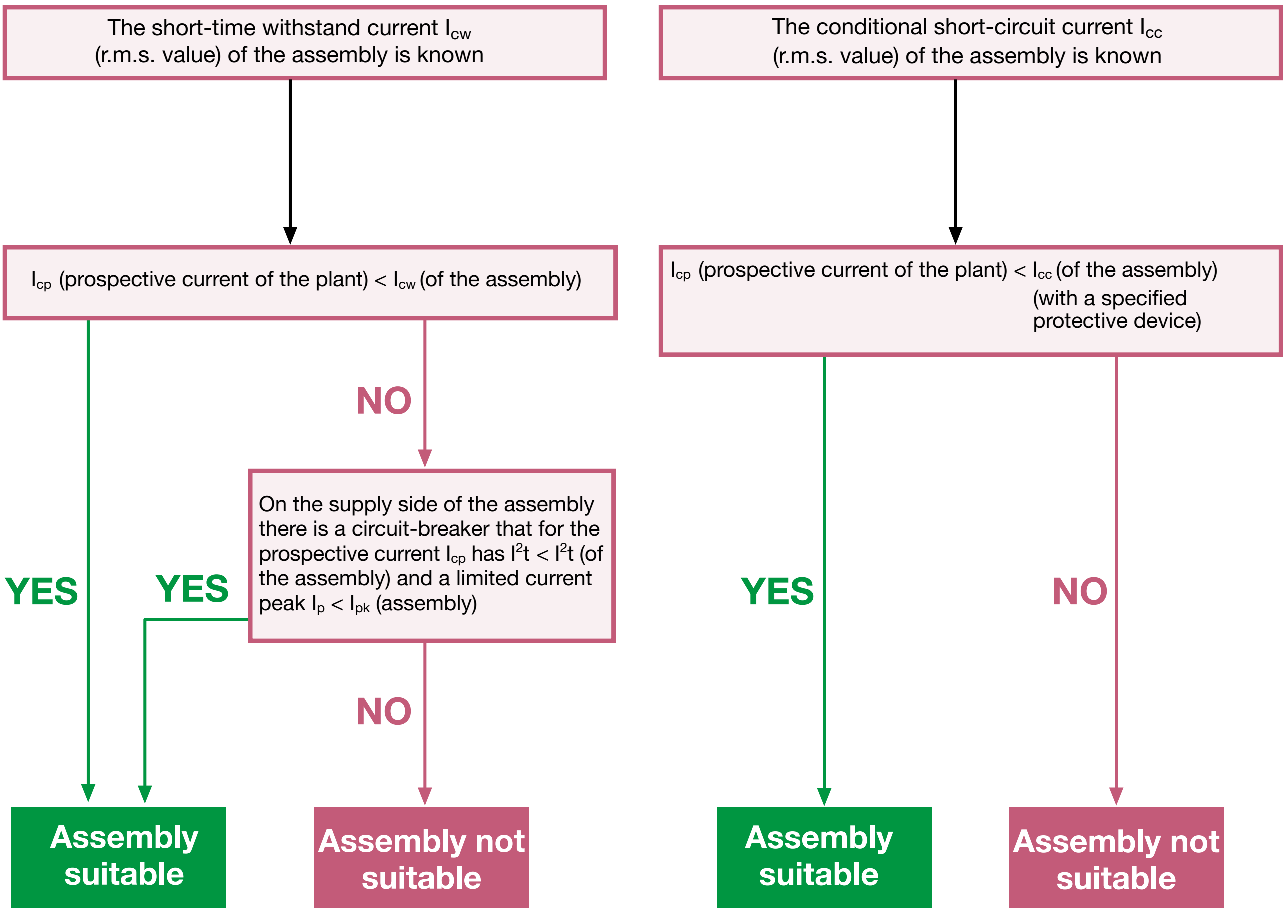
The rated conditional short-circuit current I_{cc} is the value of prospective short-circuit current, declared by the assembly manufacturer, that can be withstood for the total operating time (clearing time) of the short-circuit protective device under the specified conditions.
The rated conditional short-circuit current I_{cc} shall be equal to or higher than the prospective r.m.s. value of the short-circuit current (I_{cp}) for a duration limited by the operation of the short-circuit protective device that protects the assembly (or a circuit of the assembly).

By means of the I_{cw} or I_{cc} values and of the prospective short-circuit current of the plant it is possible to establish whether the assembly is suitable for being installed in the plant.

The following diagrams show the method to determine the compatibility of the assembly with the plant[1]

[1] *It shall be verified that the breaking capacities of the equipment inside the assembly are compatible with the short-circuit current values of the plant.*

Figura 8.2



Example

Data of the existing plant:

V_n= 400 V
f_n = 50 Hz
I_{cp}= 35 kA

By assuming to have in an existing plant an assembly with an I_{cw} equal to 35 kA and that, at the installation point of the plant, the prospective short-circuit current is equal to 35 kA.

Considering now deciding to increase the power of the plant and that the short-circuit value rises up to 60 kA.

Plant data after power increase:

U_n= 400 V
f_n = 50 Hz
I_{cp}= 60 kA

Since the I_{cw} of the assembly is lower than the short-circuit current of the plant, in order to verify that the existing assembly is still compatible it is necessary to:

- determine the values of I^2t and Ip let through by the circuit-breaker on the supply side of the assembly;
- verify that the protective devices positioned inside the assembly has the adequate breaking capacity, individually or for back-up.

I_{cw} = 35 kA from which:

- $I^2t_{\ assembly}$ = 35^2x1 =1225 MA^2s;
- $I_{pk\ assembly}$ = 35 x 2,1 = 73.5 kA (see Table 8.2).

Assuming that on the supply side of the assembly a new molded-case circuit breaker Tmax T5H (Icu=70 kA at 415V) is installed:

- $I^2t_{\ CB}$ < 4 MA^2s;
- $I_{p\ CB}$ < 40 kA.

since:

- $I^2t_{\ assembly} > I^2t_{\ CB}$
- $I_{pk\ assembly} > I_{p\ CB}$

The assembly (structure and busbar system) turns out to be suitable.

As regards the circuit-breakers positioned inside the assembly, let us suppose that they are molded-case circuit-breakers type SACE Tmax XT1, XT2, XT3 version N, with Icu=36 kA at 415V.

From the back-up tables it can be noticed that the circuit-breakers inside the assembly result suitable for the plant since their breaking capacity is increased to 65 kA by the circuit-breaker T5H on the supply side.

8.3 Choice of the distribution system in relation to the short-circuit withstand strength

The dimensioning of the distribution system of the assembly is carried out by taking into account the rated current passing through it and the prospective short-circuit current of the plant.

The manufacturer usually provides tables which allow the choice of the busbar cross-section according to the rated current and which give the distances the busbar supports must be placed at to guarantee the short-circuit withstand.

ABB SACE technical catalogue “System pro *E* power - New main distribution switchboards up to 6300A” describes the distribution systems that can be used inside System pro *E* power assemblies.
They are:

busbars with shaped section up to:
- 2500 A (IP65);
- 2860 A (IP31)

flat copper busbars up to:
- 4000 A (IP65);
- 6300 A (IP31)

flat Cupional busbars up to:
- 3200 A (IP65 and IP31)

flexible busbars up to:
- 1250 A (IP65);
- 1515 A (IP31)

Unifix cabling system up to 400 A;
distribution frames up to 400 A.

To select the distribution system compatible with the short-circuit data of the plant the following procedure must be taken:

- **If the protective devices positioned on the supply side of the distribution system are known**

from the value of the Icw of the distribution system the following is obtained:

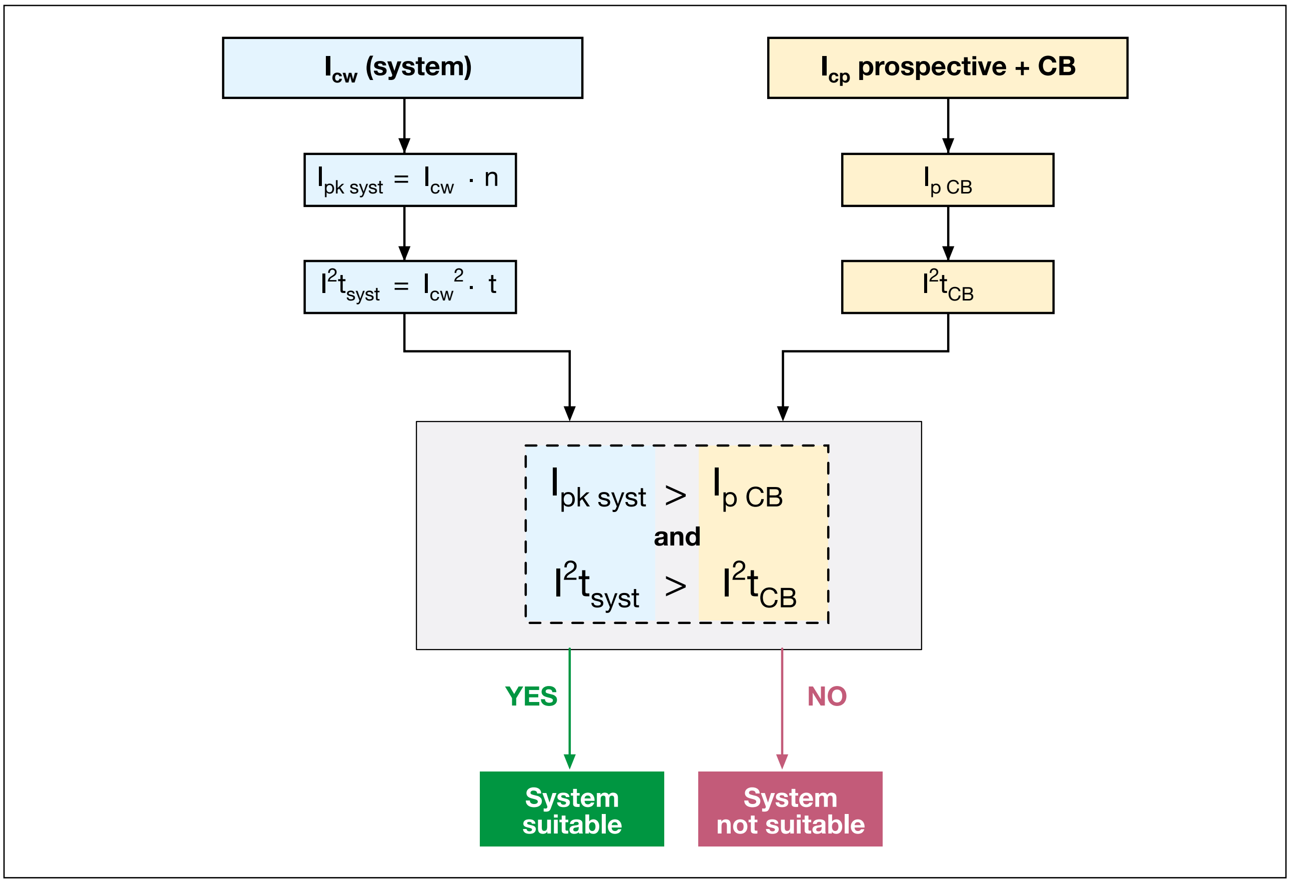
- $I_{pk\ syst} = I_{cw} \cdot n$
  (where n is the factor derived from Table 8.2)
- $I^2t_{\ syst} = I_{cw}^{\ 2} \cdot t$
  (where t is equal to 1 s).

In correspondence with the value of the prospective short-circuit current of the plant the following is determined:

- the value of the peak current limited by the circuit-breaker $I_{p\ CB}$;
- the specific energy let-through by the circuit-breaker $I^2t_{\ CB}$

If $I_{p\ CB} < I_{pk\ syst}$ and $I^2t_{\ CB} < I^2t_{\ syst}$ then the distribution system is suitable.

Figure 8.3



Example

Plant data:

U_n=400 V
f_n=50 Hz
I_{cp}=65 kA

Assuming that a 400 A busbar system with shaped section is needed.
According to the catalogue issued by ABB SACE "System pro *E* power - New main distribution switchboards up to 6300A" a possible choice could be:
PBSC0400 with In 400 A (IP65) Icw=25kA.

Assuming that a molded-case circuit-breaker Tmax T5H400 In 400 is positioned on the supply side of the busbar system, from the I_{cw} of the busbar system the following is obtained:

- $I_{pk\ sist} = I_{cw} \cdot 2{,}1 = 52{,}5$ [kA]
- $I^2t_{sist} = I_{cw}^2 \cdot t = 25^2 \cdot 1 = 625$ [(kA)^{2}s]

From the current limiting curves and the let-through energy curves of the circuit-breaker T5H400 In 400, to a prospective short-circuit current I_{cp} equal to 65 kA, the following values correspond:

- $I_{p\ CB} < 40$ kA
- $I^2t_{CB} < 4$ [(kA)^{2}s]

Since:

- $I_{p\ CB} < I_{pk\ syst}$
- $I^2t_{CB} < I^2t_{syst}$

the busbar system is suitable for the plant.

- **If the protective devices positioned on the supply side of the distribution system under examination is not known, it shall be necessary to verify that:**

I_{cp} (prospective current) < I_{cw} (distribution system)

Sections of conductor on the supply side of the device

The Standard IEC 61439-1 states that inside an assembly the conductors (distribution busbars included) placed between the main busbars and the supply side of the individual functional units (as well as the components making up these units) can be sized on the basis of the reduced short-circuit stresses generated on the load side of the short-circuit protection device of the unit.

This may be possible if the conductors are arranged so that, under normal service conditions, the internal short-circuit between phases and/or between phases and earth is to be considered as a remote possibility; it is preferable for such conductors to be of massive and rigid construction.

As an example, the Standard in the Table 4 (see Table 8.3 of this document), indicates type of conductor and installation requirements for which the installation which allow the remote hypothesis of a short-circuit between phases and/or between phases and earth can be considered a remote possibility.

If these conditions are found or when an internal short-circuit can be considered a remote hypothesis, the procedure described above can be used to check the suitability of the distribution system to the short-circuit conditions, where these are determined according to the characteristics of the circuit-breaker positoned on the load side of the busbars.

Table 8.3

Type of conductor	Requirements
Bare conductors or single-core conductors with basic insulation, for example cables according to IEC 60227-3.	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 of at least 90 °C, for example cables according to IEC 60245-3, or heat-resista nt thermo-plastic (PVC) insulated cables according to IEC 60227-3.	Mutual contact or contact with conductive parts is permitted where there is no applied external pressure. Contact with sharp edges shall be avoided. These conductors may only be loaded such that an operating temperature of 80 % of the maximum permissible conductor operating temperature is not exceeded.
Conductors with basic insulation, for example cables according to IEC 60227-3, having additional secondary insulation, for example individually covered cables with shrink sleeving or individually run cables in plastic conduits	No additional requirements
Conductors insulated with a very high mechanical strength material, for example Ethylene Tetrafluoro Ethylene (ETFE) insulation, or double-insulated conductors with an enhanced outer sheath rated for use up to 3 kV, for example cables according to IEC 60502.	
Single or multi-core sheathed cables, for example cables according to IEC 60245-4 or IEC 60227-4.	

Example

Plant data:

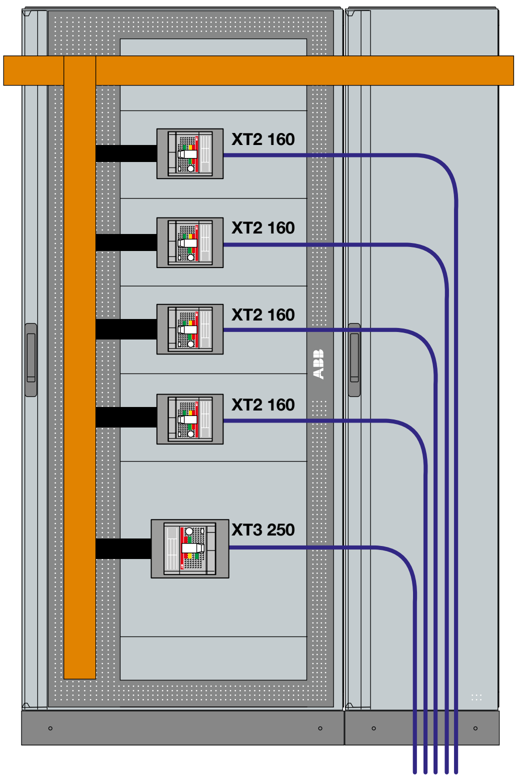
U_n = 400 V
f_n = 50 Hz
I_{cp} = 45 kA

Take into consideration the assembly in the figure, where the vertical distribution busbars are derived from the main busbars.
These are 630 A busbars with shaped section as reported in the calogue "System pro *E* power – New main distribution switchboards up to 6300A":
In 630, (IP65)
I_{cw} max 35 kA.

Being a rigid system with spacers, for the Standard IEC 61439 a short-circuit between the busbars is a remote possibility. However it is necessary to verify that the stresses reduced by the circuit-breakers on the load side of the system are compatible with the switchgear assembly.

Let us suppose that in the compartments there are the following circuit-breakers:
SACE Tmax XT3S250
SACE Tmax XT2S160

Figure 8.4



It must be checked that, in the case of a short-circuit on any output, the limitations caused by the circuit-breaker, are compatible with the busbar system.
It must therefore be verified that the circuit-breaker limiting less the peak and energy represents a sufficient limit for the busbar system.
In our case this is the XT3S In 250.
Therefore we carry out the check in the same way as in the previous paragraph:

from the I_{cw} of the busbar system it turns out that
- $I_{pk\ syst} = I_{cw} . n = 35 . 2.1 = 73.5$ [kA]
- $I^2t_{\ syst} = I_{cw}^{\ 2} . t = 35^2 . 1 = 1225$ [(kA)²s]

From the limiting and from the specifc let-through energy curves of XT3S250 In 250, it results that to a prospective short-circuit current Icp of 45 kA the following corresponds:
- $I_{p\ CB} < 30$ kA
- $I^2t_{\ CB} < 3$ [(kA)²s]

Since:
- $I_{p\ CB} < I_{pk\ syst}$
- $I^2t_{\ CB} < I^2t_{\ syst}$

the busbar system results to be compatible with the assembly.

8.4 Verification of short-circuit withstand strength by design verifications

As regards short-circuit withstand strength, the Standard IEC 61439-1 accepts the possibility of carrying out verifications by tests, or by comparison with a reference design using the check list provided in Table 13 (see Table 8.4 of this document) or by comparison with a reference design and by calculation.

In the verification made according to Table 13, the assembly to be assessed is compared with a representative sample of assembly already tested in laboratory by using the check-list in Table 13.

The test is passed and the short-circuit test is not required when "YES" is the answer to all requirements considered in the check-list.

The answer "NO" to one or more of these questions involves the verification of the characteristic to which the question relates by test or by comparison with the tested reference design and calculations.

In the case of verification by comparison utilizing calculation the assembly to be assessed is compared with an assembly already tested to verify the main circuits in accordance with Annex P[11] of IEC 61439-1. In addition, each of the circuits of the assembly to be assessed shall meet the requirements of items 1, 6, 8, 9 and 10 in the check-list. If the assessment in accordance with Annex P on the possibility of an extrapolation from the tested assembly is not passed or any of the items listed above are not fulfilled, then the assembly and its circuits shall be verified by test.

As can be deduced from this Table and from Annex P, the suggested derivations are a function of the tests carried out on a reference design assembly.

