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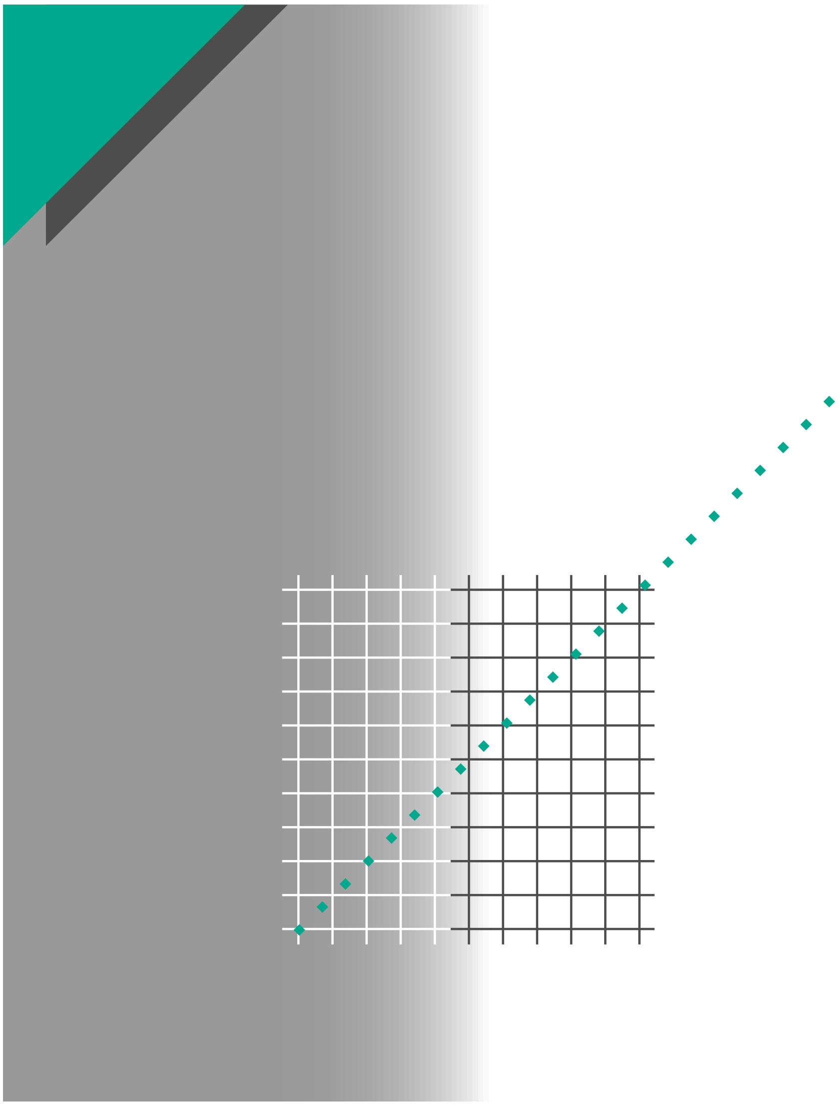
Development of LV circuit breakers to standard IEC 947-2



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n° 150

Development of LV circuit breakers to standard IEC 947-2

Etienne BLANC

Having graduated as an IEG Engineer in 1968, he joined Merlin Gerin in 1970.
For three years he was in charge of LV technical literature in the Communication Department, which he left to join the Research, Development and Quality Department where he was engaged in network research (dynamic stability, protection, discrimination, harmonic currents and security...).
He moved to the Industrial Circuit breaker Department in 1983 where he now works as a Product Manager.

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Development of LV circuit breakers to standard IEC 947-2

Development of the need for safety and of technologies is responsible for a marked recovery of industrial circuit breaker standard requirements (circuit breakers whose implementation is reserved for electricians).
Today, conformity with standard IEC 947-2, published in 1989 and reviewed and completed in 1995, can be considered as an « all-risks insurance » guaranteeing a circuit breaker's fitness for use.
Quite remarkably all countries, except Japan, have approved this standard. Japan's approval should be given in the near future.

This « Cahier Technique » presents the advantages of this standard over the former IEC 157-1, and describes the numerous tests to be satisfied by these breaking devices. These tests are highly representative of the constraints actually encountered in electrical installations.

Contents

1 Introduction

As with all electrical devices, industrial Low Voltage circuit breakers are designed, manufactured and verified according to rules collected in the standards known as « product standards » (see **fig. 1**).

Each country has its own standards (UTE for France, BS for the UK, VDE for Germany, etc...), often derived from IEC (International Electrotechnical Commission) publications which have a reference purpose.

Consequently the standards covering LV industrial circuit breakers are today, in Europe as in a large number of other countries, based on the IEC 947-2 standard which, in 1989, replaced the 1973 standard IEC 157-1 (see **fig. 2**).

In the electrotechnical field there are two different types of standards which the various participants have to consider:

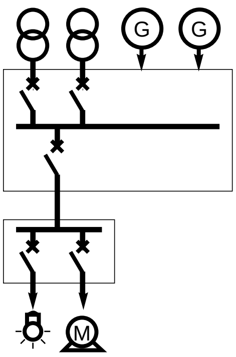
1. « product » standards
These standards exist for each component in an electrical installation. That a product conforms to its standard is, for the user, an assurance of quality and reliability.

2. « installation » standards
These bring together the various rules concerning the design, construction and use of an electrical installation to ensure:
- correct supply to loads (voltage, frequency, continuity of service, ...);
- safety of persons and equipment;
- ... and maintenance of these requirements throughout the life of the installation.

The IEC 364 and, in France the NF C 15-100, belong to this category.

In practice
Below is shown around the diagram of an electrical installation, first the components of this installation concerned by product standards and, second, the parameters defined or considered by installation standards.

Examples of components concerned by product standards:
- power sources;
- main distribution board (enclosure and switchgear);
- cables;
- secondary distribution board (enclosure and switchgear);
- cables;
- loads.



Main parameters defined or considered by installation standards:
- earthing system;
- current-carrying capacity;
- short-circuit current;
- insulation fault current;
- temperature;
- type and method of installation of cables;
- maximum permissible voltage drop;
- special risks (fire, vibration, explosion), discrimination;
- limits on use;
- etc.

fig. 1: Product and installation standards.

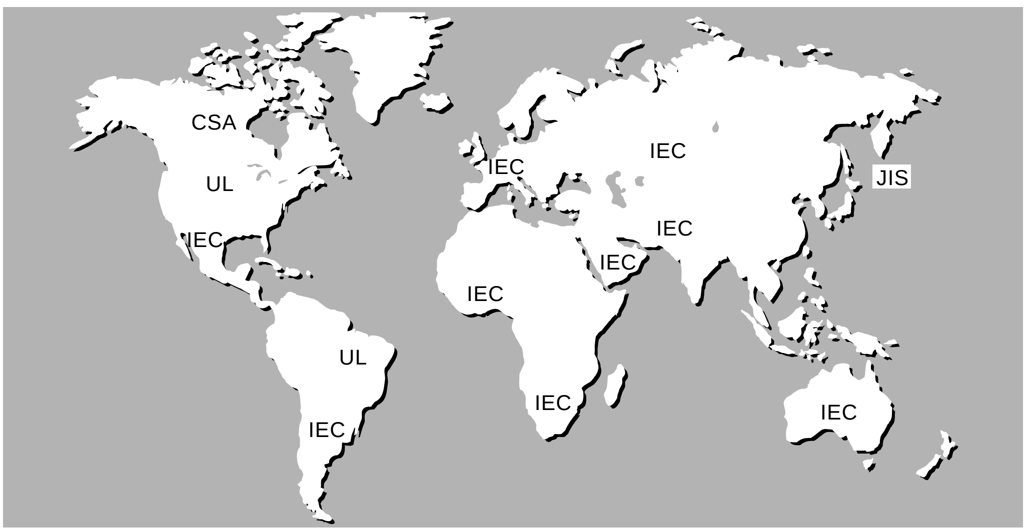


fig. 2: Map showing the influence of the various standard bodies.

1.1 Publication IEC 947-2

An extra step towards an international standard

The desire for a still wider international recognition of IEC recommendations, as well as the technical and technological progress achieved since 1973 by manufacturers, have prompted IEC sub-commitee 17B to work on a revision of publication 157-1.

The work of these international experts (including three engineers from Schneider) resulted in the publication in 1989 of the first edition of standard IEC 947-2.