[11] "Verification of short-circuit withstand strength of busbar structures by comparison with a tested reference design by calculation". Annex P essentially describes the conditions to be fulfilled to make possible the extrapolation of a busbar structure from the busbar system of a tested assembly, but it does not expound methods for the calculation of electro-dynamical stresses. Calculation is made according to IEC 60865-1 "Shortcircuit currents – Calculation of effects". For further details see IEC 61439-1: Edition 2.0 2011-08.

Table 8.4

Item No.	Requirements to be considered	YES	NO
1	Is the short-circuit withstand rating of each circuit of the ASSEMBLY to be assessed, less than or equal to, that of the reference design?		
2	Is the cross sectional dimensions of the busbars and connections of each circuit of the ASSEMBLY to be assessed, greater than or equal to, those of the reference design?		
3	Is the center line spacing of the busbars and connections of each circuit of the ASSEMBLY to be assessed, greater than or equal to, those of the reference design?		
4	Are the busbar supports of each circuit of the ASSEMBLY to be assessed of the same type, shape and material and have, the same or smaller center line spacing, along the length of the busbar as the reference design? And is the mounting structure for the busbar supports of the same design and mechanical strength?		
5	Are the material and the material properties of the conductors of each circuit of the ASSEMBLY to be assessed the same as those of the reference design?		
6	Are the short-circuit protective devices of each circuit of the ASSEMBLY to be assessed equivalent, that is of the same make and series [a] with the same or better limitation characteristics (I^2t, I_{pk}) based on the device manufacturer's data, and with the same arrangement as the reference design?		
7	Is the length of unprotected live conductors, in accordance with 8.6.4, of each non-protected circuit of the ASSEMBLY to be assessed less than or equal to those of the reference design?		
8	If the ASSEMBLY to be assessed includes an enclosure, did the reference design include an enclosure when verified by test?		
9	Is the enclosure of the ASSEMBLY to be assessed of the same design, type and have at least the same dimensions to that of the reference design?		
10	Are the compartments of each circuit of the ASSEMBLY to be assessed of the same mechanical design and at least the same dimensions as those of the reference design?		
"YES" to all requirements – no further verification required. "NO" to any one requirement – further verification is required.			
[a] Short-circuit protective devices of the same manufacturer but of a different series may be considered equivalent where the device manufacturer declares the performance characteristics to be the same or better in all relevant respects to the series used for verification, e.g. breaking capacity and limitation characteristics (I2t, Ipk), and critical distances.			

9 Verification of the dielectric properties of the assembly

Among the main performance characteristics (design verifications) of an assembly system, in addition to the thermal and the short-circuit withstand strength just examined, there is the verification of the dielectric properties.

With regard to this, the new version of the Standard IEC 61439 has introduced a double compliance, by reconfirming the power-frequency withstand voltage (U_i) property and by adding the new impulse withstand voltage (U_{imp}).

Please note that the increasing sequence relating to the different voltages of an assembly starts with Ue (the operational voltage as a function of the actual value operating in a definite plant). Then, it continues with U_n (the rated voltage of the assembly considered and declared in the relevant catalogue), go on with U_i (the assembly rated insulation voltage dielectric voltages are referred to) and finishes with Uimp, which is the rated impulse withstand voltage representing the maximum peak the system is able to withstand.
This peak value is assigned by the original manufacturer of the system, by means of proper design verifications.

9.1 Power frequency withstand voltage test

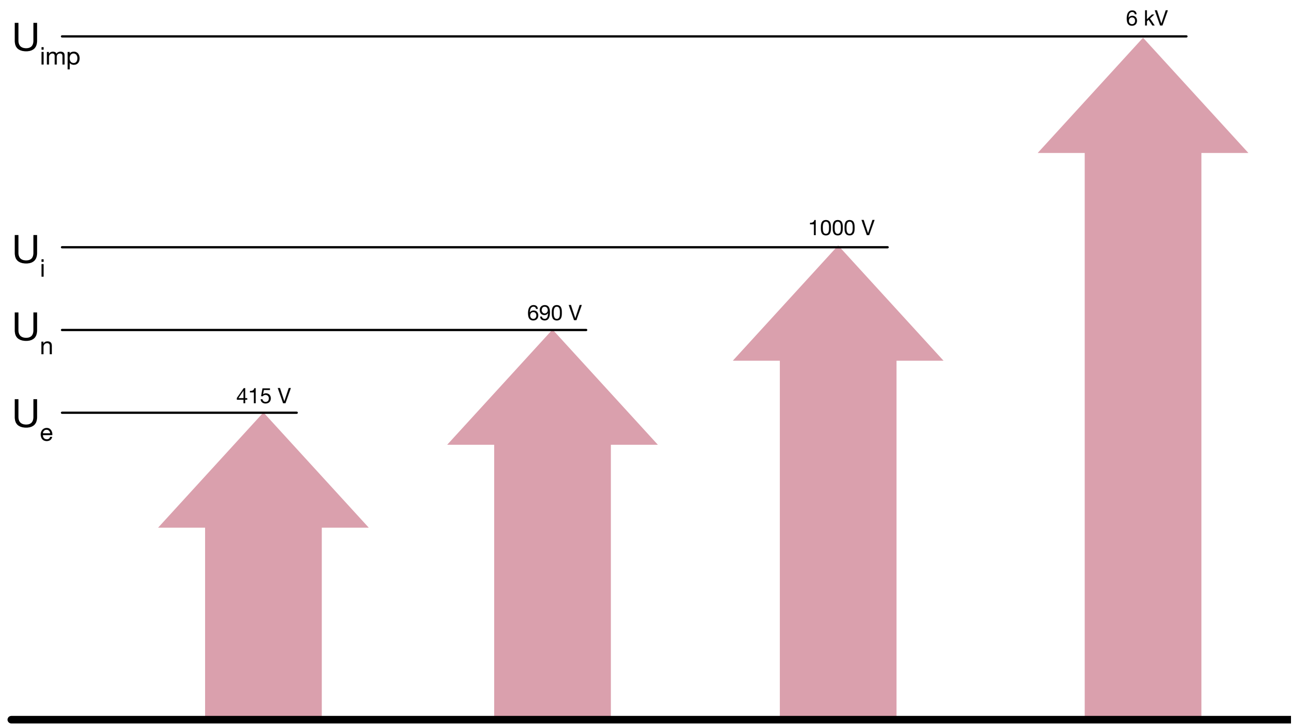
The amendements of the Standard go towards a certain technical simplification.
As regards the r.m.s. values of the test voltages to be applied in laboratories (see Table 8 of the IEC 61439-1 below), they have been reduced in comparison with the former edition, but leaving the possibility of carrying out the verification of the main circuits both in alternating current as well as in continuous current however keeping to the canonical ratio 1.41.

Table 9.1

Rated insulation voltage U_i line to line a.c. or dc. V	Dielectric test voltage a.c. r.m.s. value V	Dielectric test voltage[b] d.c V
$U_i \leq 60$	1 000	1 415
$60 < U_i \leq 300$	1 500	2 120
$300 < U_i \leq 690$	1 890	2 670
$690 < U_i \leq 800$	2 000	2 830
$800 < U_i \leq 1\,000$	2 200	3 110
$1\,000 < U_i \leq 1\,500$ [a]	-	3 820

[a] For d.c. only
[b] Test voltages based on 4.1.2.3.1, third paragraph, of the IEC 60664-1.

Figure 9.1



This test in alternating current and at 50 Hz frequency, which allows the rated insulation voltage Ui to be defined, is necessary and exclusive since no alternative verifications by calculation or by assessment is admitted; therefore, this test is mandatory for the original manufacturer. After the disconnection of all the live circuits both on the supply as well on the load side, the test is carried out in two distinct phases on the main circuits and on the auxiliary circuits.
In particular, for the main circuits, two different procedures are defined during which the test voltage is applied as follows:

- between all live parts of the main circuit connected together (including the control and auxiliary circuits connected to the main circuit) and the exposed conductive parts, with the main contacts of all switching devices in closed position;
- between each live part of different potential of the main circuit and the other live parts of different potential and exposed conductive parts connected together, with the main contacts of all switching devices in closed position.

The test voltage generated by suitable laboratory equipment, is applied by means of the classic safety clamps to the parts to be tested. The method described, which implies the application of a slope with values increasing up to a maximum to be maintained each time for five seconds, highlights a further reduction in the times of application of the voltage test (formerly, 1 minute was required).

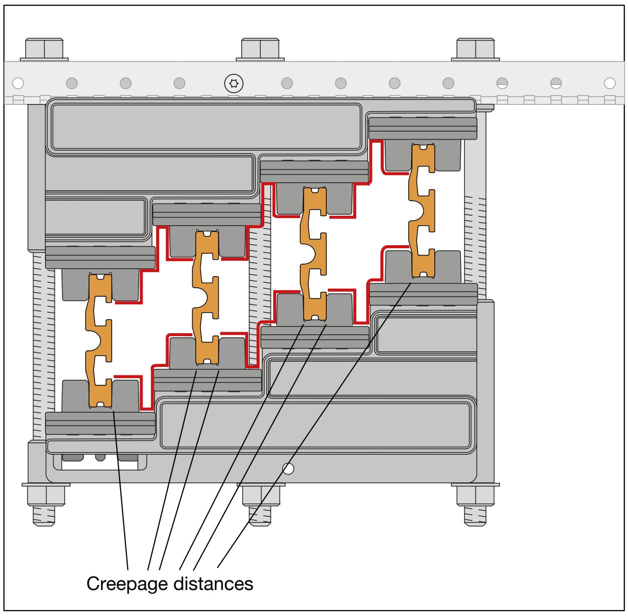
For the auxiliary circuits, which usually have working voltages lower than the main circuits, the new Standard IEC 61439 defines Table 9 (see Table 9.2).

Table 9.2

Rated insulation voltage U_i (line to line) V	Dielectric test voltage a.c. r.m.s V
$U_i \leq 12$	250
$12 < U_i \leq 60$	500
$60 < U_i$	2 Ui + 1000 with a minimum of 1500

Analogous to the voltage test in alternating current just described, there is the verification of the minimum creepage distances inside the assembly; this prescription involves all the internal components provided with insulated parts both between the active parts and to earth. The critical points are usually the busbar holder supports and the insulated terminals.

Figure 9.2



As a rule, this procedure shall take into account also the type of insulating material and the relevant comparative tracking index CTI (in Volt) expressing the maximum withstand voltage which can be withstood without discharges.
The more valuable the product (glass, ceramic material), the higher is this index (600 and over) and the lower the relevant material group.

Table 9.3

Material group	CTI (comparative tracking index)		
I		> 600	
II	600	> CTI	> 400
IIIa	400	> CTI	> 175
IIIb	175	> CTI	> 100

The above can be summarized in the following Table, which shows the minimum creepage distances in mm for each component housed in the assembly, as a function of the rated insulation voltage U_i, of the pollution degree and of the material group.

Direct measurement of such segments rarely highlights critical situations, since the normal mechanical and geometrical tolerances exceed abundantly these values.

Table 9.4

Rated insulation voltage U_i	**Minimum creepage distances mm**							
	Pollution degree							
	1 Material group[c]	**2 Material group[c]**			**3 Material group[c]**			
V[b]	**All material groups**	**I**	**II**	**IIIa and IIIb**	**I**	**II**	**IIIa**	**IIIb**
32	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
40	1.5	1.5	1.5	1.5	1.5	1.6	1.8	1.8
50	1.5	1.5	1.5	1.5	1.5	1.7	1.9	1.9
63	1.5	1.5	1.5	1.5	1.6	1.8	2	2
80	1.5	1.5	1.5	1.5	1.7	1.9	2.1	2.1
100	1.5	1.5	1.5	1.5	1.8	2	2.2	2.2
125	1.5	1.5	1.5	1.5	1.9	2.1	2.4	2.4
160	1.5	1.5	1.5	1.6	2	2.2	2.5	2.5
200	1.5	1.5	1.5	2	2.5	2.8	3.2	3.2
250	1.5	1.5	1.8	2.5	3.2	3.6	4	4
320	1.5	1.6	2.2	3.2	4	4.5	5	5
400	1.5	2	2.8	4	5	5.6	6.3	6.3
500	1.5	2.5	3.6	5	6.3	7.1	8.0	8.0
630	1.8	3.2	4.5	6.3	8	9	10	10
800	2.4	4	5.6	8	10	11	12.5	a
1000	3.2	5	7.1	10	12.5	14	16	
1250	4.2	6.3	9	12.5	16	18	20	
1600	5.6	8	11	16	20	22	25	

NOTE 1 The CTI values refer to the values obtained in accordance with IEC 60112:2003, method A, for the insulating material used.
NOTE 2 Values taken from IEC 60664-1, but maintaining a minimum value of 1,5 mm.

a Insulation of material group IIIb is not recommended for use in pollution degree 3 above 630 V.

b As an exception, for rated insulation voltages 127, 208, 415, 440, 660/690 and 830 V, creepage distances corresponding to the lower values 125, 200, 400, 630 and 800 V may be used.

c Material groups are classified as follows, according to the range of values of the comparative tracking index (CTI) (see 3.6.16):

- Material group I: $600 \le CTI$
- Material group II: $400 \le CTI < 600$
- Material group IIIa: $175 \le CTI < 400$
- Material group IIIb: $100 \le CTI < 175$

9.2 Impulse withstand voltage test

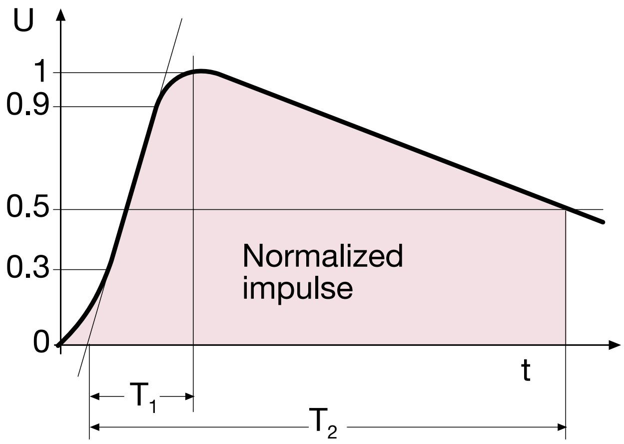
Once optional, the impulse withstand voltage test, which allows the rated impulse withstand voltage Uimp to be defined, is now a requirement, which demonstrates the Standards' strategy intended to increase more and more the importance of such performance.
In addition to the ordinary temporary overvoltages, usually incoming from the supply line, the plants and the relevant assemblies are potential victims of peaks and transient non-linear overvoltage due to atmospheric causes (lightning) both direct (when they affect materially the structure) and indirect (when their effect is mediated by the electromagnetic field induced around the impact point of lightning).
The capability of the assembly to withstand such stresses depends all on the dielectric strength of the air between the two live parts carrying the impulse. Formerly such performance was defined only by experimental testing; according to the new IEC 61439 also verification by assessment is possible as an alternative to and with the same validity of testing.
The test prescribes a 1.2/50 μs impulse voltage (see Figure 9.3) to be applied according to a particular procedure. The impulse shall be applied five times for each polarity at intervals of 1 s minimum as follows:
- between all the live parts of the main circuit at different potential connected together (including the control and auxiliary circuits connected to the main circuit) and exposed conductive parts, with the main contacts of all switching devices in closed position;
- between each live part of the main circuit at different potential and the other live parts at different potential connected together and with the exposed conductive parts, with the main contacts of all switching devices in closed position.
The auxiliary circuits not connected to the main circuits shall be connected to earth.

Once defined the profile of the impulse, the other value allowing the verification is the peak one, which represents the absolute maximum of the function.

The present tendency, which is evident in the Tables of the IEC 61439-1, enhances some round figures such as six, eight, ten and twelve kV.

The direct test is performed according to a specific Table (Table 10 of the IEC 61439-1, shown below) which suggests the alternative between effective impulse, alternating voltage (r.m.s. value) and direct voltage, with the value defined as a function of the altitude and consequently of the quality of the ambient air around the assembly under test. The test is passed if no discharges are detected.

Figure 9.3



T1: peak time = 1.2 μs

T2: time at half value of U = 50 μs

Table 9.5

Rated impulse withstand voltage U_{imp} kV	Impulse withstand voltages									
	U1,2/50, a.c. peak and d.c. kV					R.m.s. value a.c. kV				
	Sea level	200 m	500 m	1 000 m	2 000 m	Sea level	200 m	500 m	1 000 m	2 000 m
2,5	2.95	2.8	2.8	2.7	2.5	2.1	2	2	1.9	1.8
4	4.8	4.8	4.7	4.4	4	3.4	3.4	3.3	3.1	2.8
6	7.3	7.2	7	6.7	6	5.1	5.1	5	4.7	4.2
8	9.8	9.6	9.3	9	8	6.9	6.8	6.6	6.4	5.7
12	14.8	14.5	14	13.3	12	10.5	10.3	9.9	9.4	8.5

Verification by assessment (as an alternative to testing) prescribes to verify that clearances between all live parts with risk of disruptive discharges shall be at least 1.5 times the values specified in Table 1 of IEC 61439-1 below.
The 1.5 safety factor takes into consideration manufacturing tolerances.

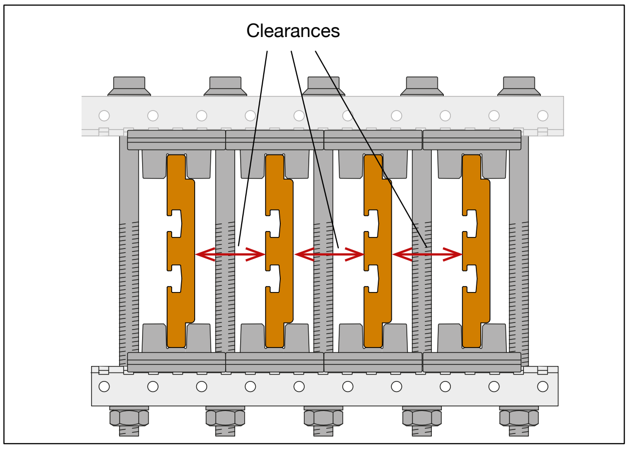
Table 9.6

Rated impulse withstand voltage U_{imp} kV	Minimum clearances mm
≤ 2,5	1,5
4,0	3,0
6,0	5,5
8,0	8,0
12,0	14,0

[a] Based on inhomogeneous field conditions and pollution degree 3.

Clearances may be verified by measurements or verification of measurements on design drawings.

Figure 9.4



It is evident that to guarantee a determined Uimp for the whole assembly, in addition to the test or verification which confirms this characteristic, also all incorporated devices shall have an equal or higher U_{imp} value.

ArTu and System pro *E* power power assemblies guarantee both 50 Hz dielectric withstand as well as impulse voltage withstand; in particular:

- versions L and M have:
  * U_n = 690 V
  * U_i = 1000 V
  * U_{imp} = 6 kV wall-mounted and 8 kV floor- mounted

- version K has
  * U_n and U_i = 1000 V
  * U_{imp} = 8 kV

- version System pro *E* power has:
  * U_n and U_i = 1000 V
  * U_{imp} = 12 kV

10 Protection against electric shocks

The following prescriptions are aimed at ensuring that the protective measures required are taken when the assembly is installed in the electrical plant, in compliance with the relative standards.

10.1 Protection against direct contact

Protection against direct contact can be obtained both by means of the assembly construction itself as well as by means of complementary measures to be used during installation.
The protective measures against direct contact are:

- **Protection by insulation of live parts**
  Live parts shall be completely covered with an insulation that can only be removed by destruction.
  This insulation shall be made of suitable materials capable of durably withstanding the mechanical, electrical and thermal stresses to which the insulation may be subjected in service.
  Paints, varnishes, lacquers and similar products used alone are generally not considered suitable for providing adequate insulation for protection against direct contact.

- **Protection by barriers or enclosures**
  All external surfaces shall provide a degree of protection against direct contact of at least IPXXB.
  Horizontal top surfaces of accessible enclosures having a height equal to or lower than 1.6 m shall provide a degree of protection of at least IPXXD.
  The distance between the mechanical means provided for protection and the live parts they protect shall not be less than the values specified for the clearances and creepage distances.
  All barriers and enclosures shall be firmly secured in place. Taking into account their nature, size and arrangement, they shall have sufficient stability and durability to resist the strains and stresses likely to occur in normal service without reducing clearances.

- **Protection by obstacles**
  This measure applies to open-type assembly.

10.2 Protection against indirect contact

The user shall indicate the protective measure to be applied to the installation for which the ASSEMBLY is intended.
The protective measures against indirect contact are:

- **Protection by using protective circuits**
  A protective circuit (coordinated with a device for automatic supply disconnection) can be realized either separately from the metal enclosure or the enclosure itself can be used as part of the protective circuit.
  The exposed conductive parts of the assembly which do not constitute a danger either because they cannot be touched on large surfaces or grasped with the hands because they are of small size (e.g. screws, nameplates, etc.) do not need to be connected to the protective circuits.
  Manual operating means, such as levers, handles and other metal devices, shall be either electrically connected in a secure manner with the parts connected to the protective circuits or provided with additional insulation adequate for the maximum insulation voltage of the assembly. Metal parts covered with a layer of varnish or enamel cannot generally be considered to be adequately insulated to comply with these requirements.
  For lids, doors, cover plates and the like, the usual metal screwed connections and metal hinges are considered sufficient to ensure continuity provided that no electrical equipment requiring earthing is attached to them. In this case, the exposed conductive parts shall be connected by a protective conductor whose cross-sectional area is in accordance with Table 10.3, depending on the highest rated operational current In of the apparatus attached, or, if the rated operational current of the attached apparatus is less than or equal to 16 A, by an equivalent electrical connection especially designed and verified for this purpose (sliding contacts, hinges protected against corrosion).
  The cross-sectional area of protective conductors (PE, PEN) in an assembly intended to be connected to external conductors shall be determined through one of the following methods:

a) the cross-sectional area of the protective conductor shall not be less than the appropriate value shown in the following Table.

Table 10.1

Cross-section of the phase-conductor S (mm)	Minimum cross-section of the corresponding protective conductor S (mm)
S ≤ 16	S
16 < S ≤ 35	16
35 < S ≤ 400	S/2
400 < S ≤ 800	200
S > 800	S/4

If a non-standard value results from the application of Table 10.1, the larger standardized cross-section nearest to the calculated value shall be used.

The values of this Table are valid only if the protective conductor (PE, PEN) is made of the same material of the phase conductor. If not, the cross-sectional area of the protective conductor (PE, PEN) is to be determined in a manner which produces a conductance equivalent to that which results by applying Table 10.1.

For PEN conductors, the following additional requirements shall apply:

- the minimum cross-sectional area shall be 10 mm^2 for a copper conductor and 16 mm^2 for an aluminium one;
- the cross-sectional area of the PEN conductor shall not be lower than that of the neutral conductor*;
- the PEN conductors do not need to be insulated within an assembly;
- the structural parts shall not be used as a PEN conductor. However, mounting rails made of copper or aluminium may be used as PEN conductors;
- for certain applications in which the current in the PEN conductor may reach high values, for example large fluorescent lighting installations, a PEN conductor having the same or higher current carrying capacity as the phase conductors may be necessary; this shall be subject of special agreement between manufacturer and user.

* The minimum cross-sectional area of the neutral in a three-phase circuit plus neutral shall be:
- for circuits with a phase conductor of cross-sectional area S ≤ 16 mm^2, 100% of that of the corresponding phases;
- for circuits with a phase conductor of cross-sectional area S > 16 mm^2, 50% of that of the corresponding phases with 16 mm^2 minimum.

It is assumed that the neutral currents do not exceed 50% of the phase currents.

b) the cross-sectional area of the protective conductor (PE, PEN) can be calculated with the aid of the following formula:

$$S_P = \frac{\sqrt{I^2 t}}{k}$$

This formula is used to calculate the cross-section of the protective conductors necessary to withstand the thermal stresses caused by currents of duration in a range between 0.2s and 5s, where:
Sp is the area of the section expressed in mm^2;
I is the r.m.s. value of the fault current (in AC) flowing through the protective device, expressed in A, for a fault of negligible impedance;
t is the trip time of the breaking device in seconds;
k is a factor whose value depends on the material of the protective conductor, on the insulation and on other elements, as well as on the initial and final temperature (see table 10.2).

Table 10.2

Values of factor k for insulated protective conductors not incorporated in bare cables or bare protection conductors in touch with cable coatings

		PVC	XLPE EPR Bare conductors	Butyl rubber
Final temperature		**160 °C**	**250 °C**	**220 °C**
K for conductor	copper	143	176	166
	aluminium	95	116	110
	steel	52	64	60

Note: it is presumed that the initial temperature of the conductors is 30°C.

The exposed conductive parts of a device that cannot be connected to the protective circuit through its own fixing means, shall be connected to the protective circuit of the assembly by means of a conductor, whose cross-section shall be chosen according to the following Table:

Table 10.3

Rated operational current I_n (A)	Minimum cross-sectional area of the equipotential protective conductor (mm^2)
$I_n \leq 20$	S
$20 < I_n \leq 25$	2.5
$25 < I_n \leq 32$	4
$32 < I_n \leq 63$	6
$63 < I_n$	10

S: cross-sectional area of the phase conductor

- **Protection realized with measures other than the use of protective circuits**
  Electrical assemblies can provide protection against indirect contact by means of the following measures that do not require a protective circuit:
  a) electrical separation of the circuits;
  b) full insulation.

10.3 Safe management of the assembly

The use of the assembly shall guarantee the usual safety protections, both in case of operation as well as in case of replacement of small components, such as lamps and fuses, on behalf of ordinary personnel, if such procedure is foreseen.
More complex and dangerous operations may be performed by authorized personnel only and refer to the carrying out of particular procedures and the use of particular safety components, as regards the accessibility of the assembly, for:
- inspections and controls;
- maintenance;
- extension works also in the presence of live parts.

11 Practical indications for the construction of assemblies

11.1 Construction of electrical assembly

Mounting of the different mechanical and electrical components (enclosures, busbars, functional units, etc.) that constitute the assembly system defined by the original manufacturer shall be carried out in compliance with the instructions (technical catalogue/assembly instruction manual) of the manufacturer.

After the preparation of the loose parts to be assembled, the first step is constructing the metalwork structure. When considering ArTu assembly, the structure can be already available as monobloc structure, and this is the case of ArTu M, or to be made up as for ArTu L and K and System pro *E* power.

For small and medium size assemblies the insertion of the components inside the assembly can be carried out more easily by arranging the enclosure horizontally on suitable trestles. Thus, working in this way it is possible to avoid keeping arms up and legs bent as it would be instead with an enclosure in vertical position.

A further advantage as regards the internal accessibility is obtained by working without the metal side panels of the structure, thus leaving bare the whole internal wiring system.
Obviously, it is suitable to proceed by mounting the apparatus from the centre towards the outside, connecting the cables little by little and inserting them in the relevant cable ducts.
Already at this stage, particular attention shall be paid to respect the minimum creepage distances and clearances between the different live parts and the exposed conductive part.

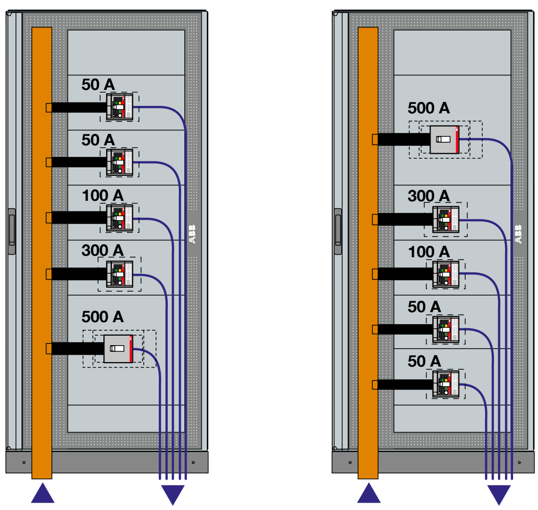
11.2 Positioning of the circuit-breakers

Here are some general indications for the best positioning of the circuit-breakers inside the assembly.
It is the panel builder that, since he better knows the details of the plant, the installation place and the actual use, can design the switchboard front in an optimal way.

- A good rule is trying to position the circuit-breakers so as to shorten the paths of the higher currents, thereby reducing the power loss inside the assembly with undoubted benefits from the thermal and economical point of view.

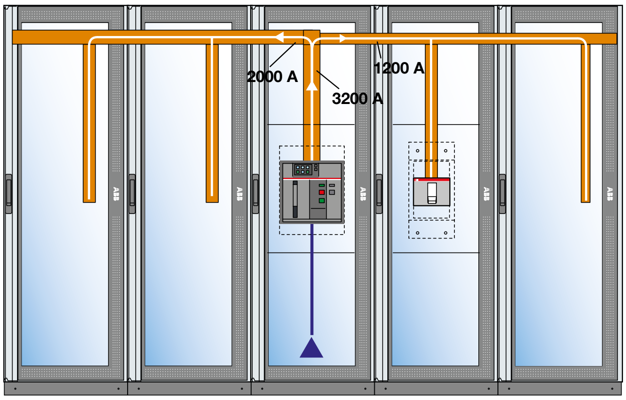
Figure 11.1

Recommended positioning method:	**Positioning method NOT recommended:**
The HIGHEST current (500 A) takes the SHORTEST path	The HIGHEST current (500 A) takes the LONGEST path



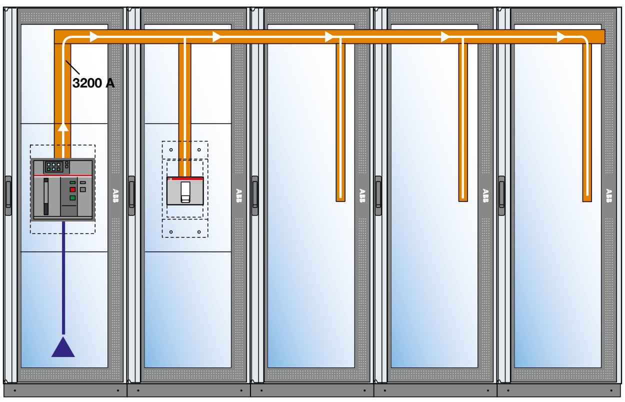
- In the case of assemblies with many columns, it is advisable to position the main circuit-breaker in the central column.
  Thus the current is immediately divided into the two branches of the assembly and the cross-sectional area of the main distribution busbars can be reduced.

Figure 11.2



In the example given in the figure, the main busbar system can be sized for 2000 A, with a considerable economic advantage.

Figure 11.3



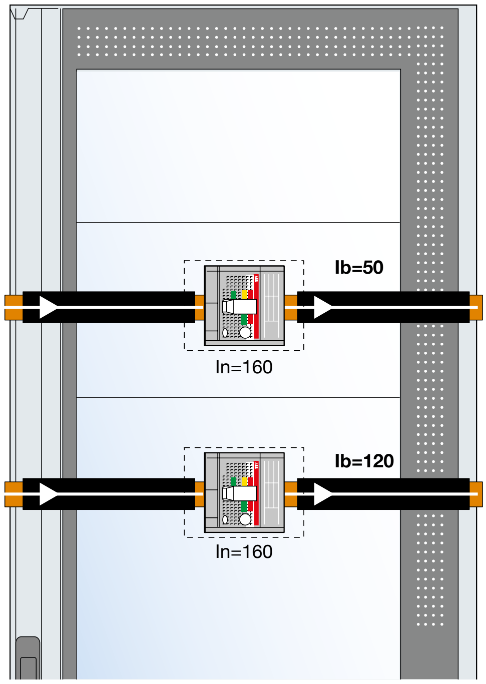
In this case, on the other hand, the main busbar system must be sized to carry 3200 A.

- It is advisable to position the largest and consequently the heaviest circuit-breakers at the bottom. This permits greater stability of the assembly, especially during transport and installation.

- In an electric assembly the temperature varies vertically:
  - the lowest areas are the coldest ones;
  - the highest areas are the hottest ones.

For this reason, it is advisable to place the apparatus passed through by a current close to the rated value at the bottom (more loads) and at the top the apparatus passed through by a current far from the rated value (more discharges).

Figure 11.4



- To facilitate the operation of large apparatus it is advisable to place them at a distance of 0.8 to 1.6 m to the ground.

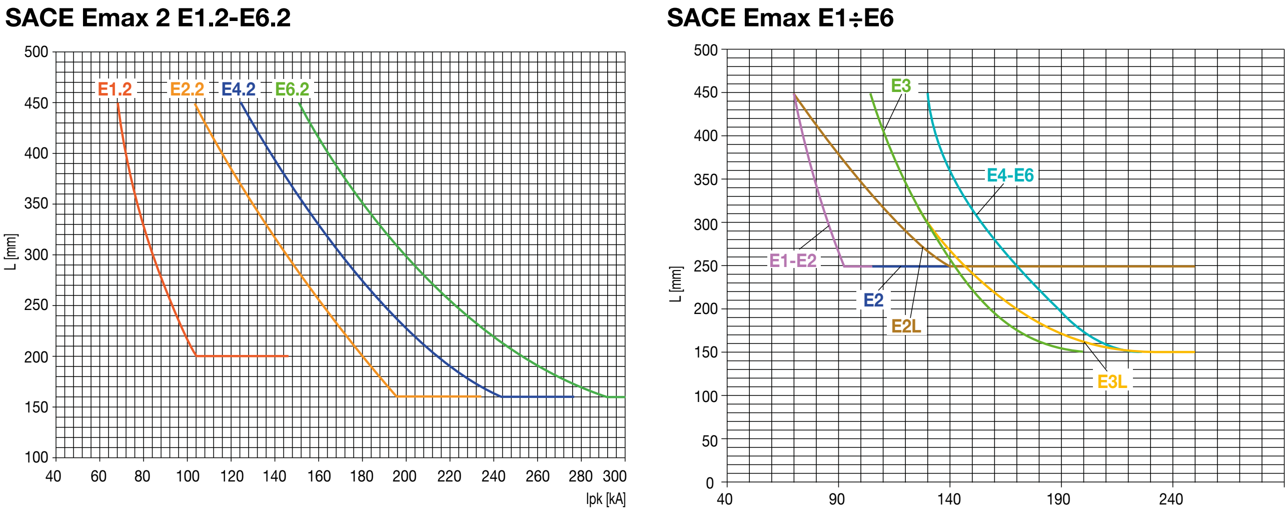
11.3 Anchoring of the conductors near to the circuit-breakers

It is necessary for the cables and busbars inside the assemblies to be fixed to the structure. In fact, during a short-circuit, the electrodynamic stresses generated in the conductors could damage the terminals of the circuit-breakers.

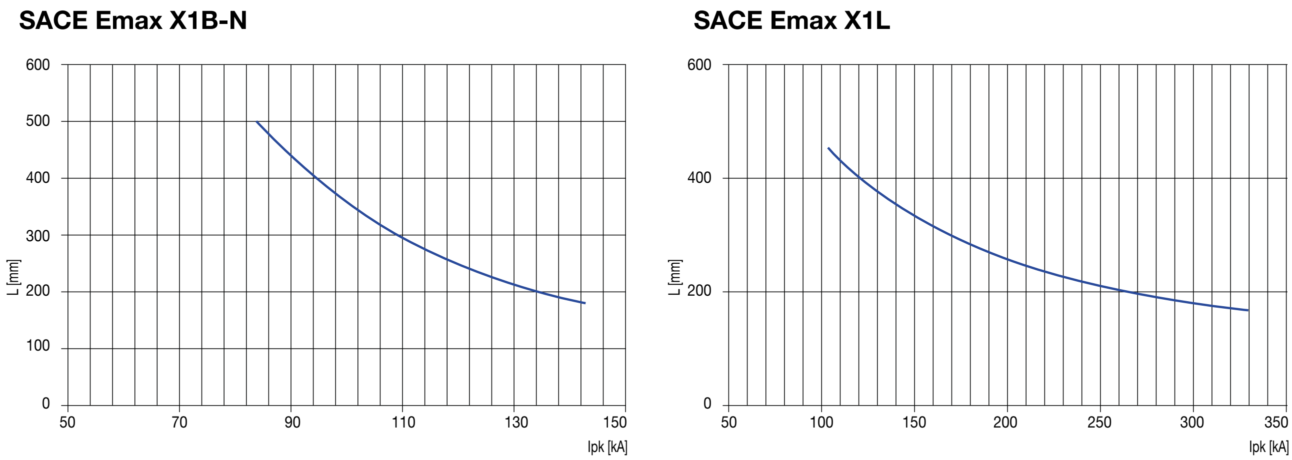
Air circuit-breakers

For information about the maximum distance in (mm) at which the first anchor plate of the distribution busbars connecting to the circuit-breaker must be positioned - according to the circuit-breaker type and to the maximum admissible short-circuit current peak (Ipk) - reference must be made to the following curves.