After a vote of approval, this gained considerable world-wide agreement (Europe, United States, Canada, Australia, South Africa....). Japan was the only exception, but should officially recognise this standard in 1997 or 1998 (see **fig. 3**).

IEC 947-2 is part of a much more comprehensive work: IEC 947

This work comprises seven documents which constitute the IEC standards for all Low Voltage electrical switchgear for industrial use:

- IEC 947-1: General rules, 2nd edition (published in September 1996),
- IEC 947-2: Circuit breakers (2nd edition) (published in December 1995)
- IEC 947-3: Switches,disconnectors, switch-disconnectors, and fuse-combinations (formerly IEC 408) (published in 1990),
- IEC 947-4-1: Contactors and motor starters (formerly IEC 158-1 and IEC 292) (published in May 1996),
- IEC 947-4-2: Semi-Conductor power controllers and starters for ac motors (published in 1995),
- IEC 947-5-1: Control circuit devices and switching elements (formerly IEC 337) (published in March 1990),
- IEC 947-5-2: Proximity detectors (published in July 1997),
- IEC 947-6-1: Automatic transfer switching equipment (published in 1989),
- IEC 947-6-2: Control and protection switching equipment (ACP) (published in August 1992),
- IEC 947-7-1: Terminal blocks for copper conductors (published in 1989).

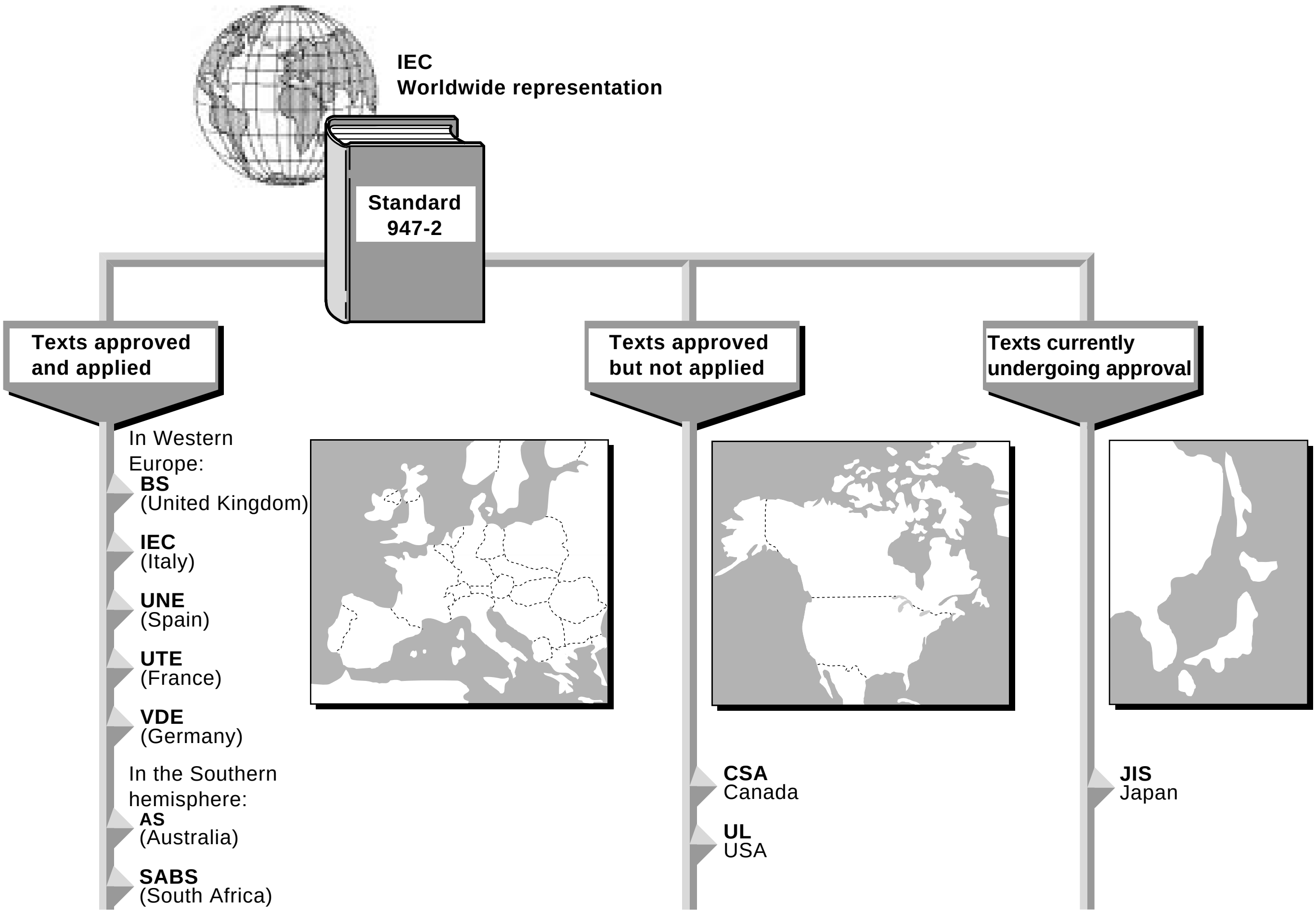


fig. 3: Worldwide representation of IEC 947-2.

This structuring allowed homogenisation of the vocabulary and general rules of the various product families. However in order to determine all the rules relating to one category of device, two documents have to be consulted:

- a first one called « General Rules (IEC 947-1) which contains the definitions, instructions and tests common to all industrial LV equipment,
- a second one called « Products » (IEC 947-2 to 7) which deals with the instructions and tests specific to the product concerned.

Thus the texts applicable to industrial LV circuit breakers are IEC 947-1 and IEC 947-2.

1.2 Stages of its application

In Europe

The texts published by the IEC 947 are first of all studied at the level of the European Commitee for Electrotechnical Standardisation (CENELEC) which brings together the 18 countries of Western Europe.

From the basic text, CENELEC establishes whether:

- it is a European Norm « EN... » which is then ratified as a national standard by all the member countries;
- it is, in the event of technical differences, a harmonisation document « HD... » which is then transformed into a national standard with the incorporation of points specific to each country.

As far as publications IEC 947-1 and 2 are concerned, no notable differences have emerged to date. Consequently, CENELEC published in 1991 two European Norms, EN 60 947-1 and EN 60 947-2, which have been part of the national standards of the various member countries since 1992.

In the USA and Canada

Although favourable comment has been expressed, the standards in force (UL in the USA and CSA in Canada) are very different from IEC 947-2 and a reaction of conservatism, even a certain protectionism, has meant that these two countries will probably retain their specific standards for a long time yet.

In Japan

The only country to have voted in the negative. It has therefore not adopted the IEC texts and keeps its own JIS standards. However, under international pressure, this country is opening up progressively to the outside world and the IEC 947 should act as a base for a new JIS standard.

In other countries of the world

Each country can ratify the IEC text as a national standard after studying it and making any modifications necessary.

The very wide approval achieved by IEC 947-2 has meant that most countries have adopted it with very few modifications.

1.3 The main new features

First of all it is very important to note that the new texts do not change the fundamental circuit breaker selection criteria, which are still its breaking capacity and the rated current.

On the other hand, the new texts guarantee the user a better assurance of quality and performance, introducing extra tests and requirements which take into account more fully the actual operating conditions of a circuit breaker in use (see appendix 1).

Moreover, this standard recognises a circuit breaker's ability to fulfil other functions, in addition to the usual ones of overcurrent protection, isolation, or personal protection by residual current device.

2.1 Performances and new tests to ensure better protection against overcurrents

What the user of a circuit breaker requires, above all else, is that it fulfils, without fail, its main purpose: in all circumstances and completely safely, to protect electrical installations against overcurrents whatever their values between In and the breaking capacity of the device.
In view of this need, IEC 947-2 has kept the main well-known characteristics of a circuit breaker (breaking capacity, rated current, operational voltage,etc...), but it now clarifies them and completes them with new principles and new performances (see appendix 2), as well as stipulating a whole series of tests, the severity of which guarantees its ability to break any value of current.

Clarification of breaking capacity

With IEC 157-1, for any one circuit breaker there were two breaking capacities called « P1 » and « P2 » defined both by the test cycle and the post-break requirements.
IEC 947-2 dispels this ambiguity. From now on, each circuit breaker has only one breaking capacity called Icu (ultimate breaking capacity) expressed in kA. Icu corresponds, in practice, to breaking capacity P1 in the former standard and it is defined in the same way:
Icu (IEC 947-2) = breaking capacity P1 (IEC 157-1)
It is this characteristic which, from the design of a network, is to be compared with the three-phase short-circuit current value at the point of installation of the circuit breaker.
Icu (of the device) ⩾ three-phase Isc (of the system).