Figure 11.5



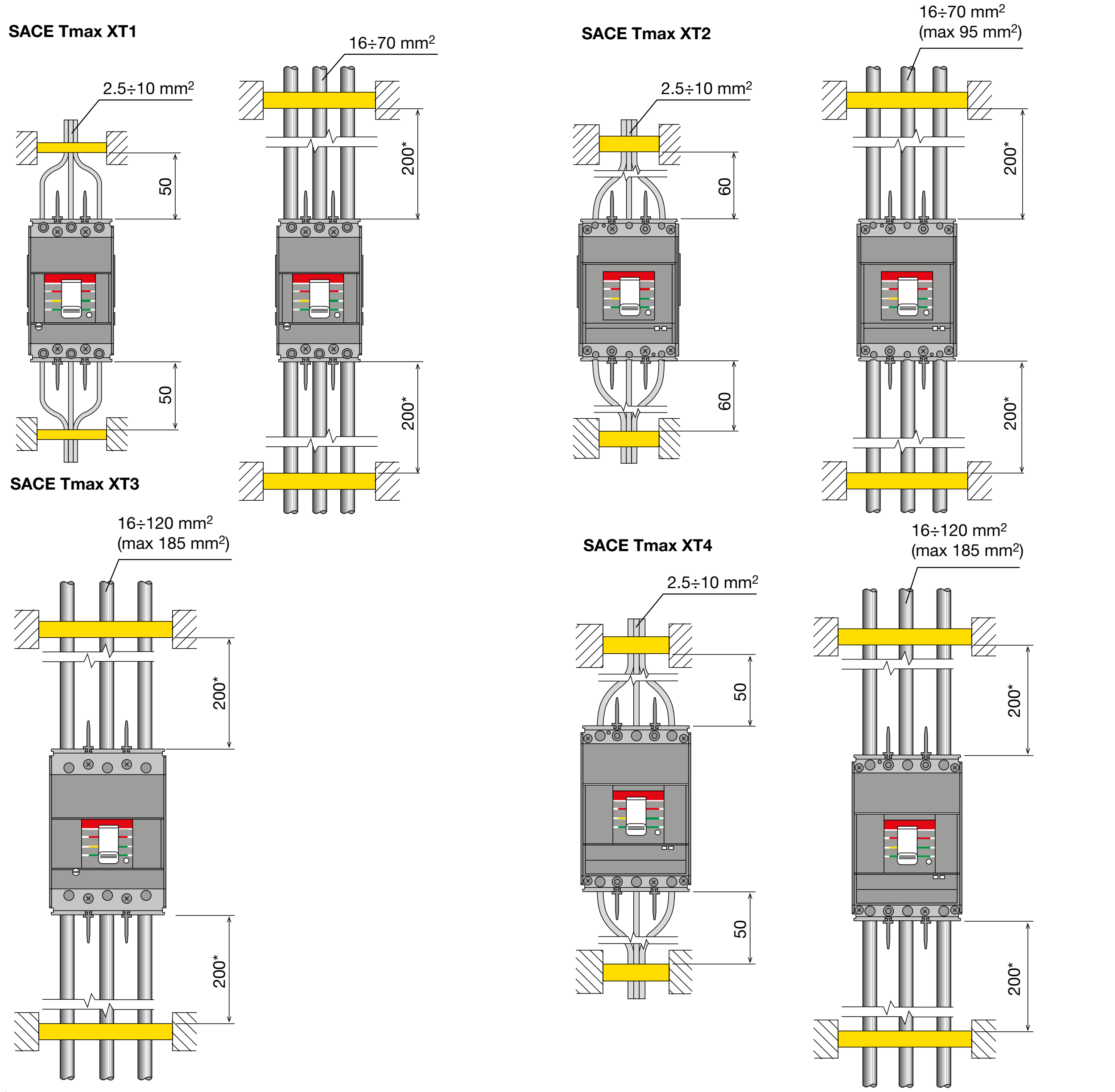
Positioning distance recommended for the first anchor plate according to the maximum prospective short-circuit current peak and to the circuit-breaker type. Circuit-breaker with horizontal and vertical terminals.



Molded-case circuit-breakers SACE Tmax XT

For the molded-case circuit-breakers SACE Tmax XT1, XT2, XT3 and XT4, Figure 11.6 gives an example of the maximum recommended distance (in mm) at which the first anchor plate shall be positioned according to the highest admissible peak current value of the circuit-breaker and the cross-sectional area of the cable. For further information and details, reference must be made to the technical catalogues and instruction manuals of the circuit-breakers.

Figure 11.6



(*) Value valid also with:
- rear adjustable terminals R (for fixed circuit-breakers)
- rear horizontal terminals HR (for the fixed part of plug-in/withdrawable circuit-breakers)
- rear vertical terminals VR (for the fixed part of plug-in/withdrawable circuit-breakers)

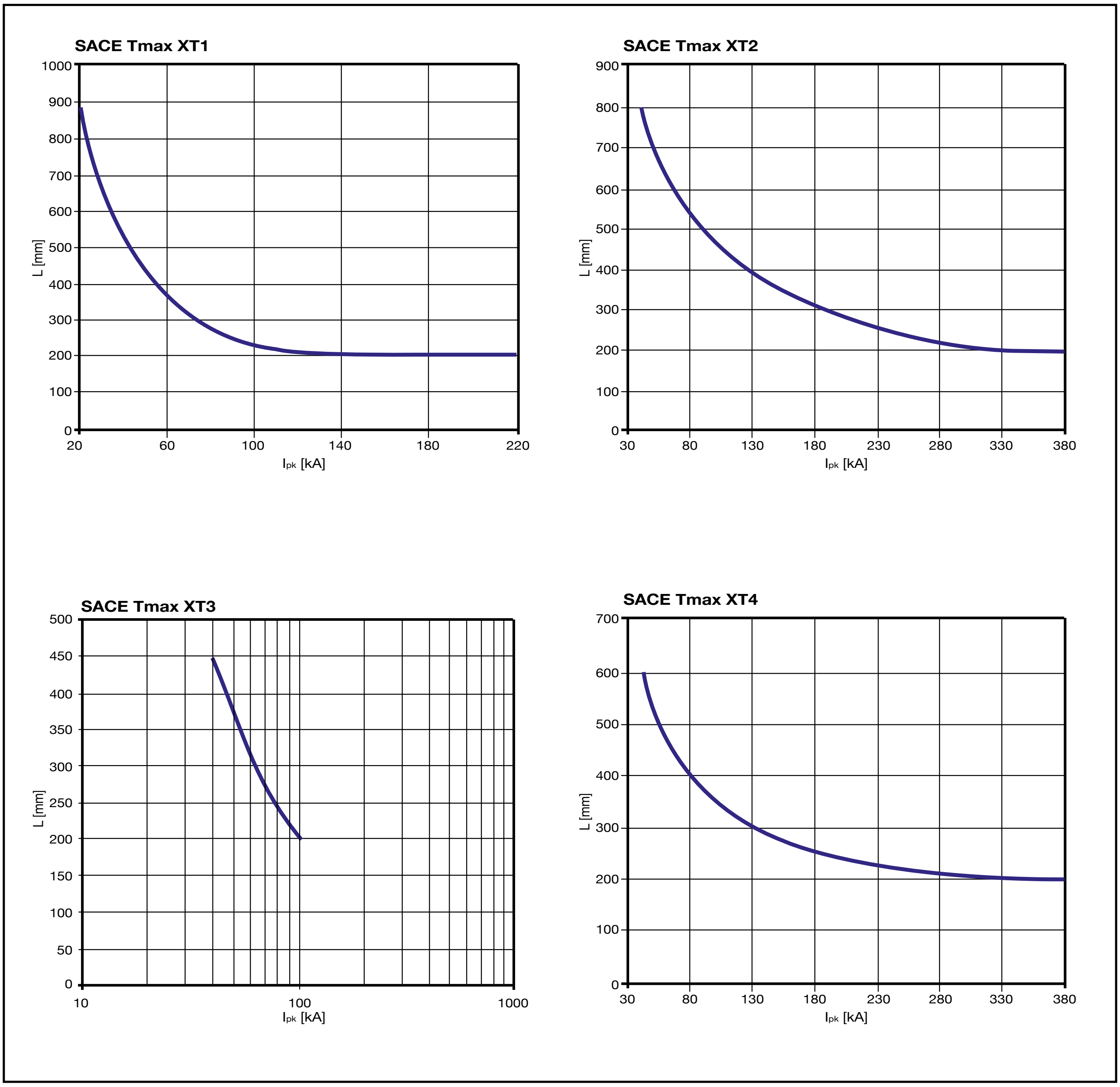
Below are the diagrams giving the maximum distances admitted between the terminals of the circuit-breaker and the first anchor plate of the conductors based on the maximum prospective short-circuit current peak and circuit-breaker typology.

With conductors, the following is meant:
- cables, for values of current up to 400 A;
- cables or equivalentbars listed in table 12 of the Standard IEC61439-1, for values of current higher than 400 A but not exceeding 800 A;
- bars, for values of current higher than 800 a and not exceeding 4000 A.

SACE Tmax XT

- Positioning distance recommended for the first anchor plate of the conductors according to the peak value of the prospective short-circuit current. These graphs are valid for connections with rigid bars.

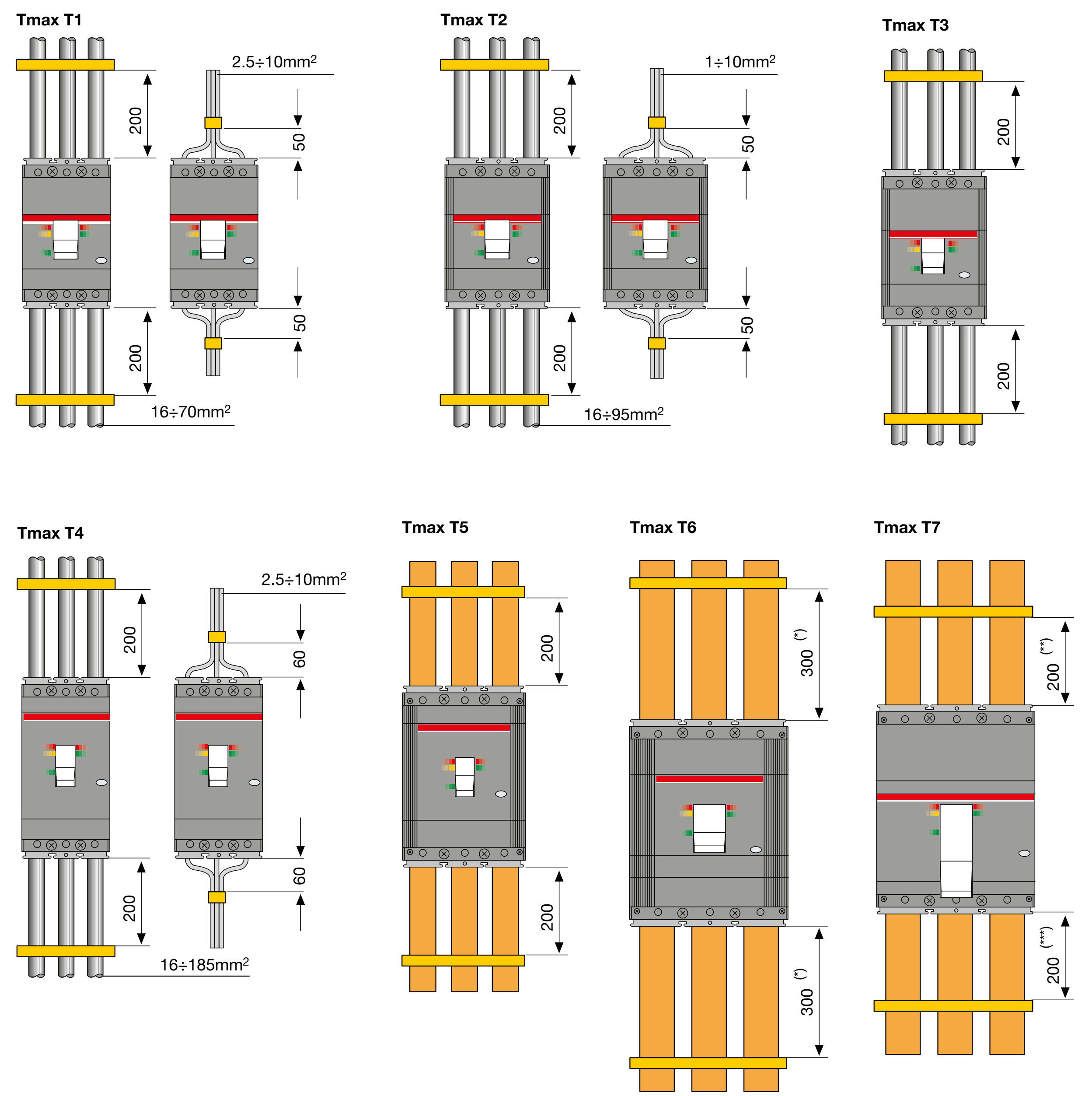
Figure 11.6a



Tmax

For Tmax molded-case circuit-breakers, Figure 11.7 gives an example of the maximum distance (in mm) recommended for the position of the first anchor plate, making reference to the highest peak current value admitted for the circuit-breaker. For further details reference shall be made to the technical catalogues and the circuit-breakers manuals.

Figure 11.7

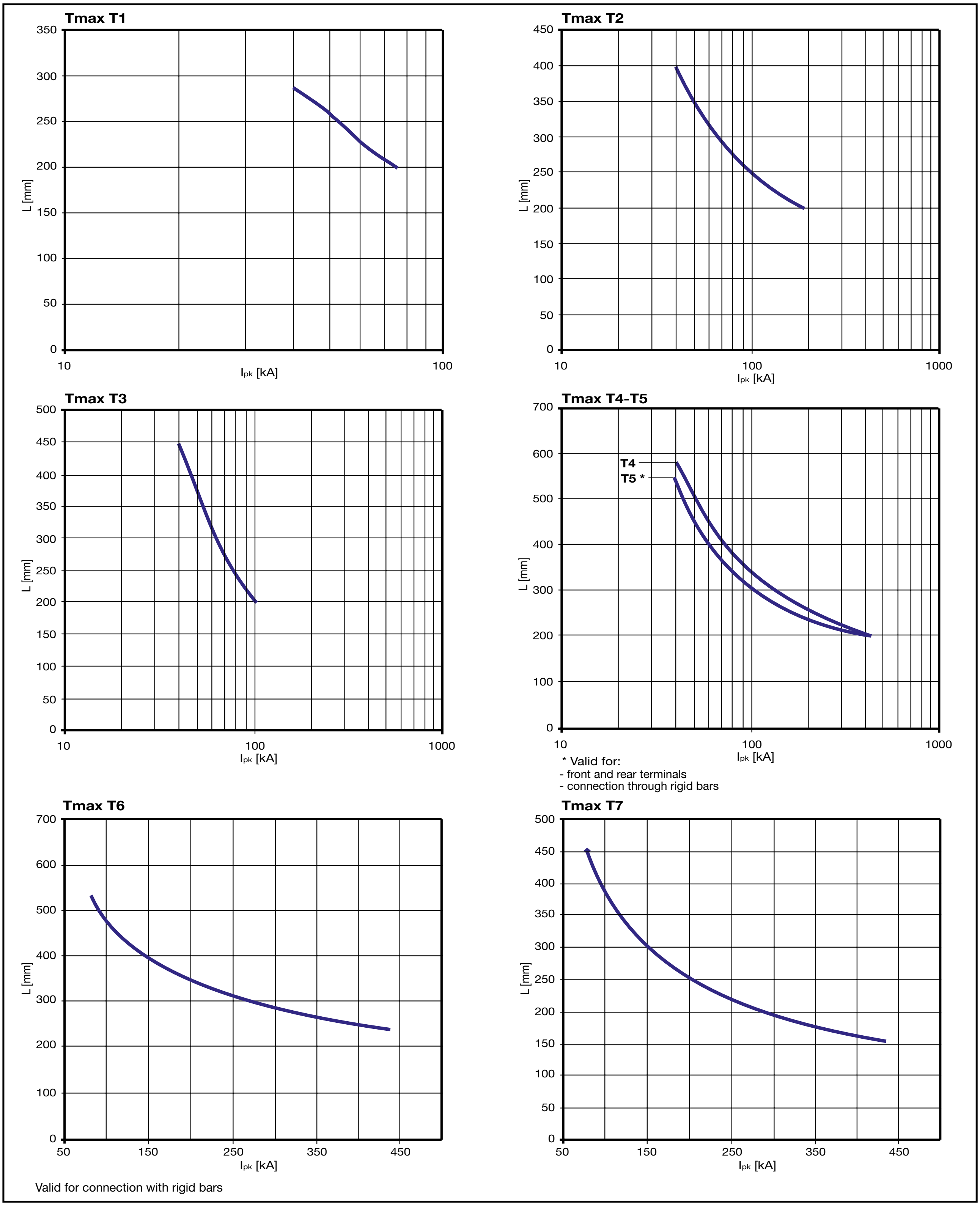


(*) 250 mm for T6 1000.
(**) 220 mm for T7, withdrawable with front extended terminals or front extended spread terminals.
(***) 240 mm for T7, withdrawable with front extended terminals or front extended spread terminals.

Tmax

- Positioning distance recommended for the first anchor plate of the conductors according to the maximum prospective short-circuit current peak. These graphs are valid for connections with rigid bars.

Figure 11.7a



11.4 Indications for the connection of the circuit-breakers to the busbar system

In order to get a connection allowing an adequate heat exchange between the terminals and the distribution system of the assembly, ABB SACE gives some indications about the minimum cross-sectional area for the cables and busbars to be used.

Table 11.1 below refers to the molded-case circuit-breakers series Tmax T and SACE Tmax XT and Table 11.2 to the air circuit-breakers series Emax, Emax X1 and SACE Emax 2.

The cross-sectional area of the cables and busbars shown in the Tables 11.1 and 11.2 are those used to determine the current carrying capacity in free air of the circuit-breakers in compliance with the product Standard IEC 60947-2.

Air circuit-breakers

Table 11.1

Circuit-breakers SACE Emax 2	Vertical terminals [n //] x [mm x mm]	Horizontal terminals [n //]x[mm x mm]
E1.2 B/C/N 06	2x40x5	2x40x5
E1.2 B/C/N 08	2x50x5	2x50x5
E1.2 B/C/N 10	2x50x8	2x50x10
E1.2 B/C/N 12	2x50x8	2x50x10
E1.2 B/C/N 16	2x50x10	3x50x8
E2.2 B/N/S/H 08	1x60x10	1x60x10
E2.2 B/N/S/H 10	1x60x10	1x60x10
E2.2 B/N/S/H 12	2x60x10	2x60x10
E2.2 B/N/S/H 16	1x100x10	2x60x10
E2.2 B/N/S/H 20	2x80x10	3x60x10
E2.2 B/N/S/H 25	4x100x5	3x60x10
E4.2 N/S/H/V 20	2x80x10	2x80x10
E4.2 N/S/H/V 25	2x100x10	2x100x10
E4.2 N/S/H/V 32	3x100x10	3x100x10
E4.2 N/S/H/V 40	4x100x10	4x100x10
E6.2 H/V/X 40	4x100x10	4x100x10
E6.2 H/V/X 50	5x100x10	5x100x10
E6.2 H/V/X 63	6x100x10	6x100x10

For further information see the Tecnichal Catalogue “SACE Emax 2 New low voltage air circuit-breakers” Chapter 6 (pages 6/16 to 6/22, Installation - Performance in switchgear”).

Table 11.2

Circuit-breakers Emax X1	Vertical terminals [n //] x [mm]x [mm]	Horizontal terminals [n //] x [mm] x [mm]
X1 B/N/L 06	2x40x5	2x40x5
X1 B/N/L 08	2x50x5	2x40x5
X1 B/N 10	2x50x8	2x50x10
X1 L 10	2x50x8	2x50x10
X1 B/N 12	2x50x8	2x50x10
X1 L 12	2x50x8	2x50x10
X1 B/N 16	2x50x10	3x50x8

Circuit-breakers Emax 2	Vertical terminals [n //] x [mm x mm]	Horizontal and front terminals [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/V 32	3x(100x10)	3x(100x10)
E4S/H/V 40	4x(100x10)	6x(60x10)
E6V 32	3x(100x10)	3x(100x10)
E6H/V 40	4x(100x10)	4x(100x10)
E6H/V 50	6x(100x10)	6x(100x10)
E6H/V 63	7x(100x10)	-

Molded-case circuit-breakers

Tabella 11.2

Circuit-breaker SACE Tmax XT	In [A]	Cables [n //] x [mm²]
XT2	≤ 8	1
XT2	10	1,5
XT2	12,5	2,5
XT1-XT2-XT4	16	2,5
XT1-XT2-XT4	20	2,5
XT1-XT4	25	4
XT1-XT2-XT4	32	6
XT1-XT2-XT4	40	10
XT1-XT2-XT4	50	10
XT1-XT2-XT3-XT4	63	16
XT1-XT2-XT3-XT4	80	25
XT1-XT2-XT3-XT4	100	35
XT1-XT2-XT3-XT4	125	50
XT1-XT2-XT3-XT4	160	70
XT3-XT4	200	95
XT4	225	95
XT3-XT4	250	120

Circuit-breaker Tmax T	In [A]	Cables [n //] x [mm²]	Busbars [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	
T3-T4	250	120	
T4-T5	320	185	
T5	400	240	
T5	500	2x150	2x30x5
T5-T6	630	2x185	2x40x5
T6	800	2x240	2x50x5
T6	1000	3x240	2x60x5
T7	1250	4x240	2x80x5
T7	1600	5x240	2x100x5

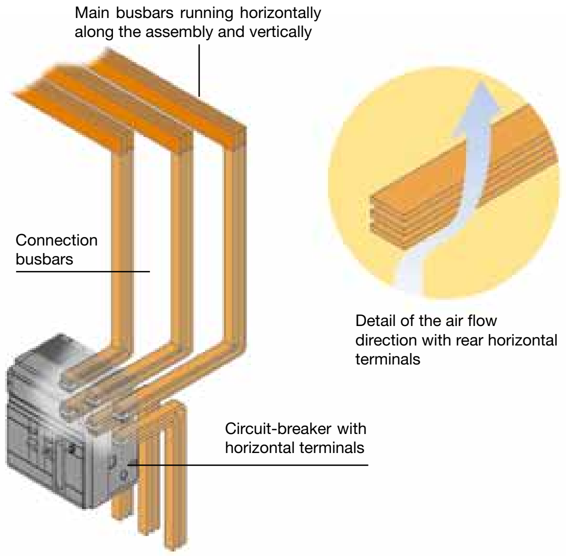
To obtain a better dissipation of heat by exploiting thermal convention*, it is advisable to use rear vertical terminals which, in comparison with the horizontal ones, impede less natural air circulation (see Figure 11.8) thus increasing heat dissipation.

With the new SACE Emax 2 circuit-breakers, the power terminals can be orientated; therefore, they can be positioned both horizontally or vertically, according to requirements, with no need of transformation kits. The orientation of the terminals can be locally modified

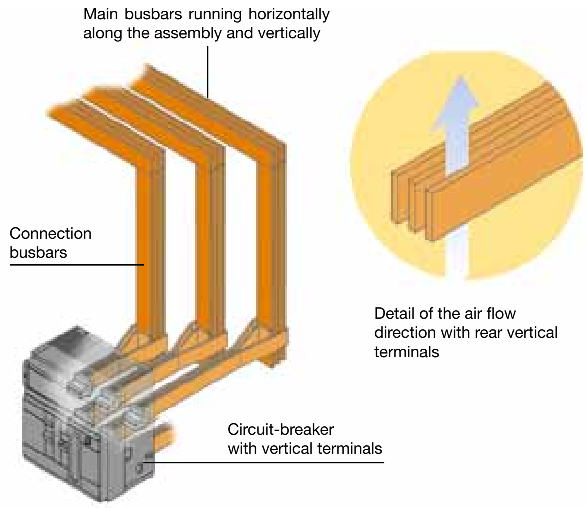
* Phenomenon based on the convective motion of the air that, by heating, tends to move upwards

Figure 11.8

Circuit-breaker with horizontal terminals and vertical main busbars



Circuit-breaker with vertical terminals and vertical main busbars

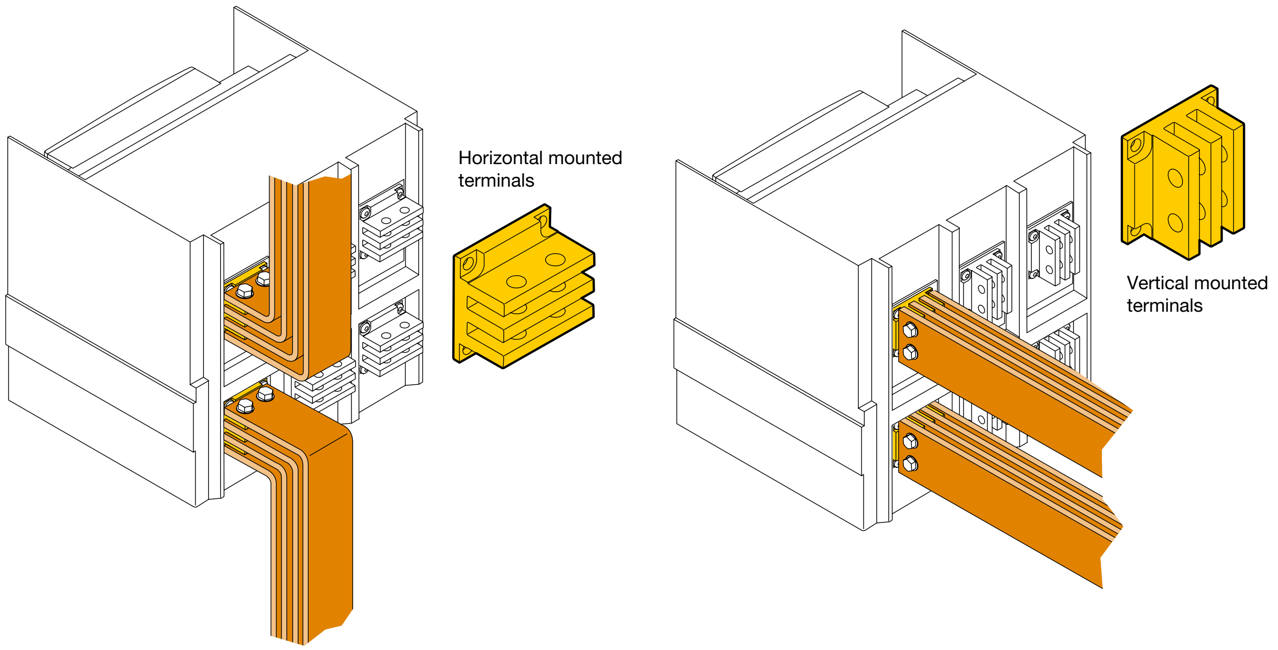


from horizontal to vertical position (or vice versa) with a 90° rotation. The orientation capability enables higher flexibility for connecting the circuit-breaker to the busbar system, and the possibility of mixed configuration with upper and lower terminals.

As standard supply, E2.2, E4.2 and E6.2 (in fixed or withdrawable version) are delivered with rear orientated terminals HR/VR (factory-mounted in horizontal position); E1.2, in fixed version, is delivered with front terminal F, whereas, in withdrawable version, is delivered with rear orientated terminals HR/VR (factory-mounted in horizontal position).

Figure 11.9

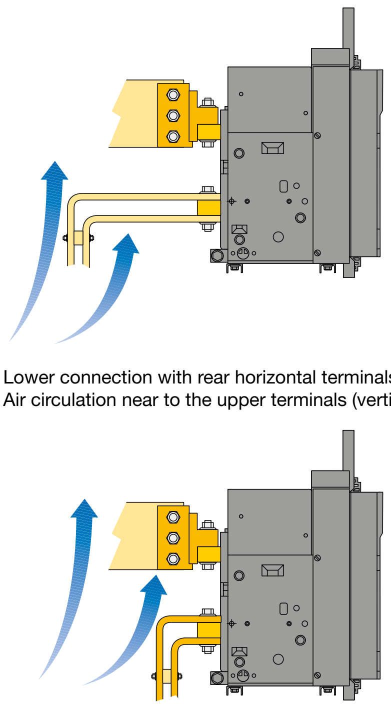
Emax E4.2 orientable terminals



When in the presence of upper vertical terminals and lower terminals of other type, or however when in the presence of different upper and lower terminals, it is necessary to adopt solutions not impeding air circulation towards the upper terminals.

As Figure 11.10 shows, the lower terminals shall not excessively divert the air flow and prevent it from reaching the upper terminals thus causing the loss of the benefits of cooling by convection.

Figure 11.10

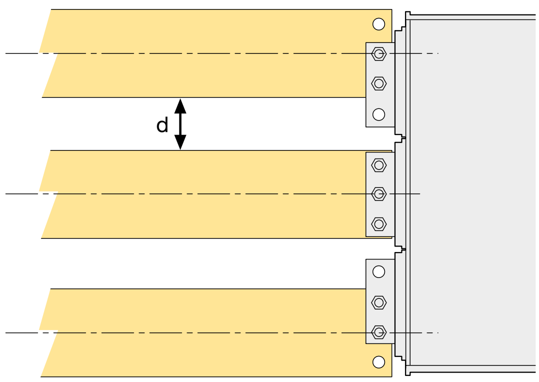


Lower connection with rear horizontal terminals.
Air circulation near to the upper terminals (vertical) Is limited.

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

To reduce heating at the circuit-breaker terminals, the positioning of the busbars gets a remarkable importance. Considering that, the more clearance between the busbars, the more heat they dissipate, and that the upper middle terminal usually has major problems from a thermal point of view, to reduce heating (for example when considering three-pole circuit-breakers), it is possible to take out of alignment the external connections with respect to the terminals, thus increasing the distance “d” (see Figure 11.11).

Figure 11.11



11.5 Indications for the installation distances of the circuit-breakers

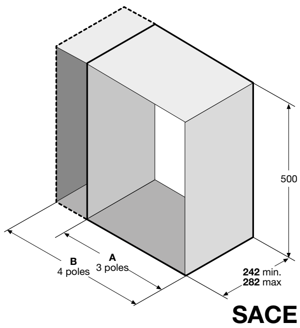
The Standard IEC 61439-1 assigns the circuit-breaker manufacturer the task of defining the indications and the prescriptions for the installation of these devices inside the assembly.

Below are, for ABB SACE circuit-breakers series Tmax T, SACE Tmax XT, Emax X1, Emax and SACE Emax 2 , the indications relevant to the distances to be complied with in the installations up to 690V a.c.; such distances are those specified in the circuit-breaker technical catalogues and in the installation manuals to which reference shall be made for further analysis.

Air circuit-breakers

Figure 11.12

Compartment dimensions



SACE Emax2 E1.2-E6.2

Emax	A [mm]	B [mm]	C [mm]	D [mm]
Fixed circuit-breakers				
E1.2	250	322	382.5 (1)	130
E2.2	400	490	500	221
E4.2	500	600	500	221
E6.2	900	1000	500	221
E6.2/f	-	1200	500	221
Withdrawable circuit-breakers				
E1.2	280	350	440 (2)	252
E2.2	400	490	500	355
E4.2	500	600	500	355
E6.2	900	1000	500	355
E6.2/f	-	1200	500	355

(1) 332.5 mm for voltages ≤ 440 V
(2) 390 mm for voltages ≤ 440 V

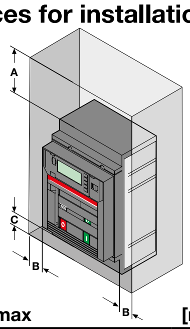
SACE Emax E1-E6

Emax	A [mm]	B [mm]	C [mm]	D [mm]
Fixed circuit-breakers				
E1	400	490	500	242
E2	400	490	500	282
E3	500	630	500	282
E4	700	790	500	282
E4/f	-	880	500	282
E6	1000	1130	500	282
E6/f	-	1260	500	282
Withdrawable circuit-breakers				
E1	400	490	500	380
E2	400	490	500	380
E3	500	630	500	380
E4	700	790	500	380
E4/f	-	880	500	380
E6	1000	1130	500	380
E6/f	-	1260	500	380

Figure 11.13

Emax X1

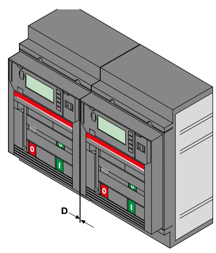
Insulation distances for installation in metal cubicle



	Emax	A [mm]	B [mm]	C [mm]
Un < 440V	X1 fixed version	50	20	10
	X1 withdrawable version	50	-	-
440 V ≤ Un≤ 690V	X1 fixed version	100	20	10
	X1 withdrawable version	100	-	-

Note: For the connections it is advisable to use insulated cables or bars, or to carry out specific type tests on the installation. For the insulation distance of the circuit-breakers up to 1000 V, please ask ABB SACE.

Distances between two circuit-breakers mounted side by side



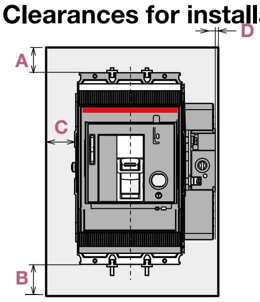
Emax	CB width [mm] 3 poles	CB width [mm] 4 poles	Distance D [mm] 3 poles	Distance D [mm] 4 poles
X1	210	280	0	0

Molded-case circuit-breakers

Figure 11.14

SACE Tmax XT

Clearances for installation in metallic cubicles



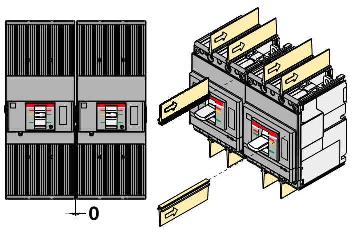
Circuit-breakers	Voltage AC [V]	Rear insulating plate	Phase separators (***)	A (**) [mm]	B (**) [mm]	C [mm]	D [mm]
XT1	Ue ≤ 690	no	YES	25	20	20	-
XT2	Ue < 440	yes (*)	YES	30	25	10	0
	440 ≤ Ue ≤ 690	yes (*)	YES	50	45	20	0
XT3	Ue ≤ 690	no	YES	50	20	20	-
XT4	Ue < 440	yes (*)	YES	30	25	20	0
	440 ≤ Ue ≤ 690	yes (*)	YES	50	45	20	0

(*) For circuit-breakers in fixed version F only.
(**) - For XT2 and XT4 W/P: with EF terminals A=B=50mm from the upper outline of the terminal and for each voltage Ue.
- For XT2 and XT4 W/P: in case of circuit-breakers with high terminal covers (HTC) A = B = 25mm (the clearance is indicated to guarantee a vent exit for gas pressure).
- For XT1 and XT3 P: with EF terminals A=50mm B= 20mm from the upper outline of the terminal.
- For XT1 and XT2: in case of circuit-breakers with high terminal covers (HTC) A = 25mm (the clearance is indicated to guarantee a vent exit for gas pressure).
- For XT1 and XT3: in case of circuit-breakers with rear terminals and cubicle with insulated base B = 0.

(***) For further information about compatibility between types of terminals and phase separators, see Chapter 3 of the Technical Catalogue "SACE Tmax XT New low voltage molded-case circuit-breakers up to 250 A". With circuit-breakers in W or P version, low terminal covers (LTC) must be placed on the moving part and phase separators must be placed on the fixed part.

Minimum clearance between two side-by-side circuit-breakers

For side-by-side mounting verify that the connection bars or connection cables do not reduce clearances. When using spread or extended terminals, verify that clearances are not reduced.

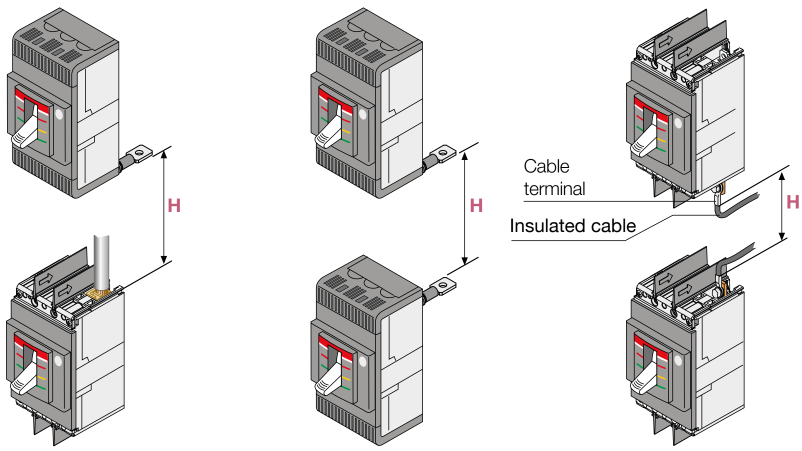


SACE Tmax	Distance D [mm]
XT1	0 (*)
XT2	0 (**)
XT3	0 (*)
XT4	0 (**)

(*) - either with phase separators between the two circuit-breakers and when ES (front extended spread) terminals are not used, or if the two circuit-breakers are provided with high terminal covers (HTC) and ES terminals are not used
- with ES or EF terminals D = 35 mm (clearance between terminals).
- with other types of terminals D = 25 mm.
(**) either with phase separators between the two circuit-breakers and when ES (front extended spread) terminals are not used, or if the two circuit-breakers are provided with high terminal covers (HTC) and ES terminals are not used
-with ES terminals D = 120 mm (clearance between the terminals)
-with EF terminals D = 35 mm (clearance between the terminals)
-with other types of terminals D = 25 mm.

Minimum clearance between two super-imposed circuit-breakers

Check that the bare bars or the connection cables do not reduce the recommended clearances. The distances reported in the table are referred to the maximum overall dimensions of the circuit-breakers in the different versions (F/W/P), including terminals and, for example, metallic lugs of insulating cables.



In case of cables with metallic lugs, an insulating screen behind the metallic lugs (on the rear of the circuit-breaker) or high terminal covers are mandatory.

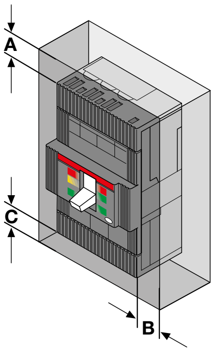
Circuit-breakers	H [mm]
XT1	80
XT2	140
XT3	140
XT4	150

For further information, see the document Product Note SACE Tmax XT – Installation tips. – The Product Note SACE Tmax XT – Installation tips (1SDC210058L0201) is available in ABB Library.

Figure 11.15

Tmax T

Insulation distances for installation in metal cubicle



Tmax	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 440 V ≤ Un ≤ 690 V: A = 60 mm , B = 25 mm, C = 45 mm
(**) - For Un < 440 V (T6N, T6S, T6H): A = 35 mm
- For Un < 440 V (T6L): A = 100 mm
- For 440 V ≤ Un ≤ 690 V: A = 100 mm
- For T6V: A = 150 mm
(***) - For 440 V ≤ Un ≤ 690 V: A = 100 mm
Note: As regards the insulation distances of 1000 V circuit-breakers, ask ABB SACE.

Minimum distance between two superimposed circuit-breakers

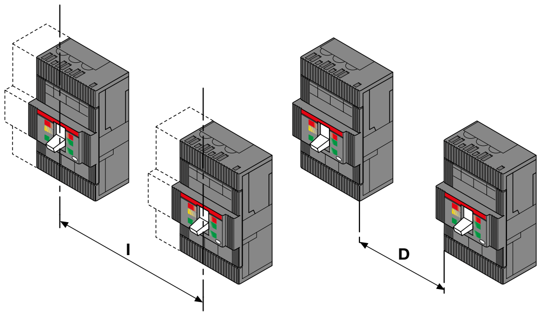
For superimposed assembling check that the connection bars or the connection cables do not reduce the air insulation distance.

Tmax	H [mm]
T1	80
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 distances to be respected must be added to the maximum overall dimensions of the various different versions of the circuit-breakers, including the terminals. For 1000 V versions, please ask ABB SACE.

Distance between two circuit-breakers side by side

For side-by-side or superimposed mounting verify that the connection bars or connection cables do not reduce clearances.