Service breaking capacity: Ics

Prospective short-circuit currents are normally calculated using extreme assumptions all aiming at increased safety. In particular:

- the short-circuit is three-phase;
- it is said to be « bolted », i.e. without arc;
- resistance of connections is not taken into account;
- the short-circuit is considered to occur at the load side terminals of the circuit breaker without intervening cables;
- cable resistances are calculated at normal operating temperatures (in overcurrent, these resistances are greater because they increase at the same time as the cables heat up).

The result is that, when a short-circuit occurs (already a very rare occurrence), its real value is lower (or even much lower in the case of terminal circuits) than the prospective Isc.
On the other hand, it is important that those currents of higher probability be disconnected under very good conditions so that after elimination of the fault, the resumption of service is sure to be quick and safe for the entire installation.
It is for this reason that IEC 947-2 introduces a new characteristic, Ics, known as « service breaking capacity », generally expressed as a percentage of Icu (value to be chosen by the manufacturer from 25, 50, 75 or 100%) defined in the following way:

- the circuit breaker carries out three successive disconnections of Ics current;
- the ability of the device to fulfil all its functions is then verified by a series of measurements (temperature rise under In, capacity to break its rated current by achieving 5% of electrical endurance, dielectric withstand, trip operation, etc...).

This establishes Ics as a performance which can be considered not simply as breaking capacity (as was the breaking capacity P2 of IEC 157-1), but as the ability of the circuit breaker to ensure completely normal service, even after having disconnected several short-circuit currents (O-CO-CO).

The short-time withstand current Icw (for category B circuit breakers)

IEC 947-2 defines two categories of circuit breakers:

- those of category A for which no short-circuit trip delay is provided. These are generally moulded case circuit breakers such as Compact NS. This requirement is not synonymous with non-discrimination on tripping (see « Cahier Technique » n° 167).
- those of category B for which, in order to achieve time discrimination, it is possible to delay tripping during short-circuit conditions with values lower than Icw. These are generally air circuit breakers (Masterpact type) and some of the higher rated moulded case circuit breakers such as Compact C1251N.

For the latter, the new IEC imposes an extra test to verify their ability to withstand, thermally and electrodynamically, the Icw current during the associated delay, without repulsion of the contacts which would give rise to excessive wear and tear (see **fig. 4**).

Breaking in IT earthing system

In the IT earthing system, circuit breakers may be obliged to break with a single pole, a « double fault » current under phase-to-phase voltage (see **fig. 5**).
Appendix H of IEC 947-2 takes account of this type of breaking, and imposes a specific breaking test for the circuit breakers used in IT earthing systems.
Circuit breakers which have not successfully completed this test are marked with the symbol (IT) and must not be used for IT earthing systems.

Co-ordination between circuit breakers

The term co-ordination concerns the behaviour of two devices, C1 and C2, placed in series in an electrical distribution circuit,

	Permissible short-time current Icw		Associated delay Δt
	In ⩽ 2500 A	**In > 2500 A**	
Values as in IEC 947-2	Icw ⩽ 12 In (with min. 5 kA)	Icw > 30 kA	0.05 s (minimum value) 0.1 s, 0.25 s, 0.5 s, 1 s (preferred values)
Example: Masterpact M20 H2	Icw = 75 kA		1 s

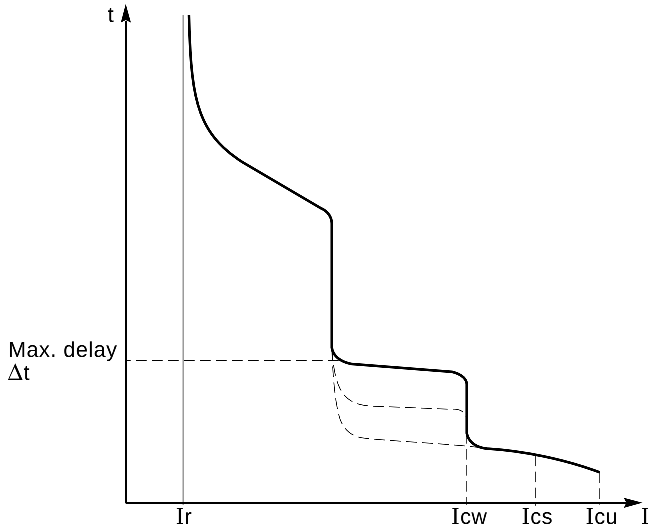


fig. 4: Additional test for category B circuit breakers.

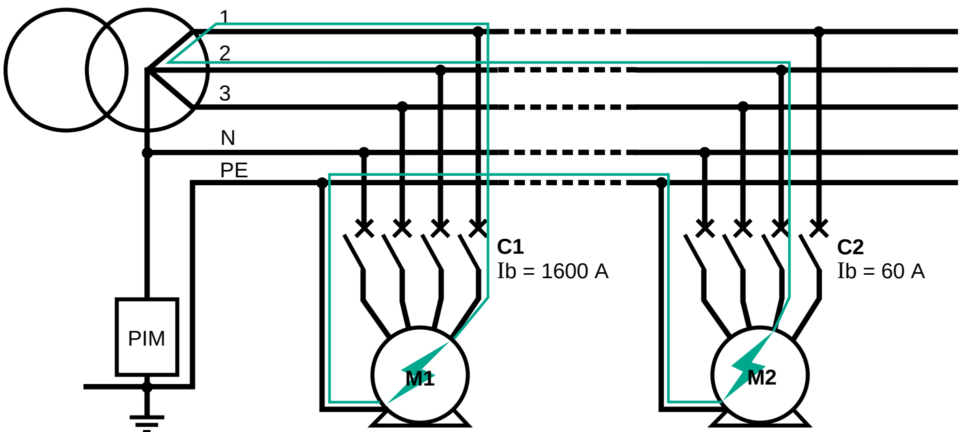


fig. 5: Example of « double fault » current breaking in an installation using the IT earthing system. The difference in ratings between two circuit breakers (C1 and C2) means that only one (C2) may be in a position to eliminate the fault with a single pole under phase-to-phase voltage.

with a short-circuit downstream of C2 (see fig. 6). It covers two principles:

- the first is well known: discrimination, which is an increasing requirement of modern low voltage electrical distribution systems,
- the other is less well known (although recognised in installation standards): cascading, which consists of installing a device, C2, whose breaking capacity Icu2 is less than the three-phase short-circuit current at its terminals Isc2 and which is protected or « helped » by device C1 for any current between Icu2 and Isc2 (see fig. 7). The main advantage of this technique is to be able to install at C2 a device of a lesser performance, thus more economical, without endangering the safety of the installation.

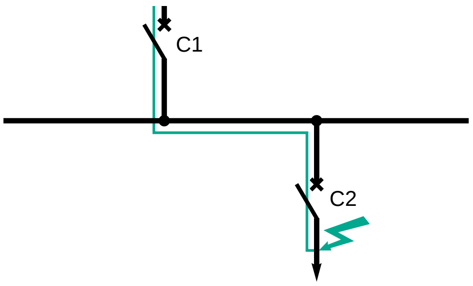


fig. 6: Two circuit breakers, C1 and C2, placed in series on a circuit.

To determine and guarantee co-ordination between two circuit breakers, it is necessary to carry out a preliminary theoretical approach, and to confirm the results by means of suitable tests. This is what Merlin Gerin has always done in order to draw up tables of discrimination and cascading which are at present ratified in appendix A of IEC 947-2.

The theoretical methods or approaches are:

- for discrimination, comparing the limitation characteristics of the loadside circuit breaker with the non-tripping characteristics of the lineside device (see fig. 8). This method is very precise and requires little in the way of confirmation testing.
- for cascading, comparing the limitation characteristics of the lineside device with the maximum withstand of the loadside device (see fig. 9). As this method is much less precise, IEC 947-2 requires that the results are verified by more numerous tests.