Minimum centre distance between two side-by-side circuit-breakers

Tmax	CB width [mm] 3 poles	CB width [mm] 4 poles	Centre distance I [mm] 3 poles	Centre distance I [mm] 4 poles
T1	76	101	77	102
T2	90	120	90	120
T3	105	140	105	140

Minimum distance between two side-by-side circuit -breakers

Tmax	Minimum distance D [mm]
T4 (*)	0 (for Un < 500 V a.c.)
T5 (*)	0 (for Un < 500 V a.c.)
T6N/S/H/L (**)	0
T7	0

(*) - For 500 V ≤ Un ≤ 690V: D = 40 mm
(**) - For T6V: D = 100 mm

11.6 Other logistical and practical indications

When assembling switchgear, attention shall be paid to gravity too.

Experience and common sense show that is advisable:

- to distribute homogeneously and comfortably the different components inside the assembly in the full respect of the ergonomics, of their use and of their possible repairing or replacement;
- to keep low the global center of gravity by positioning the heaviest equipment at the bottom, so that the maximum static stability can be achieved;
- to avoid overloading of the moving doors, so that frictions are not increased and the functionality and endurance of the hinges are not compromised;
- not to exceed the maximum fixing capacity of the rear and side panels reported in the assembling information sheets.

Here are some figures showing the static loading capacity of the different panels of ABB assemblies.

However, it is advisable to position transformers, bigger-size and consequently heavier circuit-breakers and ventilation motors, if any, at the bottom, so that a better stability of the assembly is ensured, above all during transport and installation.

After internal mounting has been completed, the sides, covers and closing doors of the metalwork structure are fixed. Then, the whole is lifted to the vertical position and after a last visual inspection the assembly becomes available for final testing (routine tests).

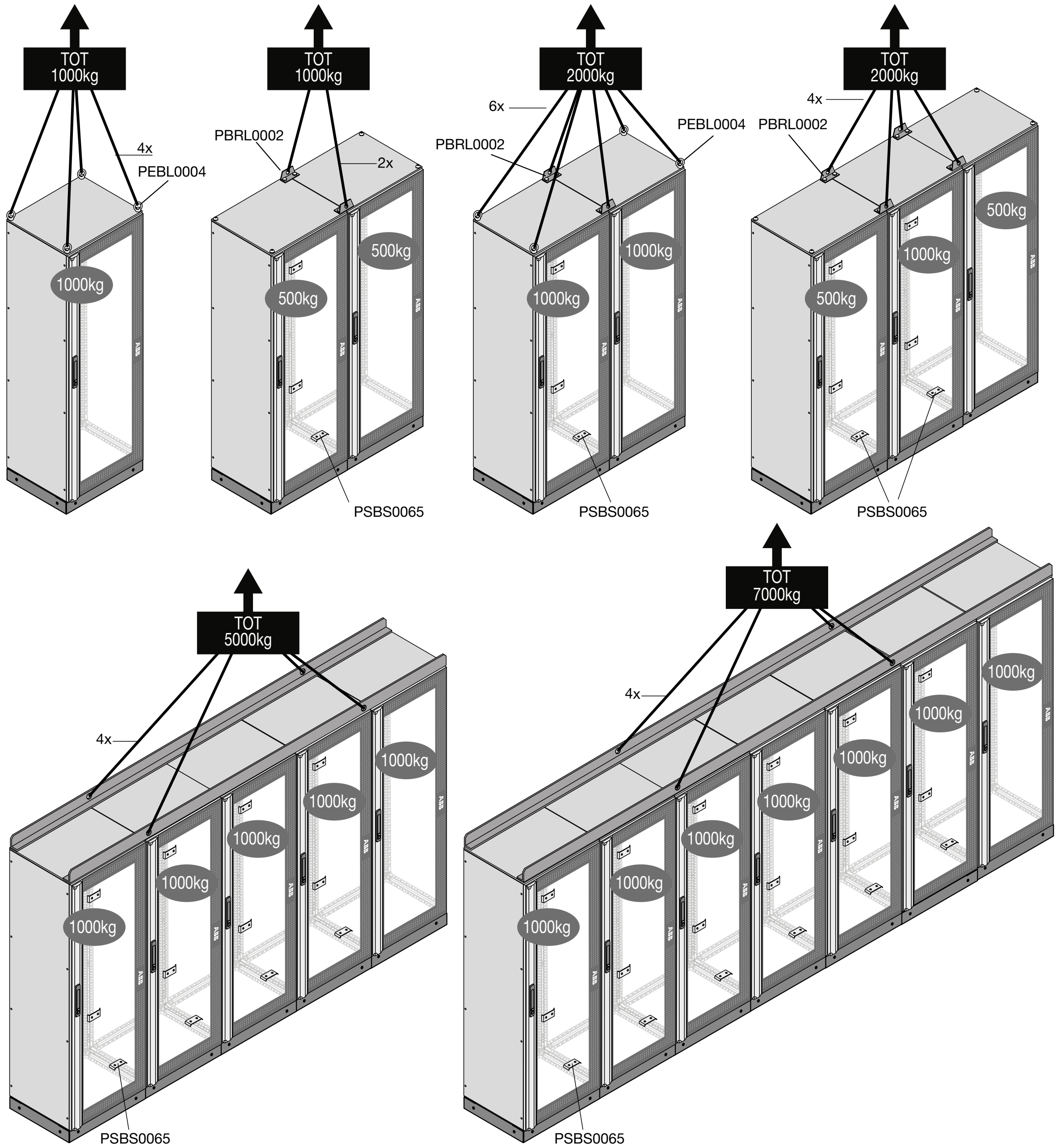
11.7 Handling, transport and final installation

In case of large power or automation systems, another critical situation is represented by the coupling of more compartments to get a set of assemblies.

Here is the mechanical connection which must be particularly painstaking, because of the remarkable stresses which the metalwork structures transmit to each other, above all in the delicate phase of loading and transport. Once again the importance of the assembly sheets emerges; they must be clear, detailed and complete, with all the information regarding tightening, relevant operation sequences, as well as the indication of the errors which are likely due to carelessness or inaccuracy. The following Figure highlights some points which require particular concentration to panel builders; attention shall be paid to the proper fixing which block to one another and in safety the metalwork structures. Particular attention shall be paid to the upper box shown in the figure and available in some versions.

Generally, this junction box is not suitable to support the

Figure 11.16

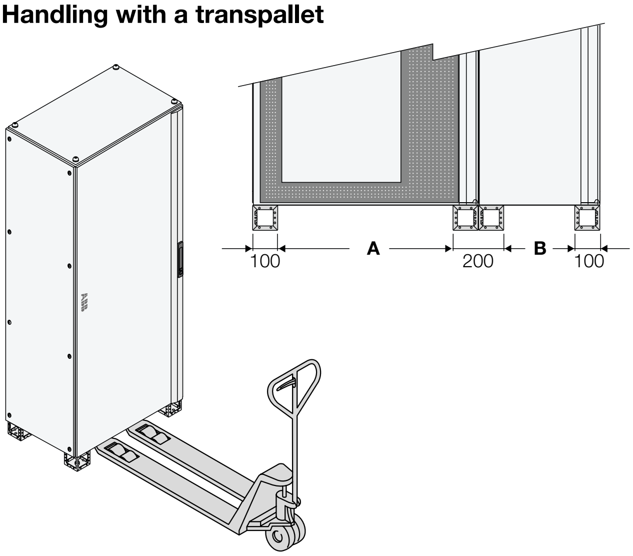


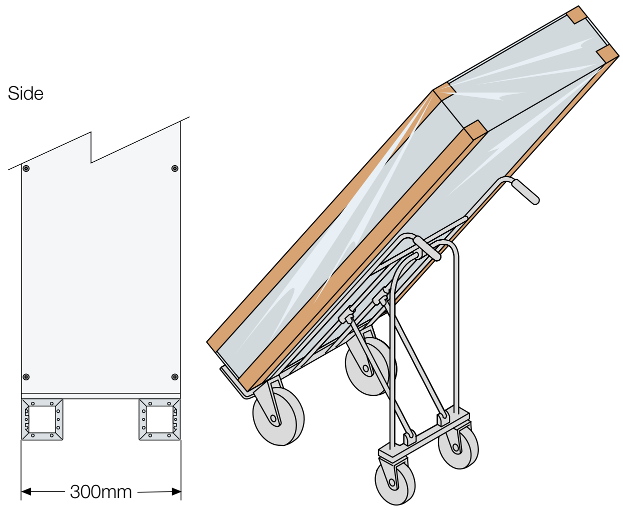
whole weight of the under hanging switchboard.
Consequently, it shall be mounted only after the switchboard has been lifted (as shown in Figure 11.17) and positioned where required.
When connecting more compartments the necessity of complying with the maximum static carrying capacity emerges both to guarantee an adequate resistance to vibrations and to enable proper lifting and transport to the final place of installation.
Usually the maximum values allowed are sufficient to meet also the heaviest cramming, without taking particular measures.

Figure 11.16 shows some arrangements involving also large overall dimensions and big weights. It should be noticed that every cubicle may have different loading capacity as regards weight and, for each configuration, the relevant methods for fixing, rope pulling and lifting are prescribed.
The new Standard IEC 61439-1 prescribes a specific test to be carried out at the laboratory to verify the lifting capacity.
Shallow switchboards should be handled in the following way:

Figure 11.17

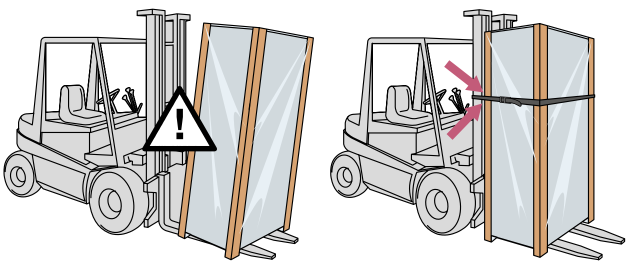
Handling with a transpallet





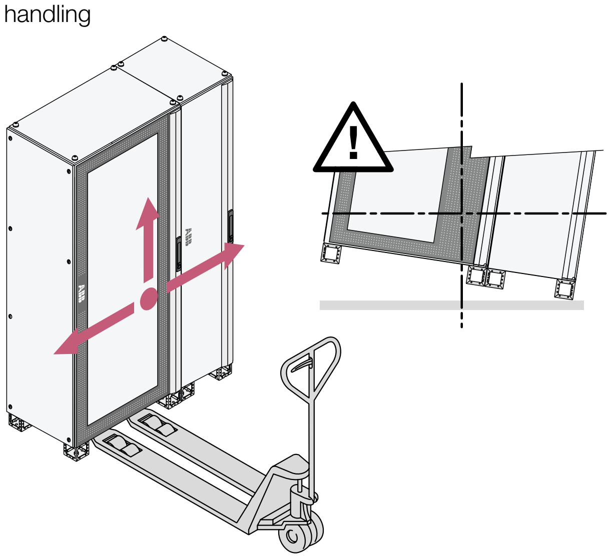
Dimensions	A (mm)
Width 300mm	198
Width 400mm	298
Width 600mm	498
Width 800mm	698
Width1000mm	898
Width 1250mm	1098

For extra safety, it is advisable to fasten the switchboard to the lift truck when using this type of vehicle for transport.



Check the center of gravity before handling structures measuring W =800/1000mm (with internal or external cable compartment) containing busbar systems.

handling



The switchboard, once wired and assembled, must be transported safely and easily, both when leaving the workshop of the panel builder as well as when entering the installation premises.
Due to the big overall dimensions and weights, it is advisable to follow suitable procedures and to use mechanical means “ad hoc”, as well as to pay particular attention while moving the assembly, so that the losses of balance, vibrations, shocks and risks of overturning of the switchboard are controlled and reduced to a minimum.

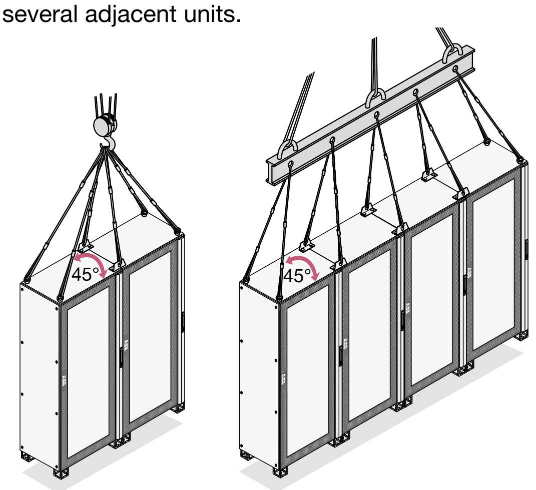
The properly dimensioned base strips of ABB SACE metalworks of ArTu and System pro *E* power series permit user-friendly insertion of the forks of the forklift trucks for lifting, after which the vertical anchoring of the switchboard to the side of the fork is advisable (see Figure 11.18). The absence of protrusions and sharp edges prevents any further risk of lesions or contusions for the operators.

Figure 11.18

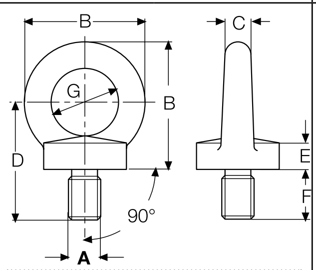
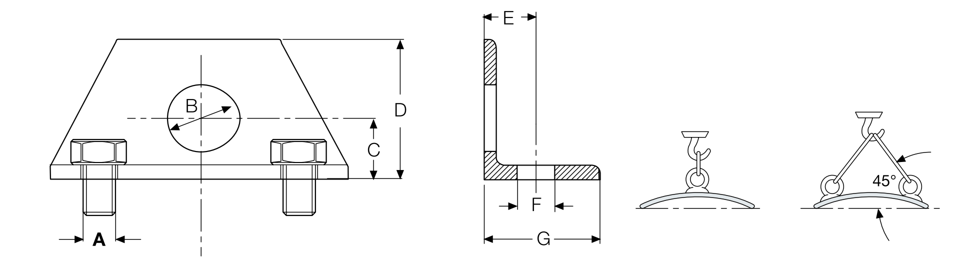
Handling with a bridge crane

Before handling switchboards with a crane or bridge crane, make sure that:
- the ropes or chains are in an excellent condition;
- the angle between the lifting ropes and the top of the switchboard must be ≥45°;
- up to 3 units can be carried at the same time;
- maximum weight lifted as established by Standard DIN 580 (M12).

To comply with the conditions described above, use a lifting beam with the appropriate characteristics when lifting several adjacent units.



Standard DIN 580 concerning mechanical connection components (only for eyebolts)

Eyebolts		Lifting reinforcements							
									
A	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)	Load 1 (kg)	Load 2 (kg)	Tightening (Nm)
Eyebolts									
M12	54	12	28	10	22	30	340	240	8*
Lifting reinforcements									
M12	Ø40	37	80	25	Ø14	60	510	350	40

* Tighten manually without mechanical tools since this could cause damages by reducing the eyebolt capacity.

11.8 Operations on switchgear assemblies in service

During standard handling and operation of assemblies, already positioned and in service in the plant or on-board, some intrusive actions may be necessary on them because of faults, normal ageing of the components, modifications or process expansions and more.
Access to assemblies is possible for:
- *inspection and other similar operations:*
  - *visual inspection;*
  - *inspection of the switching and protection devices;*
  - *setting of relays and trip units;*
  - *conductor connections and markings;*
  - *adjusting and resetting;*
  - *replacement of fuse-links;*
  - *replacement of indicating lamps;*
  - *measuring (of voltage and current, with suitable tools);*
  - *maintenance (also upon agreement between manufacturer-panel builder and user-customer);*
  - *expansions works either under or not under voltage (relevant national Standards, EN 50110-1 and relevant amendments).*

To this purpose it should be kept in mind that the present IEC Standards make a distinction between standard routine interventions, when just switching and control operations are carried out, and out-and-out electrical interventions, when the personnel operate directly on or close to live parts (either under or not under voltage) with consequent electrocution hazards.

The following illustration shows some examples of both situations.

From the definitions above it results that, as ABB SACE during the whole manufacturing process of circuit-breakers, metalwork structures and other auxiliary parts, also panel builders manufacturing the assembly do not carry out any electrical work. In fact, under such conditions, metal and insulating parts are handled but when they are not supplied yet; thus, since there are no electrocution hazards for definition, it cannot be considered as an electrical work.

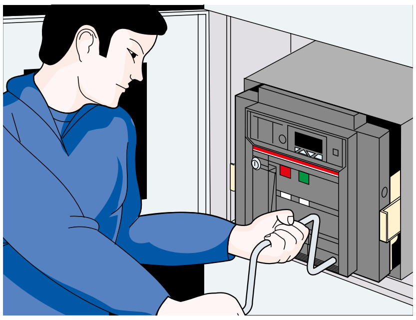
Figure 11.19

These are electrical works

Repair

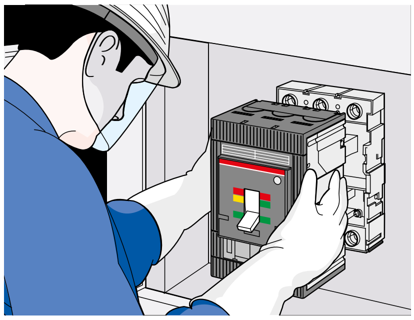
Assembly under voltage

Replacement



Work not under voltage, performed in compliance with the Standard CEI 11-27

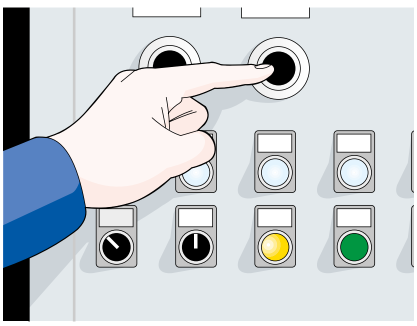
Replacement



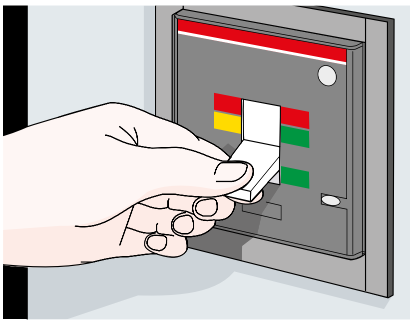
Assembly under voltage

These are not electrical works

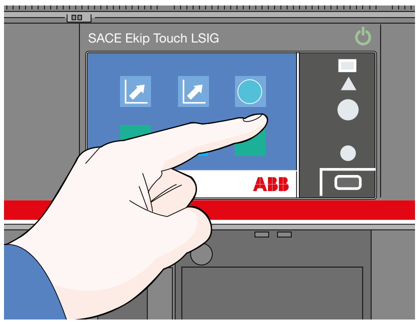
Operations



Circuit-breaker switching



Settings



12 Guide to the certification of assemblies

12.1 Compliance of assemblies with the Standards

ABB offers a system of assemblies subject to a series of verifications to guarantee the construction of equipment in full compliance with the IEC Standards performing only routine tests (commissioning test only on the assembly) and with no need for further laboratory tests.
To this end, it is necessary to use ABB metalwork structures (with the relevant accessories), ABB circuit-breakers (miniature, moulded-case and air series) and ABB SACE distribution systems and to observe the choice criteria and the mounting instructions of the different components.

Here are summarized the verifications prescribed by the Standard IEC 61439 to be carried out by the original manufacturer and the additional verifications to be performed by the end manufacturer of the assembly.
The first (original manufacturer) performs the design verifications (formerly type tests), that is:
- Strength of materials and parts;
- Degree of protection of assemblies;
- Clearances and creepage distances;
- Protection against electric shock and integrity of protective circuits;
- Incorporation of switching devices and components;
- Internal electrical circuits and connections;
- Terminals for external conductors;
- Dielectric properties;
- Verification of temperature rise;
- Short-circuit withstand strength;
- Electromagnetic compatibility (EMC);
- Mechanical operation.

As already seen, as an alternative or in addition to, the original manufacturer derives the assembly by comparison with the original design verified by tests or by assessment. For further details see Table 1.1 of this Technical Application Paper.
Instead, the assembly manufacturer shall perform the routine verifications (commissioning test), which comprise some visual inspections and the only real and instrumental test, that is a verification of dielectric properties.
- Dielectric properties: power-frequency withstand test at 50 Hz and impulse withstand voltage.

12.2 Main verifications to be carried out by the original manufacturer

Verification of temperature rise
As regards the verification of the temperature rise limits, the assembly may be verified:
1) by laboratory testing with current;
2) by derivation from the rated characteristics of a tested reference design;
3) by calculations (for single-compartment assemblies with rated currents not exceeding 630 A or for assemblies with rated currents not higher than 1600 A).
For further details see Chapter 7 of this Technical Application Paper.

Verification of dielectric properties
As specified in the Standard, the performance of this type test on the assembly parts which have already been type-tested in compliance with the relevant Standards is not required if the dielectric withstand has not been compromised during assembling operations.
As regards ABB assemblies and enclosures, their dielectric properties are shown in Table 12.1.

These characteristics are to be considered already verified, provided that the mounting instructions have been properly followed.

Table 12.1

		Rated voltage	Insulation voltage	Rated impulse withstand voltage
System pro *E* power	up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 12 kV
ArTu L	Wall-mounted D=200 mm	up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 6 kV
	Floor-mounted D=250 mm	up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 8 kV
ArTu M	Wall-mounted D=150/200 mm	up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 6 kV
	Floor-mounted D=250 mm	up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 8 kV
ArTu K		up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 12 kV
Enclosures SR2		up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 6 kV
Enclosures AM2		up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 8 kV
Enclosures IS2		up to 1000V AC/1500V DC	up to 1000V AC/1500V DC	up to 12 kV

Verification of short-circuit withstand strength
The short-circuit withstand strength is the subject of Chapter 8 of this Technical Application Paper.
As specified in the Standard, verification of short-circuit withstand strength is not required:
1) when it is not necessary according to the flow charts of clause 8.1;
2) for the auxiliary circuits of the assembly intended to be connected to transformers whose rated power does not exceed 10 kVA (for a rated secondary voltage of not less than 110 V), or does not exceed 1.6 kVA (for a rated secondary voltage less than 110 V), and whose short-circuit impedance is not less than 4% for both of them.

In particular, for the distribution systems (see the catalogue "System pro *E* power – New main distribution switchboards up to 6300A"), the short-circuit withstand strength is verified by the positive outcome of the flow charts of clause 8.3 and by the proper implementation of mounting instructions.

As regards the different types of switchgear, the following characteristics are considered as verified:

Table 12.2

		Rated short-time withstand current Icw		
		phase-to-phase	phase-to-neutral	Rated peak withstand current I_{pk}
System pro *E* power		120 kA (1s) - 69 kA (3s)	72 kA (1s)	264 kA
ArTu L	Wall-mounted D=200 mm	25 kA (1s)	9 kA (1s)	52.5 kA
	Floor-mounted D=250 mm	25 kA (1s)	21 kA (1s)	74 kA
ArTu M	Wall-mounted D=150/200 mm	25 kA (1s)	9 kA (1s)	52.5 kA
	Floor-mounted D=250 mm	35 kA (1s)	21 kA (1s)	74 kA
ArTu K		105 kA (1s) - 50 kA (3s)	60 kA (1s)	254 kA
Enclosures IS2		65 kA (1s)	39 kA (1s)	143 kA

Verification of the short-circuit withstand strength of the protective circuit

Table 12.3

Verification of the effective connection of the exposed conductive parts of the assembly and of the protective circuit	By complying with the assembling instructions of the metal components, the effective earth continuity between the exposed conductive parts is verified, with negligible resistance values
Short-circuit withstand strength of the protective circuit: phase-earthing busbar	By complying with the assembling instructions and the indications on page 44 and 45 of this technical paper the short-circuit withstand strength of the protective circuit is verified

Maximum short-circuit withstand strength phase-earthing busbar for structure

System pro *E* power		72 kA (1s)
ArTu L	Wall-mounted D=200 mm	9 kA (1s)
	Floor-mounted D=250 mm	21 kA (1s)
ArTu M	Wall-mounted D=150/200 mm	9 kA (1s)
	Floor-mounted D=250 mm	21 kA (1s)
ArTu K		60 kA (1s)
Enclosures IS2		39 kA (1s)

Verification of the creepage distances and clearances
By complying with the mounting and erection instructions for ABB SACE metalwork structures and circuit-breakers, the creepage distances and clearances are guaranteed.

Verification of mechanical operation
By complying with the mounting instructions for ABB SACE metalwork structures and circuit-breakers, the mechanical operation is ensured.

Verification of the degree of protection
By complying with the mounting instructions for ABB SACE metalwork structures and circuit-breakers the following degrees of protection are verified:

Table 12.4

		Without door	With door and ventilated side panels	Without door with kit IP41	With door
System pro *E* power		IP 30 / IP 31	IP 40 / IP 41	-	IP 65
ArTu L	Wall-mounted D=200 mm	IP 31	-	-	IP 43
	Floor-mounted D=250 mm	IP 31	-	-	IP 43
ArTu M	Wall-mounted D=150/200 mm	-	-	-	IP 65
	Floor-mounted D=250 mm	IP31	-	-	IP 65
ArTu K		IP 31	IP 41	IP 41	IP 65
Enclosures SR2		-	-	-	IP 65
Enclosures AM2		-	-	-	IP 65
Enclosures IS2		-	-	-	IP 65

12.3 Routine verifications (testing) to be carried out by the assembly manufacturer

The routine tests, sometimes called testing of the assembly, prescribed and defined by the Standard IEC 61439-1, shall be carried out on the assembly by the manufacturer, after assembling and wiring.
These verifications are intended to detect faults in materials and workmanship faults of the components and/or in the assembly construction.
A good result of the routine tests allows the issue of a positive test report (testing and inspection report).

Procedures and performance modalities of routine verifications
The assembly manufacturer can define a procedure regarding:
- test conditions (skilled personnel, area of the workshop destined for testing, etc.) and safety measures;
- reference documents (technical dossiers, mounting instructions, technical standards, etc.);
- identification of the material and visual inspections, mechanical and electrical checks;
- dielectric tests;
- check on the means of protection and verification of the service continuity of the protective circuit;
- measurement of the insulation resistance as an alternative to the dielectric test;
- the final documentation (test report).

Although the routine tests are usually carried out in the workshop of the assembly manufacturer or of the panel builder, the installer is not exempt from checking that after transport and installation the switchgear assembly has not undergone such damages or modifications that it no longer meets the requirements already verified by the routine tests.

Test conditions and safety measures
It is recommended that the assemblies ready to undergo the routine tests inside the workshop be positioned in separate areas where only qualified personnel have free access.
Should this not be possible, for example due to lack of space, the area for the tests must be marked off by barriers, notices or visible barriers.
Of course the verifications can only start after assembling.

During the verification of the dielectric properties, for example during the applied voltage test, the insulating gloves provided must be worn and the suitable pistol type push rods with retractile tips must be used. The operator's body and arms should be suitably protected, except when the voltage is applied from an adequately safe distance.

Here are some rules for carrying out the individual tests in safety.
Before testing:
- position the assembly in a suitable area;
- install the protection barriers properly;
- make the assembly power supply connections properly (earth and power supply);
- make the joined connections according to the same principles (interconnection between exposed conductive parts and connections to earth);
- make sure that the safety devices used perform properly (e.g. the emergency push button, the flashing danger-signaling devices, etc.);
- make sure that inside the area reserved for testing there are no unauthorized persons.

During testing:
- in the event of a suspension of the tests, even if temporary, it is necessary that the equipment being tested is disconnected;
- for verifications or electrical measurements to be carried out under voltage, it is necessary that the person in charge is aware of dangers, that the measuring instruments used meet the safety requirements and that suitable protective devices and means are used (e.g. insulating gloves, etc.);
- cables or electric equipment shall not be left outside the marked off testing area.

Reference documents

The elements specific to the switchgear assembly to be tested, to which the tester can duly refer, are the diagrams (single-line, functional, mimic diagrams, etc.), the drawings (switchboard front, overall dimensions, etc.) and the particular specifications received with the assembly.

In addition to the latest edition of the technical Standards the assembly is declared to comply with, the inspector, may also refer to IEC 60529 (degrees of protection provided by enclosures) and to IEC 60664-1(rules for insulation coordination of equipment).

12.4 Routine verifications in compliance with the Standard IEC 61439-2

Routine verifications represent the last technical job of the assembly manufacturer before the delivery of the switchgear assembly completed and before invoicing and shipment to the customer. The Standard describes the verifications in the following order:

- **Degree of protection of enclosures**
  It represents the first routine test prescribed by the Standard IEC 61439-1.
  Actually, it is reduced to a visual inspection.

- **Clearances and creepage distances**
  Clearances usually results, also at visual inspection, quite higher than necessary.
  As regards creepage distances, reference shall be made to the values defined by the Standard (shown in Table 9.6, clause 9.2 of this Technical Application Paper); for further details reference shall be made to clause 12.6 of the Technical Application Paper, "Routine verification of impulse withstand voltage".

- **Protection against electric shock and integrity of the protective circuits**
  It is based on a visual inspection and on some verifications of the correct mechanical tightness on a random basis. The proper realization of the protective circuit is verified:
  - visually (e.g. checking of the presence of devices which guarantee contact for earthing conductor continuity etc.);
  - mechanically (checking of connection tightness on a random basis);
  - electrically (verification of the circuit continuity).

  The tools used are a tester and a torque wrench.

- **Incorporation of built-in components**
  The real correspondence of the installed equipment with the assembly manufacturing instructions is checked.

- **Internal electrical circuits and connections**
  Verification on random basis of correct tightening of terminals is required.

- **Terminals for external conductors**
  Correspondence of cables and terminals is checked according to the wiring diagram.

- **Mechanical operation**
  Levers, pushbuttons and any possible mechanical actuating element are operated on a random basis .

- **Dielectric properties**
  See clause 12.6.

- **Wiring, operational performance and function**
  The nameplate is checked and, if necessary, electrical operation and any possible safety interlocks shall be verified by test.

12.5 Further checks during testing

Further checks to be carried out during testing may be:

Visual inspections

They are carried out visually taking into account:

a) compliance of the assembly with diagrams, designations, drawings and type of enclosures, number and characteristics of equipment, cross-sectional area of conductors and presence of identification marks on cables and devices (initialing, inscriptions on plates, etc.);

b) presence of components which allow the degree of protection (top, gaskets) and the absence of faults on the enclosure (cuts, perforations which might jeopardize the degree of protection) to be guaranteed;

c) compliance with the specific prescriptions, if required in the assembling list, such as:
   - coating or treatment of busbars (resin coating, silver plating, etc.);
   - type of cable (fireproof, ecological, etc.);
   - completion spare parts;
   - painting check (color, thickness, etc.).

Mechanical checks

They shall be carried out complying with the relevant documents, making reference to the following specifications:

- correct assembling of the equipment (connections and, on a random basis, proper tightening of the connections);
- positioning and tightening of nuts and bolts;
- mechanical locks and controls (rack-in locking devices, mechanical interlocks, key interlocks and manual operating mechanisms for the removal of circuit-breakers and switch-disconnectors by using the operating levers and accessories provided with the assembly);
- closing and possible blocks of the doors and adhesion of the dust-proof seals to the assembly structure.

Electrical checks

Functional tests consist in checking the correct functioning of all the circuits (electrical and electromechanical) by simulating, as far as possible, the different service conditions of the assembly.

For example, tests on current and voltage circuits can be carried out by supplying the secondary circuits of the CTs and VTs, without disconnecting the CTs from the circuit. Electrical checks may include the verification of the proper operation of circuits and equipment, in particular:

- control, signaling, alarm, trip and reclosing circuits;
- lighting and heating circuits, if present;
- protection and measuring circuits (overcurrent, overvoltage, earth and residual current trip units, contactors, ammeters, voltmeters, etc.);
- terminals and contacts available in the terminal box;
- insulation control devices (also creepage distances and clearances must be verified for connections and adaptations carried out at workshop).

To carry out these checks, in addition to the normal mechanical tools used for assembling, also some electrical tools are necessary. A periodical calibration is necessary to obtain reliable results.

The tools generally used are:

- a tester or multimeter;
- a test bench (AC and DC) to supply the assembly during the test of the operation under voltage;
- a torque wrench (to check that the correct tightening torques have been applied to the connections) and other tools.

12.6 Further details on routine verifications of dielectric properties

These tests are intended to verify the insulation, the excellence of the insulating materials and correct connection of the equipment being tested.
During testing, for switchgear assemblies exceeding 250 A, the test voltage at 50 Hz frequency is applied for 1 second, at the different polarities and with the r.m.s. values defined by the Standard (see Tables 9.1 and 9.2 at clause 9.1 of this Technical Application Paper);
for 690 V ≤ Ui ≤ 800 V the test voltage value is 2000 V.
These tests are not required on auxiliary circuits protected by devices with ratings not exceeding 16 A, or when the circuits have already passed an electrical function tests.

Dielectric test

Once disconnected the assembly on both the supply as well as on the load side, the voltage test is applied with all the protection and switching apparatus closed, or the test voltage shall be applied successively to the different circuits of the assembly.
For this test, a voltage generator at industrial frequency (dielectrometer) may be used.
The test is satisfactory if during voltage application neither punctures or flashovers occur.
All current-consuming devices (windings, power supply, measuring instruments, measurement modules, electronic residual current circuit-breakers, etc.) in which the application of test voltages would cause damages shall be disconnected.

Table 12.5

Residual current releases

Circuit-breaker	Residual current release	Operation to be carried out
Tmax T1-T2-T3	RC221	Turn the special selector on the release front to Test-position. Disconnect YO2 trip coil
Tmax T1-T2-T3 T4-T5 (4-pole only)	RC222	Turn the special selector on the release front to Test-position. Disconnect YO2 trip coil
Tmax T3 e T4 (4-pole only)	RC223	Turn the special selector on the release front to Test-position. Disconnect YO2 trip coil
SACE Tmax XT1-XT3	RC Sel 200*-RC Inst-RC Sel-RC B Type** *for XT1 only ** for XT3 only	Turn the special selector to Test-position. Disconnect YO2 trip coil
SACE Tmax XT2-XT4	RC Sel	Turn the special selector to Test-position. Disconnect YO2 trip coil
SACE Tmax XT1-XT2-XT3- XT4	RCQ020/A	Disconnect all the wires related to the terminals of RCQ020/A unit
Tmax T1..T7	RCQ-RCQ020/A (rated current up to 800A)	Disconnect all the wires related to the terminals of RCQ020 unit
Emax X1 (rated current up to 800 A)	RCQ020/A	Disconnect all the wires related to the terminals of RCQ020 unit
Emax E1..E3 (rated current up to 2000A)	RCQ	Manual disconnection

Electronic trip units

Circuit-breakers	Trip units	
Tmax T2-T4-T5-T6	PR221-PR222DS/P	No operation
	PR222DS/PD-PR223DS e EF	Disconnect, if any, the rear connectors X3 and X4
SACE Tmax XT2-XT4	Ekip family	No operation
Tmax T7 Fixed version	PR231-PR232	No operation
	PR331	Disconnect, if any, wiring relevant to: T5, T6, K1, K2, W3, W4, 98S, 95S
	PR332	Disconnect, if any, wiring relevant to: T5, T6, T7, T8, T9, T10, K1, K2, K11, K12, K13, K14, K15, K21, 98S, 95S, W1, W2, W3, W4, C1, C2, C3, C11, C12, C13
Tmax T7 Wthdrawable version	PR231-PR232 PR331-PR332	Take the circuit-breaker to the racked-out position
Emax X1 Fixed version	PR331	Disconnect, if any, wiring relevant to: T5, T6, K1, K2, W3, W4, 98S, 95S
	PR332-PR333	Disconnect, if any, wiring relevant to: T5, T6, T7, T8, T9, T10, K1, K2, K11, K12, K13, K14, K15, K21, 98S, 95S, W1, W2, W3, W4, C1, C2, C3, C11, C12, C13.
Emax X1 Wthdrawable version	PR331-PR332-PR333	Take the circuit-breaker to the racked-out position
Emax E1-E6	PR121	Disconnect, if any, wiring relevant to: T5, T6, K1, K2, W3, W4
Fixed version	PR122-PR123	Disconnect, if any, wiring relevant to: T5, T6, T7, T8, K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, K12, K13, K14, K15, W1, W2, W3, W4, C1, C2, C3, C11, C12, C13, D1, D2, D13, D14, R1, R2, 37, 38.
Emax E1-E6 Wthdrawable version	PR121-PR122-PR123	Take the circuit-breaker to the racked-out position
SACE Emax 2 (E1.2 to E6.2) Withdrawable version	Ekip Dip, Ekip Touch/Ekip Hi-Touch trip units	Take the circuit-breaker to withdrawn position
SACE Emax 2 (E1.2 to E6.2) Fixed version	Ekip Dip, Ekip Touch/Ekip Hi-Touch trip units	Disconnect (if any) wirings or terminals for auxiliary connections related to: Ekip Signalling 4K, S51, S33, M, YR, Trip Unit I/O, YU/YO2, YC, YO, Ekip Supply and all other cartridge modules

Measurement modules

Circuit-breaker and trip unit	Measurement module	Operation to be carried out
Emax equipped with PR122 or PR123 Fixed version	PR120/V	Turn the special selector to the Test-position marked as "Insulating Test"
Emax X1 equipped with PR332 or PR333 Tmax T7 equipped with PR332 Fixed version	PR330/V	Turn the special selector to the Test-position marked as "Insulating Test"
SACE Emax 2 (equipped with Ekip Touch/Equip Hi-Touch) Fixed version	Ekip Measuring/Measuring Pro	Remove Ekip Measuring/Measuring Pro module

Furthermore, all the accessories of the circuit-breakers connected directly to the mains shall be disconnected (undervoltage releases, shunt opening releases, shunt closing releases, measurement modules, motor operating mechanisms, etc.).
For further information about the indications and the operations to be carried out as regards ABB SACE devices and accessories, reference shall be made to the relevant technical product manuals.

Routine verification of insulation resistance
In compliance with the Standard IEC 61439-1, as an alternative to the dielectric test, for assemblies rated up to 250 A only, it is sufficient to verify by measuring a suitable insulation resistance.
The test shall be performed by applying a voltage of 500 Vd.c. between circuits and exposed conductive parts, and the test is satisfactory if the insulation resistance is at least 1000 ohm/V per circuit referred to the rated voltage to earth of these circuits. Also in this case, the devices absorbing current must be disconnected.
For the test an insulation measuring device (megohmmeter or megger) can be used.

Clearances and creepage distances
During final testing this verification is carried out by comparing the actual clearances between the live parts and between the live and the exposed conductive parts with the minimum insulation distances prescribed by the Standard. Where the clearances are:
- less than the values given in Table 9.6, an impulse voltage withstand test must be performed (see clause 9.2 of this document);
- not evident by visual inspection to be larger than the values given in Table 9.6, verification shall be by physical measurement or by an impulse voltage withstand test (see clause 9.2 of this document).