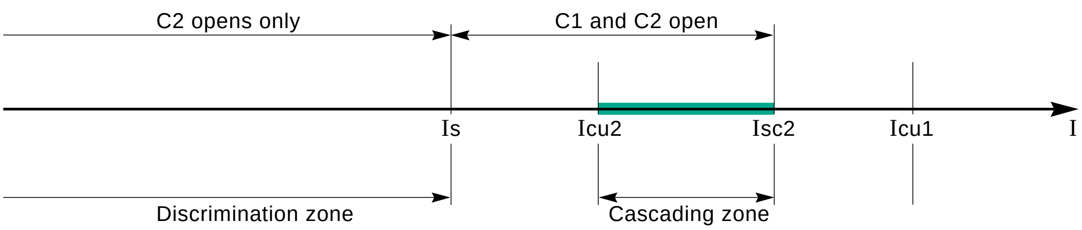
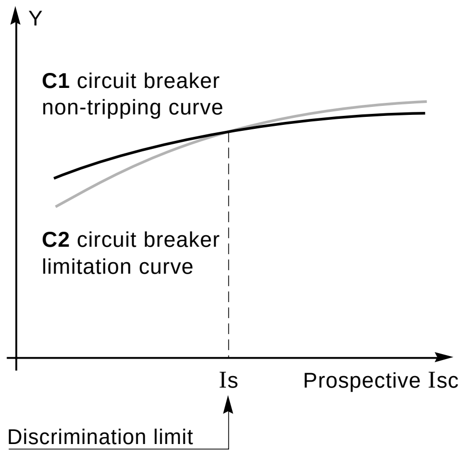


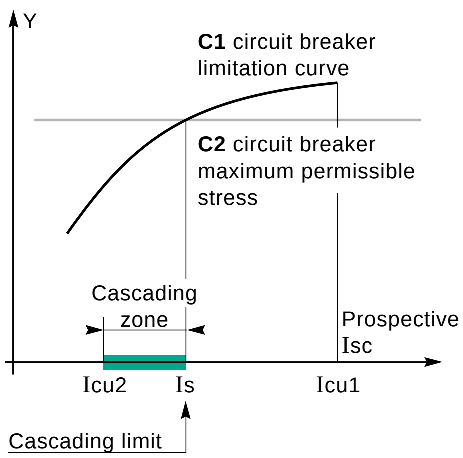
fig. 7: The principle of cascading between 2 circuit breakers, breaker C2 whose breaking capacity Icu2 is less than the three-phase short-circuit current at its terminals (Isc2), is protected or assisted by breaker C1.



Depending on the type of trip unit used by circuit breaker C1, Y is expressed in:

- A^2 s (thermal stress) for a thermal-magnetic release,
- kA peak for an electronic release.

fig. 8: Theoretical determination of the discrimination limit between two circuit breakers.



In all cases, verification must be made using curves (Y) expressed in A^2 s (thermal stress) and in kA peak.

fig. 9: Theoretical determination of the cascading limit between two circuit breakers.

2.2 Dielectric strength for « insulation co-ordination »

What is insulation co-ordination?

Every electrical installation is subject to occasional overvoltages of various origins such as:

- atmospheric overvoltage,
- switching overvoltage,
- overvoltages arising from faults,
- overvoltages following MV/LV arcing,
- etc,…

The study of these overvoltages (origin, value, location, etc) and the rules applied in order to achieve protection against them, are known as insulation co-ordination (see « Cahiers Techniques » n° 151 and n° 179).

In industrial LV systems, overvoltage protection is considered to be achieved when the equipment can withstand the following two types of test without suffering damage:

- the familiar dielectric tests at 50 Hz, e.g. withstand at (2 Ui + 1000 V)/1 min, which simulates the risk of installation faults at higher voltages;
- impulse voltage withstand tests (1.2/50 µs: see **fig. 10**) of value Uimp (imp as impulse) variable according to location of the installation; recently introduced, these are representative of atmospheric and switching overvoltages.

The performance Uimp, which the switchgear must withstand, is defined in the installation standards according to the table in **figure 11**.

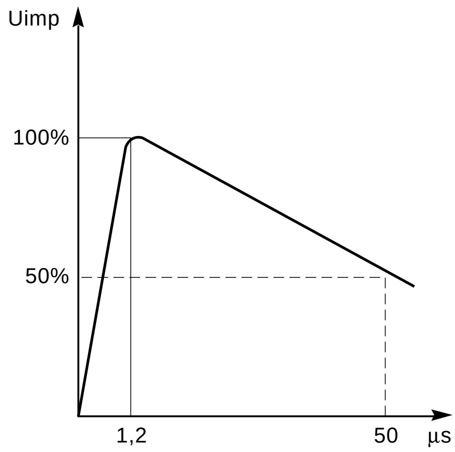
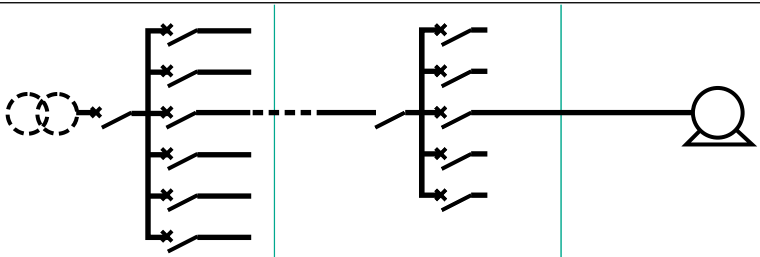


fig. 10: impulse wave for industrial circuit breakers 1.2/50 µs.

Nominal installation voltage	Applications		
	At the main system incomer or main LV board	On the final distribution circuits	At load level
230 / 400 V	6	4	2.5
400 / 690 V	8	6	4



Assumed overvoltage levels chosen for Merlin Gerin circuit breakers

6 kV = **Multi 9**

8 kV = **Compact and Masterpact**

fig. 11: Assumed transient overvoltage levels (source: IEC publication 38 and NF C 15-100 1990 edition, at a height of 2,000 m).

Since Uimp must be valid for altitudes of up to 2,000 m, while testing is carried out generally at sea level, the test impulse level is increased by 23% (or 9.8 kV for Uimp = 8 kV).

Impulse voltage applied	Impulse voltage levels	
	Circuit breakers	**CB-disconnectors (with class II front face)**
Between phases	9.8 kV	9.8 kV
Between upstream and downstream, circuit breaker open	9.8 kV	12.3 kV
Between phases and earth	9.8 kV	14.7 kV

Tests relevant to Compact and Masterpact

fig. 12: Voltage impulse withstand tests for industrial circuit breakers: during the tests, no breakdown shall occur between phases, between open contacts or between phase and earth.

Impulse voltage withstand tests

Publications IEC 947 take into account the rules of insulation co-ordination and require that impulse voltage withstand tests are carried out on the switchgear. Thus for industrial circuit breakers of Uimp = 8 kV, the tests detailed in the table in **figure 12** are carried out.

In this table, note:

- that for the value Uimp to be valid up to a height of 2,000 m, the tests which are generally carried out at sea level are raised by 23%;
- that a specific test is required for devices with class II front face according to IEC 1140 (formerly IEC 536).

This design characteristic, in addition to the extra safety it provides for operators, allows the assembly of class II equipment while keeping the manual control handle accessible (see **fig. 13**).

Thus, for example, all Merlin Gerin Compact and Masterpact circuit breakers have class II front faces.

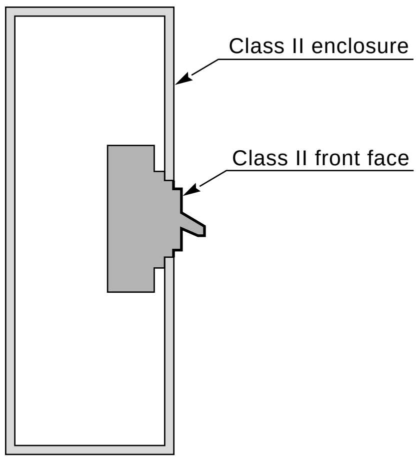


fig. 13: Class II equipment with circuit breaker having a class II front face.

2.3 Taking introduction of electronics into account in industrial circuit breakers

Miniaturisation, lower costs and the new possibilities offered by electronics have recently led manufacturers as a whole to partly replace thermal-magnetic releases by electronic ones.

The emergence of this technology, used in severe environmental conditions (strong current, harmonics, extreme temperatures, mechanical impact, etc...) has required publication of appendices F and J of IEC 947-2 in which additional requirements for electronically protected circuit breakers are defined.

In particular they describe the various electromagnetic compatibility (EMC) tests to be carried out on the circuit breakers:

- tests for immunity to:
  - harmonics (IEC 1000 - 4.13) (see **fig. 14**),
  - current sags and breaks (EN 50 160),
  - frequency variations (EN 50 160),
  - conducted transients (IEC 1000 - 4.4),
  - HF (high frequency) perturbations (IEC 1000 - 4.4),
  - electromagnetic fields (IEC 1000 - 4.8.9.10),
  - electrostatic perturbations (IEC 1000 - 4.2)
- tests for limitation of radiated emissions at radio frequencies.