The prescribed measures with regard to creepage distances shall be subject to a visual inspection.
Where it is not evident by visual inspection, verification shall be by physical measurement.

12.7 Final documentation and end of verifications

Up to now, in Italy, the professional role and duties of the panel builder from a legal point of view has not been codified yet.
As in ABB SACE, he is considered a generic builder of products he manufactures according to the state of the art, on which he shall apply nameplate, CE mark (for Europe only) and which he shall finally invoice and sell to customers.
Compliance with the technical Standards (IEC 61439) is not mandatory, but it is a declaration of conformity, that is a condition sufficient but not necessary for the state of the art.
This Technical Application Paper is based on Standards and consequently it suggests solutions according to the state of the art.
From a strictly judicial point of view, the manufacturer who supplies an assembly shall mandatory:
- construct it according to the state of the art; the full compliance with a harmonized technical Standard (e.g.: IEC 61439-2) implies also compliance with the state of the art and CE marking of the assembly;
- apply clear and readable nameplates and CE mark (for product supplies in Europe);
- enclose the use and maintenance manuals of the components and of the assembly itself (usually provided with them);
- draw up and file (for at least 10 years) the technical dossier to which also the declaration of conformity is attached. The assembly manufacturer is not obliged to hand over the declaration of conformity to the customer. It must be kept with the technical dossier (for at least 10 years);
- draw up the invoice and hand it over to the customer.

Furthermore, the technical Standards IEC 61439 require for the assembly:
- total compliance with design, assembling and final testing procedures described in the relevant documents (the Standard IEC 61439-1 plus the specific product Standard relevant to the type of assembly in question);
- the application of a more complete nameplate indicating also the fabrication year and the specific product Standard, in addition to the CE mark, the name of the manufacturer and the serial number;
- enclosed, a specific technical documentation showing the nominal characteristics and performances and all the other recommendations and indications for an optimal use.

Even if not expressly required neither by the law nor by the Standards, in order to guarantee quality and completeness, for the final testing it is useful to adopt analytical report forms in which all the verifications are registered, also in details. Thus, it is possible to check one by one the different items to guarantee that all required operations have been carried out.
An example of the testing documents summarizing the verifications required and, for each of them, the results necessary to guarantee that an assembly complies with the IEC 61439 is given in Annex A.

13 Example of construction of a System pro *E* power switchboard

This section has the aim of helping the panel builder and the designer in the construction of an ABB SACE System pro *E* power switchboard.

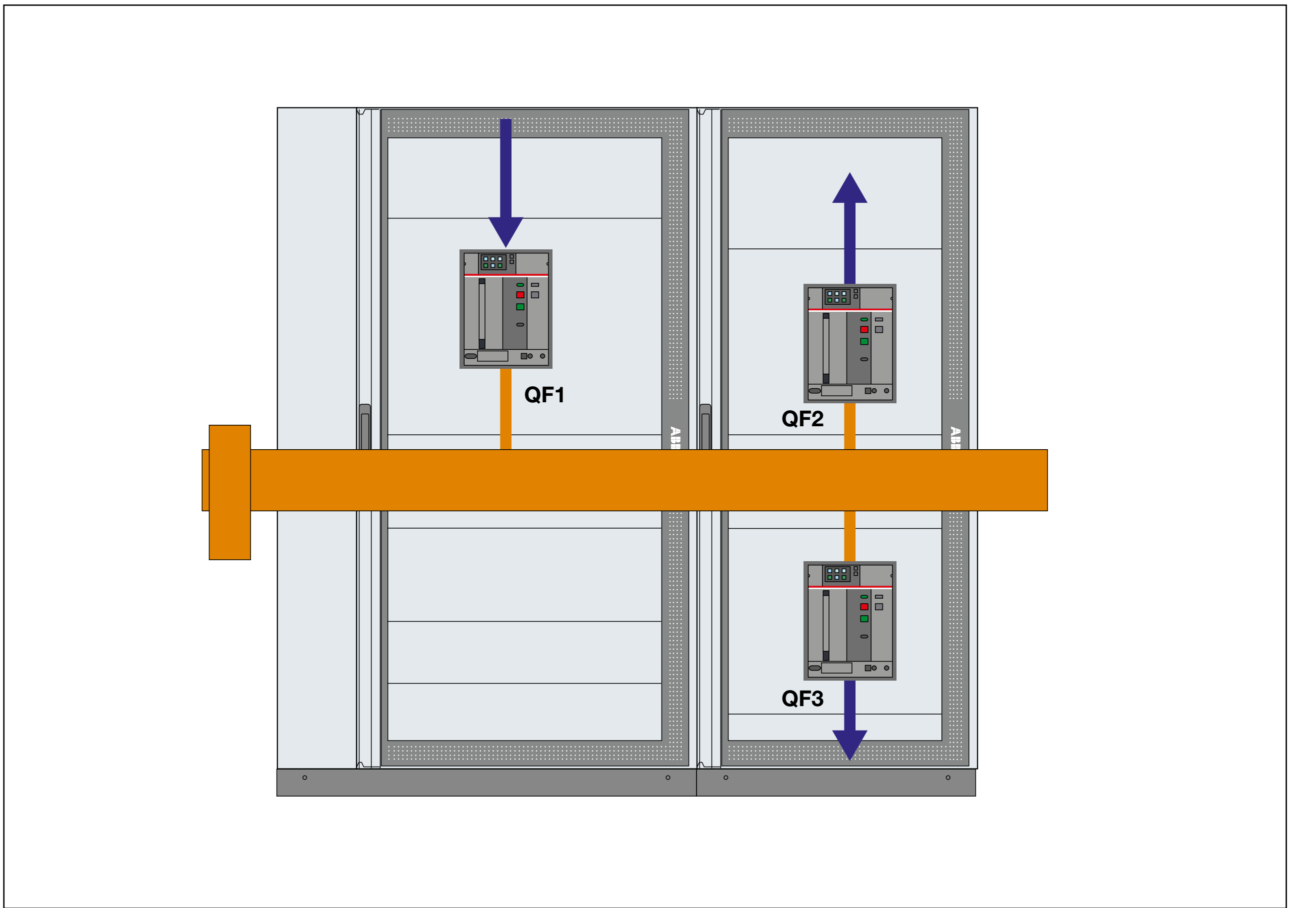
To this purpose, starting from the front view of a switchboard, by selecting the suitable components, an assembly will be realized, complete with the relevant declaration of conformity with the Standard IEC 61439-2.
Characteristics of the assembly, according to the specifications:
- internal separation: Form 4b;
- IP 41;
- exposed wall-mounted.

Let us suppose that realization of a main distribution assembly is required, consisting of a 6300A main circuit-breaker and two outgoing circuit-breakers, respectively 4000A and 3200A rated current.

In particular:
1 Emax2 E6.2 6300 Ekip dip LSIG 4p W – In 6300 (main circuit-breaker of the switchboard QF1);
1 Emax2 E4.2 4000 Ekip Dip LSIG 4p W – In 4000 (QF2);
1 Emax2 E4.2 3200 Ekip Dip LSIG 4p W – In 3200 (QF3).
Due to reasons of selectivity with the circuit-breakers of the switchboards on the load side, air circuit-breakers have been chosen that are branched from the busbars. The main distribution busbar short-circuit current is 120 kA. As regards housing of these devices, the main circuit-breaker has been positioned in one column, and the circuit-breakers of the outgoing feeders in another one.

A possible layout of the busbars and of the circuit- breakers is shown in the following figure:

Figure 13.1



Distribution system

As regards the busbars inside the assembly, by first approximation, they are selected according to the size of the circuit-breaker:

Main distribution busbar system
(circuit-breaker QF1)
(From the catalogue "System pro *E* power - New main distribution switchboards up to 6300A")

3x**PBFC2001** In=6300A (IP41) I_{cw} max =120 kA

Joining pieces between circuit-breakers and busbars
(circuit-breakers QF2, QF3)
Clause 11.4 of the Technical Application Paper shows the cross-sectional areas of the busbars for the connection of the circuit-breakers:

E4.2 4000 cross sectional area 4x(100x10)
E4.2 3200 cross sectional aerea 3x(100x10)

Moreover, the maximum anchoring distance of the first anchor plate must be respected. CON :
See section 11.3 of this Technical Application Paper for further information about the maximum distance (in mm) of the first anchorage plate of the busbars connecting to the circuit-breaker, according to the circuit-breaker type and to the peak current value (I_{pk}) of the admitted maximum short-circuit current.

Earthing busbar
As shown on page 44 and 45 of this technical Application Paper, the earthing busbar shall have a minimum cross-sectional area equal to ¼ of the cross-section of the main busbars. Therefore a bar 160x10 has been chosen.

Metalwork structure
As regards the metalwork structure, a System pro *E* power switchboard with door (IP 41) is used.
In order to house the circuit-breakers, the busbar system and the outgoing cables, two columns are used.

For a correct selection of the structure it is advisable to consult the catalogue "System pro *E* power - New main distribution switchboards up to 6300A", where:
- to house Emax2 E.6.2 circuit-breakers, a switchgear assembly with 900mm depth and 1250mm width plus one installation kit **PVGE6230** are required.

As specified in the catalogue "System pro *E* power - New main distribution switchboards up to 6300A", the metalwork structure shall be completed by the side-by-side kits **PSBS0065**).

Compliance with the Standard IEC 61439-2

It is necessary to verify the compliance of the assembly with the Standard IEC 61439-2.

Thermal verification of the switchgear assembly

With reference to clause 10.10.3 of the Standard IEC 61439-1, since the arrangement of the assembly to be constructed is similar to an arrangement already verified by laboratory tests and, in particular, since it has:
- same type of construction as used for the test
- larger or same overall dimensions as used for the test
- the same cooling conditions as used for the test (natural convection and same ventilation openings);
- the same internal separation as used for the test
- lower or equal power loss in the same section as used for the test

the temperature rise limits result to be verified.

Verification of dielectric properties

The dielectric properties of the assembly under examination are the same as those declared by System pro *E* power, provided that the mounting instructions of each single component are properly followed.

To this purpose, it is up to the assembler to provide so that the positioning of every single part (delivered loose and with the relevant fixing supports) is carried out in compliance with the Standards.

It should be kept in mind that increasing the separation form involves a proportional reduction in the internal assembling areas. Besides, the use of extraneous parts (metal parts made to measure, containers or locking metal terminals) as well as of electrical components with metal enclosures (such as cards, starters, monitors, shields and so on) may reduce or jeopardize the dielectric withstand of the whole.

To verify the product specifications, ABB SACE has carried out the appropriate verification tests both in alternating current at 50 Hz as well as with impulse frequency, obtaining the following performances:

- Rated voltage U_n = 400 V;
- Insulation voltage U_i = 1000 V;
- Rated impulse withstand voltage U_{imp} = 12kV.

Verification of the short-circuit withstand strength

Through the choices made for the busbars and the circuit-breakers, and following correctly the mounting instructions, the short-circuit withstand strength is verified up to the values declared in the catalogue.

In addition to the fixing distances between the busbars and their relevant busbar supports, it is necessary to comply with the mechanical tightening torques between busbars and busbar supports and verify that they are in the range from the minimum to the maximum values required. Moreover, it is necessary to comply with the maximum admissible wiring distances between the incoming or outgoing terminal of the devices and the first busbar support; such distances are shown in clause 11.3 of this document.

In the case considered, no particular derivations by comparison with a tested reference design are required, since the rated short-time withstand current of the arrangement, reaching an I_{cw} value of 120kA, results to be sufficient.

Verification of the short-circuit withstand of the protection circuit

By respecting the mounting instructions of the metal components, the real electrical continuity between the exposed conductive parts is verified with negligible resistance values. If, as from design, a cross-sectional area for the earthing busbars is chosen by applying the Table of the Standard or by calculating it in full compliance with the maximum I^2t value of the materials, also the short-circuit withstand of the protection circuit is verified.

Verification of clearances and creepage distances

By respecting the assembling and mounting instructions of ABB SACE metalwork structures and circuit-breakers, handed over with each product, the adequate creepage distances and clearances are guaranteed.
In each case, the verification tests after mounting enable detection and correction, whenever necessary, of any possible fault of position and distance both between the live parts as well as towards the exposed conductive parts.
This control is recommended above all in case of layouts in form 3 and 4.

Verification of mechanical operation

This is one of the routine tests to verify the correctness of the connections supplying the remote control, setting and safety systems of the switchgear assembly, the plant or the machine.

By following the mounting instructions of ABB SACE metalwork structures and circuit-breakers, mechanical operation is verified.

Verification of the degree of protection

By complying with the mounting instructions of metalwork structures, circuit-breakers and relevant frames, sealing and fairleads supplied with ABB SACE equipment, it is possible to obtain a degree of protection IP up to **IP65**.

Verification of continuity

The Standard IEC 61439 prescribes grounding of all the accessible exposed conductive parts of the assembly. During the verification test, an in-depth visual inspection shall be carried out on these connections, which may be bolted, welded or other.
System pro *E* power fully meets this requirement thanks to a single connection to earth for the metalwork structure (generally along one of the bus riser). In fact, simple mechanical fixing between panels, covers, nameplates, eyebolts etc. by means of bolts and screws, when appropriately laboratory-tested, is considered more than sufficient to ensure also galvanic continuity to earth.
Thus, it is possible to get over the problems of corrosion, contact, and transmission of the zero potential energy to all the dangerous parts.

Annex A: Forms for the declaration of conformity and test certificate

DECLARATION OF CONFORMITY
LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES IN COMPLIANCE WITH THE STANDARD IEC 61439-2 (CEI EN 61439-2)

The Company ....

With the premises at ....

Builder of the switchgear assembly ....

....

declares, under its own responsibility, that the above mentioned switchgear assembly has been constructed according to the state of the art and in compliance with all the specifications provided by the Standard IEC 61439-2.

Also declares that ABB SACE components have been used, and respect has been paid to the selection criteria and assembling instructions reported in the relevant catalogues and on the instruction sheets, and that the performances of the material used declared in the above-mentioned catalogues have in no way been jeopardized during assembling or by any modification.
These performances and the verifications carried out therefore allow us to declare conformity of the switchgear assembly under consideration/in question with the following requirements of the Standard:
Constructional requirements:
- Strength of material and parts of the assembly;
- Degree of protection of enclosures;
- Clearances and creepage distances;
- Protection against electric shock and integrity of protective circuits;
- Incorporation of built-in components;
- Internal electrical circuits and connections;
- Terminals for external conductors

Performance requirements
- Dielectric properties;
- Temperature-rise;
- Short-circuit withstand capability;
- Electromagnetic compatibility (EMC);
- Mechanical operation

finally, declares, under its own responsibility, that all the routine verifications prescribed by the Standard have been carried out successfully, and precisely:
Design specifications:
- Degree of protection of enclosures;
- Clearances and creepage distances;
- Protection against electric shock and integrity of protective circuits;
- Incorporation of built-in components;
- Internal electrical circuits and connections;
- Terminals for external conductors;
- Mechanical operation

Performance specifications:
- Dielectric properties;
- Wiring, operational performance and function

Date and Place .... Signature ....

....

(Full name and function of the person in charge of signing on behalf of the manufacturer)

TEST CERTIFICATE
LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES – IN COMPLIANCE WITH THE ROUTINE VERIFICATIONS PRESCRIBED BY THE STANDARD IEC 61439-2 (CEI EN 61439-2)

The Company ....

With the premises at ....

Manufacturer of the assembly ....

....

issues the following

TEST CERTIFICATE
attesting with this document that all the technical verifications prescribed by the Standards applicable to the product and in particular those in the Standard IEC 61439-2 (CEI EN 61439-2) have been carried out, as well as that all the legal and statutory obligations required by the provisions in force have been fulfilled.

Date and Place ....

....

Signature ....

(Full name and function of the person in charge of signing on behalf of the manufacturer)

CE DECLARATION OF CONFORMITY
LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR ASSEMBLIES IN COMPLIANCE WITH THE STANDARD IEC 61439-2
(CEI EN 61439-2)

The Company ....

With the premises at ....

Manufacturer of the assembly ....

....

declares, under its own responsibility, that the switchgear assembly

type dsignation ....

serial no ....

reference Standard IEC 61439-2
year of affixing CE marking ....

conforms to what is foreseen by the following European Community directives (including the latest modifications thereto), as well as to the relative national implementation legislation

Reference no.	**Title**
Directive 2006/95/CE,	Low Voltage Directive
Directive EMC 2004/108/CE	Electromagnetic Compatibility Directive (1)

And that the following harmonized Standard has been applied

Standard code	**edition**	**title**
IEC 61439-1	Edition 2.0 2011-08	IEC 61439-1 (CEI EN 61439-1) Low voltage switchgear and controlgear assemblies Part 1: General Rules
IEC 61439-2	Edition 2.0 2011-08	IEC 61439-2 (CEI EN 61439-2) Low voltage switchgear and controlgear assemblies Part 2: Power switchgear and controlgear assemblies

(1) Omit this Directive in the cases where compliance with the same is not required.

Date and Place ....

....

Signature ....

(Full name and function of the person in charge of signing on behalf of the manufacturer)

CHECK-LIST- ROUTINE VERIFICATIONS

Customer...

Plant ....

Order/Assembly: ....

Checking operations	Verified	Result	Operator
1) Construction			
a) degree of protection of the enclosure			
b) clearances and creepage distances			
c) protection against electric shock and integrity of protective circuits			
d) incorporation of switching devices and components			
e) internal electrical circuits and connections			
f) terminals for external conductors			
g) mechanical operation.			
2) Performance			
a) dielectric properties			
b) wiring, operational performances and function.			

Verification carried out by:

During assembling	After assembling

TEST REPORT – ROUTINE VERIFICATION (TESTING)

Customer..

Plant ....

Order no. ....

Type designation and identification number of the switchgear assembly

Assembly drawing ....

Functional diagram ....

Other diagrams..

Rated operational voltage ....

....

Routine verification tests carried out in compliance with the Standard IEC 61439-2 (CEI EN 61439-2)

	Result
- degree of protection of the enclosure;	
- clearances and creepage distances;	
- protection against electric shock and integrity of protective circuits;	
- incorporation of switching devices and components;	
- internal electrical circuits and connections;	
- terminals for external conductors;	
- mechanical operation.	
- dielectric properties;	
- wiring, operational performances and function.	

Tests carried out at ....

In the presence of Mr ....

Having passed the above tests, the switchgear assembly under consideration results in compliance with the Standard IEC 61439-2 (CEI EN 61439-2).

Technical Application Papers

QT1
Low voltage selectivity with ABB circuit-breakers

QT2
MV/LV trasformer substations: theory and examples of short-circuit calculation

QT3
Distribution systems and protection against indirect contact and earth fault

QT4
ABB circuit-breakers inside LV switchboards

QT5
ABB circuit-breakers for direct current applications

QT6
Arc-proof low voltage switchgear and controlgear assemblies

QT7
Three-phase asynchronous motors
Generalities and ABB proposals for the coordination of protective devices

QT8
Power factor correction and harmonic filtering in electrical plants

QT9
Bus communication with ABB circuit-breakers

QT10
Photovoltaic plants

QT11
Guidelines to the construction of a low-voltage assembly complying with the Standards IEC 61439 Part 1 and Part 2

QT12
Generalities on naval systems and installations on board

QT13
Wind power plants

QT14
Faults in LVDC microgrids with front-end converters

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