They also make provision for dry heat, damp heat (see **fig. 15**) and rapid temperature change tests.

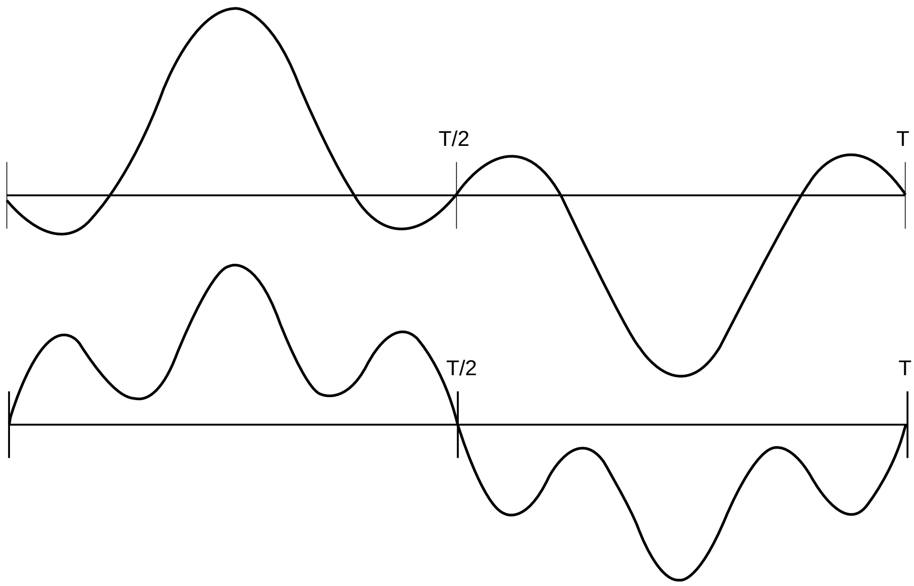


fig. 14: Waveforms applied to devices for harmonic immunity tests.

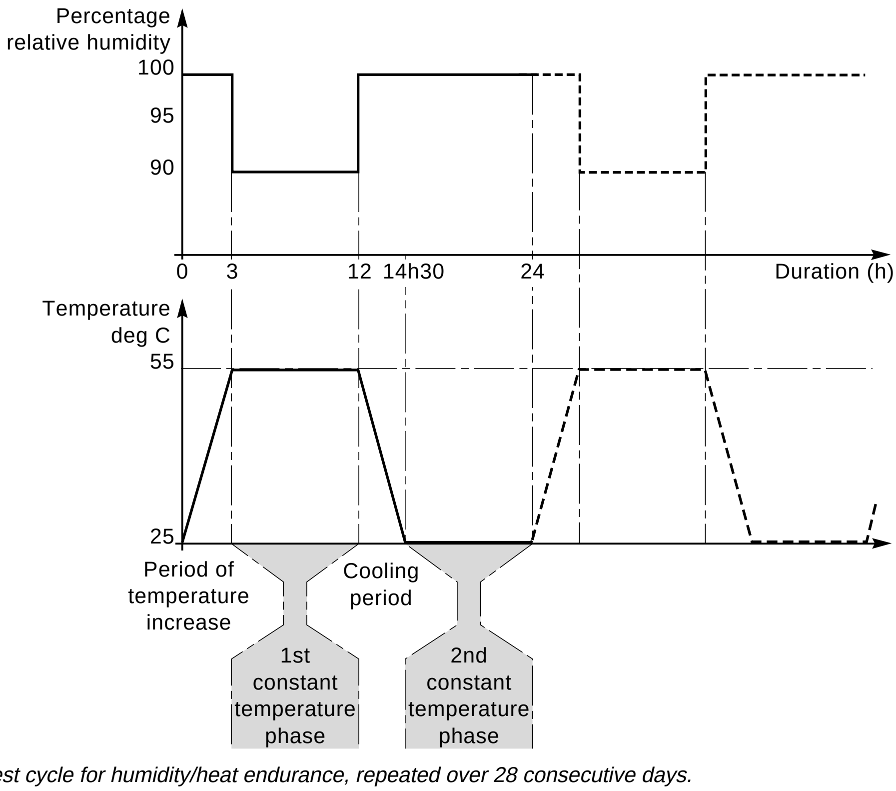


fig. 15: Test cycle for humidity/heat endurance, repeated over 28 consecutive days.

2.4 Disconnection and residual current protection: two extra functions now recognised

For a number of years, certain manufacturers including Merlin Gerin have worked within major constraints when proposing suitable circuit breakers for disconnection.

Likewise, during the sixties Merlin Gerin was the first manufacturer to propose residual current circuit breakers comprising a circuit breaker plus an additional module or « Vigi module » ensuring protection of persons in the event of an insulation fault on the loadside. These two functions are now taken into consideration by IEC 947-2.

Disconnector-circuit breaker

A circuit breaker can be said to be suitable for disconnection and bear the disconnector circuit breaker symbol visible on its front face (see **fig. 16** and **17**) if it has been successfully subjected to a whole series of tests described in the table in **figure 18**).

Residual current circuit breakers

Numerous manufacturers have made use of this Merlin Gerin technology (see **fig. 19**). Today

fig. 16: Symbols

1. Measurement testing of leakage currents

Intended to ensure that an open circuit breaker conducts no leakage current which could endanger a user.

■ four tests are carried out at 110% of the maximum rated voltage:

□ new device, leakage current should not be greater than 0.5 mA per pole,

□ after the breaking test at Ics, leakage current must not be greater than 2 mA per pole,

□ after endurance testing, leakage current must not be greater than 2 mA per pole,

□ after the breaking test at Icu, leakage current must not be greater than 6 mA per pole.

■ in this last case, the breaker is at the end of its life and we can say, therefore, that a circuit breaker or isolator will never have a leakage current greater than 6 mA (a very low current which is not dangerous).

2. reinforced voltage impulse withstand

For a circuit breaker declared unsuited to isolation, the test consists of applying an impulse voltage Uimp between the phases, then between the phases and the earth of the breaker.

For a circuit breaker declared suited to isolation, a third test is carried out between the incoming and the outgoing terminals with the contacts open and with a higher impulse voltage (see **fig. 12**). Thus for a device considered suited to isolation and for which Uimp = 8 kV, the value of the impulse voltage applied across open contacts at sea level between the incoming and outgoing terminals will be 12.3 kV instead of 9.8 kV.

3. Mechanical strength test

This test, often called « welded contact test » consists of holding the contacts closed while applying a force of 3 times the normal force to the handle for 10 sec.

During this test, the position indicator must not indicate open and no padlocking device may be engaged.

fig. 18: The three tests to demonstrate circuit breaker isolation.

fig. 17: A Merlin Gerin Compact circuit breaker-disconnector.

fig. 19: Vigicompact, a Merlin Gerin industrial residual current circuit breaker.

the industrial residual current circuit breaker is a very widely-used device for which there were no construction standards, the quality of which could therefore vary considerably from one manufacturer to another.

At the request of French representatives, and based on a project set up in France, IEC 947-2 has devoted an appendix (appendix B) to this type of product.

Among the important points covered, the following verifications should be noted:

- non deterioration of residual current protection units (Vigi modules) after breaking at Icu and Ics,
- absence of untimely tripping in the event of:
  - overcurrent at 6 In,
  - 8/20 µs impulse current wave,
  - system capacitance load,
- operation under severe environmental conditions: 28 day cycle of damp heat (see **fig. 15**).

3 A test standard based on reality

The life of a circuit breaker in an electrical installation is punctuated with a certain number of successive events such as:

- manual opening/closing (or remote with electrical operating mechanism), on no-load, at current ⩽ In, or, more exceptionally, on overload,
- tripping by undervoltage release or shunt trip,
- overvoltage impulses (atmospheric or switching),
- overload tripping,
- exceptional tripping on short-circuit or insulation fault,
- locking in the OPEN position for circuit maintenance ,...

It is therefore usual for a test standard relating to protective devices such as circuit breakers, not only to guarantee all the published performances but also to simulate more closely the successive constraints to which they may be subjected during use.

It is with this in mind that the type tests required in IEC 947-2 have been grouped in sequences and that they are to be repeated on a specified number of devices.

3.1 Sequence tests

With IEC 157-1 each test was carried out on a new device.

From now on, with IEC 947-2, the same device is subjected to a series of cumulative tests grouped in sequence.

Five sequences are defined and each type of circuit breaker must be subjected to two, three or four of these sequences according to its characteristics (see the table in **figure 20**).

Without a doubt, one of the most significant is sequence 1 which provides an excellent illustration of the exceptional constraints imposed on the devices.

Test sequences	Type of circuit breaker				Tests to be performed successively on one circuit breaker	Additional tests for isolating circuit breakers
	Cat. A	Cat. B Icw < Ics	 Icw = Ics	 Icw = Ics = Icu		
Sequence 1 General operating characteristics	X	X	X	X	1. verification of tripping thresholds 2. dielectric properties, test: Uimp between phases Uimp between phase and earth Uimp between incoming and outgoing terminals 3. mechanical endurance 4. electrical endurance 5. operation of overcurrent release at 6 In 6. dielectric withstand at 2 Ui (50 Hz - 1 min) 7. temperature rise at In 8. verification of overcurrent release calibration	1. ditto 2. dielectric properties ditto ditto Uimp + 25% between I/O + leakage current test (⩽ 0.5 mA per pole at 110% Ue) 3. ditto 4. ditto 5. ditto 6. ditto + leakage current test (⩽ 2 mA per pole at 110% Ue) 7. ditto 8. ditto
Sequence 2 Service breaking capacity Ics	X	X			1. 3 successive breaks at Ics with cycle O - 3 min - CO - 3 min - CO 2. verification of operating ability (5% of electrical endurance) 3. dielectric withstand at 2 Ui (50 Hz - 1 min) 4. temperature rise at In 5. verification of overcurrent release calibration	1. ditto 2. ditto 3. ditto + leakage current test (⩽ 2 mA per pole at 110% Ue) 4. ditto 5. ditto
Sequence 3 Ultimate breaking capacity Icu	X (1)	X (1)	X (1)		1. verification of overcurrent releases at 2 Ir 2. 2 successive breaks at Icu, cycle O - 3 min, CO 3. dielectric withstand at 2 Ui (50 Hz - 1 min) 4. verification of overcurrent release calibration	1. ditto 2. ditto 3. ditto + leakage current test (⩽ 6 mA per pole at 110% Ue) 4. ditto
Sequence 4 Short-time withstand test Icw		X			1. verification of overcurrent releases at 2 Ir 2. short-time withstand test for the time duration indicated by the manufacturer 3. temperature rise at In 4. 2 successive breaks at the maximum voltage for Icw, cycle O - 3 min - CO 5. dielectric withstand at 2 Ui (50 Hz - 1 min) 6. verification of overcurrent release calibration	1. ditto 2. ditto 3. ditto 4. ditto 5. ditto 6. ditto
Combined test sequence			X	X	1. verification of overcurrent releases at 2 Ir 2. short-time withstand test for the time duration indicated by the manufacturer 3. 3 successive breaks at Ics with cycle O - 3 min - CO - 3 min - CO 4. verification of operating ability (5% of electrical endurance) 5. dielectric withstand at 2 Ui (50 Hz - 1 min) 6. temperature rise at In 7. verification of overcurrent release calibration	1. ditto 2. ditto 3. ditto 4. ditto 5. ditto + leakage current test (⩽ 2 mA per pole at 110% Ue) 6. ditto 7. ditto

(1) if Icu = Ics, this sequence is not necessary.

***fig. 20**: Tests conducted in sequence according to IEC 947-2.*

3.2 Very wide sampling of circuit breakers tested

For the purpose of covering all of the published possibilities, the preceding sequences are repeated on several circuit breakers of the same type but with different configurations (see **fig. 21**):

- three-pole and four-pole,
- fitted with different trips,
- at different voltages,
- with different settings,
- with loadside and lineside supply if the circuit breaker is suitable,
- with or without residual current protection, if provided,
- etc, …

Thus the certification report covers all the published performances and guarantees the user that the device will correctly fulfil its function, regardless of:

- network characteristics,
- circuit breaker equipment,
- settings chosen.

- **Sample 1:**
Test Ics = 100 kA at Ue min. 240 V on a device fitted with the largest trip unit TM 160 D set to its maximum 160 A. Supply via upstream terminals.
- **Sample 2:**
Same test with device fitted with the smallest trip unit TM 16 D set to its minimum 12.5 A. Supply via upstream terminals.
- **Sample 3:**
Test Ics =70 kA at intermediate Ue 415 V on a device fitted with the largest trip unit TM 160 D set to its maximum 160 A. Supply via upstream terminals.
- **Sample 4:**
Test Ics = 10 kA under max. Ue 690V on a device fitted with the largest trip unit TM 160 D set to its maximum 160 A. Supply via downstream terminals.
- **Samples: 5, 6, 7, 8**
Same as samples 1, 2 , 3, 4 but using a device fitted with a residual current Vigi protection module.

***fig. 21**: The Ics service breaking capacity test sequence applied to a Vigicompact NS 160H circuit breaker: it must be repeated on 8 devices.*

4.1 Fundamental selection criteria for circuit breakers are unchanged

To determine the circuit breaker to be installed at a point in the electrical installation, it is primarily necessary to know two parameters:

- the load current I_B;
- the value of the three-phase short-circuit current (prospective Isc) at the origin of the wiring installation.

The circuit breaker is selected, as always, by comparing its setting current Ir with load current I_B, and its breaking capacity Icu with the prospective Isc (see **fig. 22**). These two basic rules are included in the installation standard NF C 15-100 and remain unchanged.

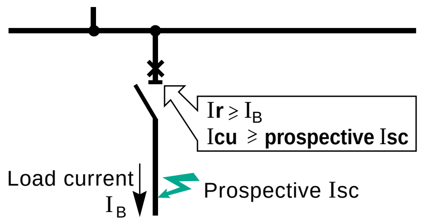


fig. 22: Basic parameter governing the selection of an outgoing circuit breaker.

4.2 Use of « service breaking capacity » Ics

For reasons developed in chapter 2, IEC 947-2 has defined the new service breaking capacity characteristic, Ics, which expresses the ability of a device to continue to operate normally after short-circuit breaking at a « probable » value.

Although there may be no regulations in the installation standards (IEC 364 or NF C 15-100) corresponding to the use of performance Ics, it is important, and wise, in order to ensure optimum continuity of service, to choose a device whose performance Ics is such that Ics ⩾ probable Isc.

a) Circuit breakers installed near power sources:

These devices are usually installed as general incomers, connecting up the switchboard or as a main LV board outgoer which, as a result of their proximity with transformers, must provide protection against virtually non-impedant faults. In actual fact the single-phase ph/N and ph/PE faults are of the same magnitude as the three-phase Isc due to:

- low zero-sequence source impedance,
- reduced connection resistances,
- low impedance cabling between source and device.

In these conditions, the probable short-circuit currents will be close to the theoretical value of the prospective Isc (see the calculation example in appendix 3).

It is therefore important to choose devices whose Ics performance is close to or equal to Icu.

The Merlin Gerin Masterpact and Compact NS ranges, designed for use at this distribution level, therefore logically have an Ics = 100% Icu.

b) Lower rated circuit breakers used at a distance from power sources:

These devices, usually installed in subdistribution switchboards, protect cabling between switchboards, or between switchboards and loads.

In this case, the probable short-circuits are greatly diminished because when they occur they are nearly always single-phase or two-phase, and located at the extremity of the protected wiring system.

Their value can be estimated as being at most equal to 80% of two-phase Isc calculated at the end of the wiring system,

Calculations show that the probable short-circuit current is in most cases less than 50% of prospective Isc (see appendix 3).

Although this is not strictly speaking an installation requirement for standards, use in this case of circuit breakers whose Ics is > 50% is a wise precaution guaranteeing long service life of the installation.

All the devices in the Merlin Gerin Multi 9 range are normally used at this distribution level, and have a service breaking capacity at least equal to 50% Icu.

4.3 Two devices in one: the circuit breaker-disconnector

Among the qualities required of an electrical installation, one in particular is of major importance for the user and that is the capability, in the event of a breakdown, to take out of service only the absolute minimum of the installation.
Reminder: take out of service = isolate + lock in « isolated » position (by padlock or switch-lock) + check absence of voltage at the point of intervention.
The most flexible solution is naturally the ability to fit such isolating/padlocking devices at all stages of distribution. Circuit breaker-disconnectors provide a practical solution, at no extra cost, for this problem.
For this reason all Merlin Gerin Compact and Masterpact industrial circuit breakers are circuit breaker-disconnectors lockable by padlock (see **fig. 23**), and/or by switch-lock (see **fig. 24**).

fig. 23: Padlocking device on a Merlin Gerin Compact circuit breaker.

fig. 24: Interlocking devices on a Merlin Gerin Masterpact circuit breaker.

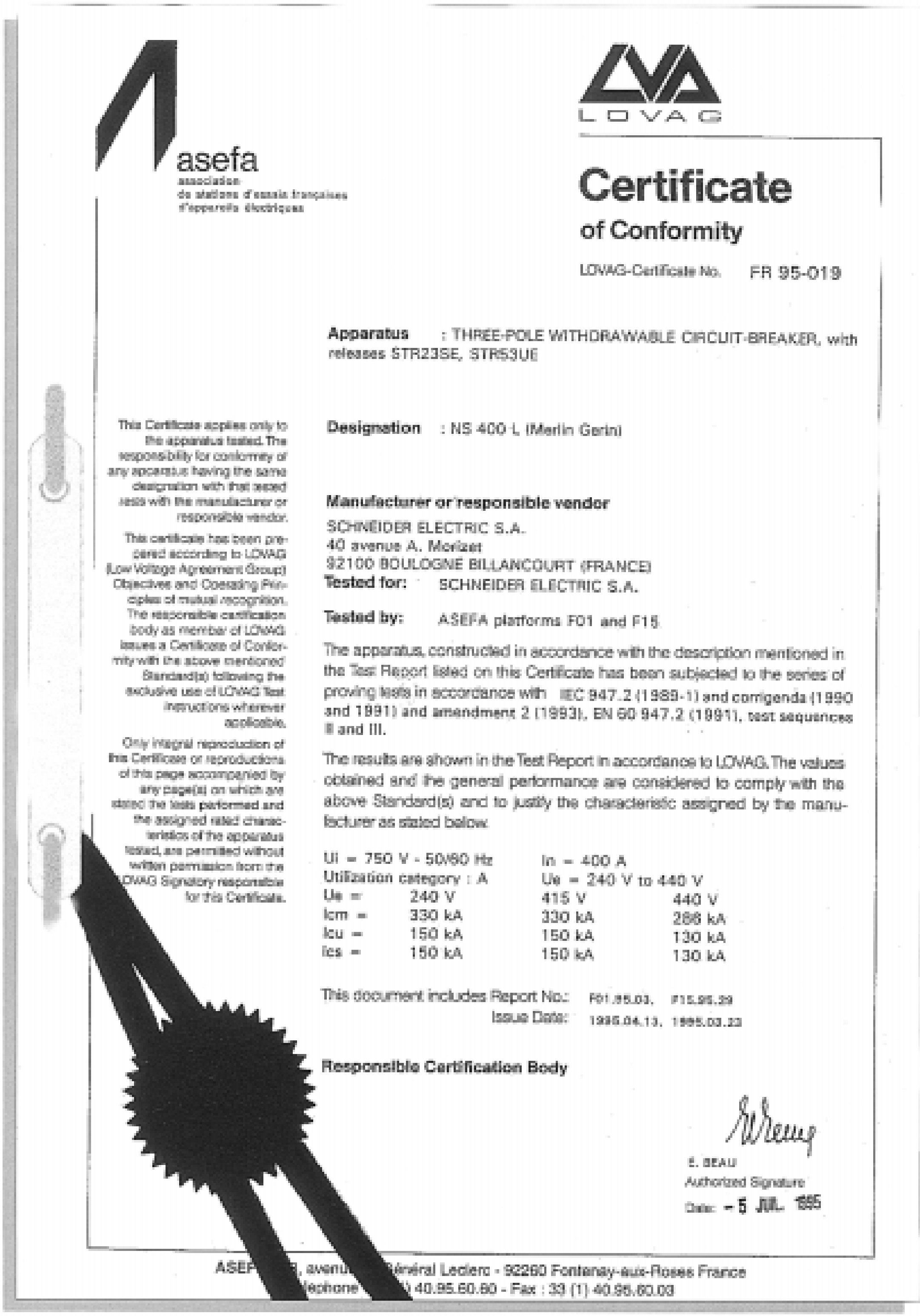
4.4 « All risks insurance »: conformity with IEC 947-2

For the designer, a circuit breaker's conformity with IEC 947-2, or with the national standards derived from it, constitutes the best possible assurance of quality and reliability in the environment of LV electrical installations.

This assurance results from the fact that the technological progress achieved by leading manufacturers has been taken into consideration by the standards, together with a comprehensive test standard which closely resembles actual operating conditions.

Conformity with IEC 947-2 is verified by accredited laboratories, and certified by organisations such as the ASEFA in France and the LOVAG at European level as part of an international Mutual Recognition agreement.
Figure 25 shows an example of a certificate of conformity.

Note that final distribution circuit breakers, particularly in the domestic sector, must comply with standard IEC 898. However, for use in industrial installations, some circuit breakers are governed by the stipulations of standard IEC 947-2 (see appendix 4).



asefa
association de stations d'essais françaises d'appareils électriques

LOVAG

Certificate
of Conformity

LOVAG-Certificate No. FR 95-019

This Certificate applies only to the apparatus tested. The responsibility for conformity of any apparatus having the same designation with that tested rests with the manufacturer or responsible vendor.

This certificate has been prepared according to LOVAG (Low Voltage Agreement Group) Objectives and Operating Principles of mutual recognition. The responsible certification body as member of LOVAG issues a Certificate of Conformity with the above mentioned Standard(s) following the exclusive use of LOVAG Test instructions wherever applicable.

Only integral reproduction of this Certificate or reproductions of this page accompanied by any page(s) on which are stated the tests performed and the assigned rated characteristics of the apparatus tested, are permitted without written permission from the LOVAG Signatory responsible for this Certificate.

Apparatus : THREE-POLE WITHDRAWABLE CIRCUIT-BREAKER, with releases STR23SE, STR53UE

Designation : NS 400 L (Merlin Gerin)

Manufacturer or responsible vendor
SCHNEIDER ELECTRIC S.A.
40 avenue A. Morizet
92100 BOULOGNE BILLANCOURT (FRANCE)

Tested for: SCHNEIDER ELECTRIC S.A.

Tested by: ASEFA platforms F01 and F15

The apparatus, constructed in accordance with the description mentioned in the Test Report listed on this Certificate has been subjected to the series of proving tests in accordance with IEC 947.2 (1989-1) and corrigenda (1990 and 1991) and amendment 2 (1993), EN 60 947.2 (1991), test sequences II and III.

The results are shown in the Test Report in accordance to LOVAG. The values obtained and the general performance are considered to comply with the above Standard(s) and to justify the characteristic assigned by the manufacturer as stated below.

Ui = 750 V - 50/60 Hz		In = 400 A	
Utilization category : A		Ue = 240 V to 440 V	
Ue =	240 V	415 V	440 V
Icm =	330 kA	330 kA	286 kA
Icu =	150 kA	150 kA	130 kA
Ics =	150 kA	150 kA	130 kA

This document includes Report No.: F01.95.03, F15.95.29
Issue Date: 1995.04.13, 1995.03.23

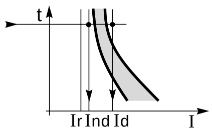
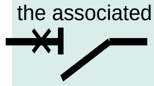
Responsible Certification Body

E. BEAU
Authorized Signature
Date: 5 JUIL. 1995

ASEF... , avenu... Général Leclerc - 92260 Fontenay-aux-Roses France
...éphone ...) 40.95.60.60 - Fax : 33 (1) 40.95.60.03

fig. 25: Example of a certificate of conformity issued by the ASEFA.

Appendix 1: main differences between IEC 157-1 and IEC 947-2

IEC 157-1	**IEC 947-2** (1995 edition and 1997 amendment)	**Comments**
Breaking capacity P1 cycle.	Ultimate breaking capacity Icu (sequence 3).	Equivalent characteristic.
Breaking capacity P2 cycle.		The new Ics characteristic is compulsory and more rigorous than the P2 cycle of IEC 157-1, as its tests are followed (after breaking) by an operating check at In.
	Service breaking capacity Ics (sequence 2).	
Each test is performed on a new device (operation, endurance, overloads, breaking capacity).	Tests are conducted in sequence.	More severe because of the cumulative testing on one device, but closer to real conditions.
Verify (three poles loaded) at the two asymptotes: Ind = 1.05 Ir Id = 1.35 Ir (≤ 63 A) or Id = 1.25 Ir (> 63 A)	Verify (three poles loaded) at the two asymptotes: Ind = 1.05 Ir Id = 1.30 Ir	where : t = 1 h (≤ 63 A) or t = 2 h (> 63 A) 
No other verification of overcurrent releases.	Verification of tripping: ■ pole by pole (sequences 3.4.5); ■ all poles loaded (sequence 2).	Better guarantee of operation of releases.
Nothing.	Definition of tests for isolation with the associated symbol: 	The circuit breaker-disconnector is recognised by installation standards to ensure the isolating function.
Nothing.	Voltage impulse withstand test. Characteristic Uimp.	Allows insulation co-ordination throughout the installation.
Co-ordination only between fuse and circuit breaker.	Includes a co-ordination appendix.	Takes into account two-circuit breakers in series.
Nothing.	Appendix B: devoted to circuit breakers fitted with residual current protection.	Standardisation of industrial residual current circuit breakers.
Nothing.	Appendix F: devoted to circuit breakers fitted with electronic releases.	Defines the additional tests specific to proper operation of electronic releases.
Nothing.	Appendix G: devoted to measurement of power dissipation by circuit breaker.	Standardises power dissipation measurement.
Nothing.	Appendix H: describes the test sequence for circuit breakers used in IT earthing systems.	Guarantees users that a device can be installed in IT earthing system without other verifications.

Definitions relating to voltage

Ue: rated service voltage.

Ui: rated insulation voltage (> Ue max.).

Uimp: rated impulse withstand voltage.

Definitions relating to current

I_B: circuit operational current, as in NF C 15-100, paragraph 433-2.

Icm: rated short-circuit making capacity.

Ics: rated service breaking capacity (normally expressed as a % of Icu).

Icu: rated ultimate short-circuit breaking capacity (expressed in kA).

Icw: rated short-time withstand current.

IΔn: rated residual operating current (often called residual sensitivity).

In: rated current = maximum value of current used for the temperature rise tests (e.g. for a Compact NS250 circuit breaker: In = 250 A).

Is: discriminating current limit.

Isc: short-circuit current at a given point in the installation.

Various definitions and symbols

 symbol for circuit breaker.

 symbol for circuit breaker/ disconnector.

Cat A : category of circuit breakers without time delay on opening under short-circuit conditions.

Cat B : category of circuit breakers with time delay on opening under short-circuit conditions ($Isc \leqslant Icw$).

Appendix 3: probable Isc calculation examples

1/ Downstream of a circuit breaker installed in a main LV board (see **fig. 26**)

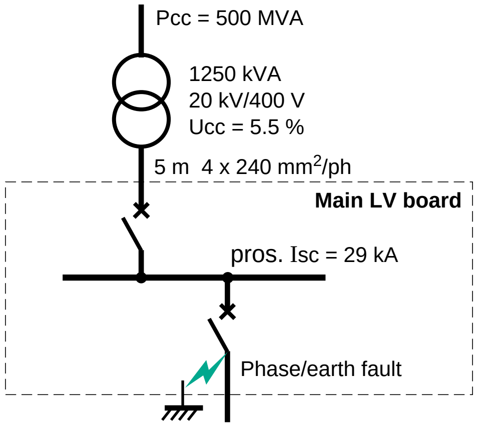


fig. 26

	Calculation of maximum prospective Isc (Three-phase short-circuit at circuit breaker installation point)	**Calculation of the most probable Isc** (Phase/earth short-circuit with an arc in the main LV board)
Lineside impedance	$Za \approx Xa \approx \frac{400^2}{Pcc} = 0.32\ m\Omega$	$Za \approx Xa \approx \frac{400^2}{Pcc} = 0.32\ m\Omega$
Transformer impedance	$Zt = Zd = \frac{400^2}{Pn} \times Ucc$ $Xt = 7.04\ m\Omega$ where $Zt \approx Xt$	$Zt = \frac{1}{3}(Zd + Zi + Zh)^*$ $Zt = \frac{2.4}{3} Zd = 5.63\ m\Omega$ where $Zt \approx Xt$
	*: For a transformer with delta/zig-zag connection, direct impedance Zd and negative phase-sequence impedance Zi are equal: zero-sequence impedance equals 0.4 Zd.	
Impedance of transformer - main LV board connection cable + Busbar impedance (≈ 5 m)	$Rph = 22.5 \times \frac{10}{4 \times 240} = 0.234\ m\Omega$ $Xph = 10 \times \frac{0.1}{4} = 0.25\ m\Omega$	$Rph = 0.234\ m\Omega$ $Xph = 0.25\ m\Omega$ $R_{PE} = 0.468\ m\Omega$ $X_{PE} = 0.25\ m\Omega$ (PE cross-section = 1/2 cross-section of phases)
	$\text{pros. Isc} = \frac{230}{\sqrt{(0.32 + 7.04 + 0.25)^2 + (0.234)^2}}$ pros. Isc = 30.2 kA	$\text{prob. Isc} = \frac{230 \times 0.8}{\sqrt{(0.32 + 5.63 + 0.25 + 0.25)^2 + (0.234 + 0.468)^2}}$ prob. Isc = 28.4 kA (the arc is taken into account by the factor 0.8)
Conclusion:	As probable Isc is very close to prospective Isc, it is advisable to choose a device whose Ics is equal to 100% Icu, e.g. a Merlin Gerin NS160N circuit breaker.	

2/ Downstream of a circuit breaker installed in the subdistribution switchboard
(see **fig. 27**)

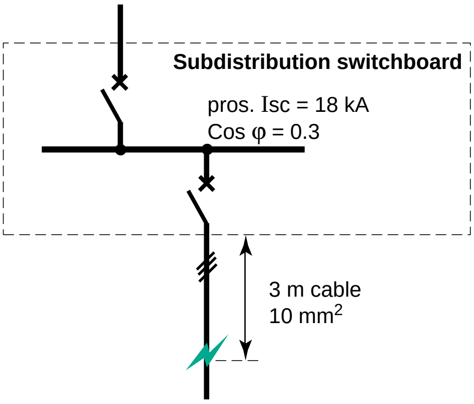


fig. 27

	Calculation of the probable Isc (Two-phase short-circuit with an arc at least 3 m from the switchboard)
Lineside impedance	$Za = \frac{230}{18\,10^3} = 12.78\ m\Omega$ $Ra = 12.78 \times 0.3 = 3.83\ m\Omega$ $Xa = 12.19\ m\Omega$
Cable impedance	$Rph = \frac{22.5 \times 3}{10} = 6.75\ m\Omega$ $Xph = 3 \times 0.08 = 0.24\ m\Omega$
Connection impedance	$R = 4\ m\Omega$ $X : \varepsilon$
Total impedance per phase	$\sum R = 14.58\ m\Omega$ $\sum X = 12.43\ m\Omega$ $Zt = \sqrt{(14.58)^2 + (12.43)^2} = 19.16\ m\Omega$ $\text{prob. Isc} = 0.8 \times \frac{230 \times \sqrt{3}}{2 \times 19.16}$ prob. Isc = 8.3 kA (the arc is taken into account by the factor 0.8)
Conclusion:	The probable Isc is less than 50% of prospective Isc (18 kA). It is thus usual to choose a device with an Ics equal to 50% of Icu, for example a Merlin Gerin C60L circuit breaker.

Appendix 4: standard IEC 898 for domestic circuit breakers

Industrial circuit breakers covered by the standard IEC 947-2 are selected, installed and used by experienced professionals.
This is not always the case with circuit breakers for final distribution, particularly where they are used in the domestic field (by inexperienced users), hence the standard IEC 898.
IEC 898 circuit breakers which form part of « domestic and similar switchgear » are easier to install (for example they do not have an adjustable threshold), while still guaranteeing a high level of safety. Their use by professionals means that some of them also come under IEC 947-2.
IEC 898 dates from 1987. It became a European Norm in mid-1990. Since then national standards harmonised with the European Norm (EN 60 898) have been published in CENELEC member countries.
There are some notable differences between IEC 947-2 and EN 60 898. It is of interest to be aware of them since small circuit breakers are often used in industrial final distribution.

	IEC 947-2	EN 60 898
Voltage Un (V)	< 1000	< 440
Current	(1)	In ⩽ 125 A
Thermal trip	1.05 at 1.03 In	1.13 at 1.45 In
Magnetic trip	(2)	«curves B-C-D»
Breaking capacity	Icu	Icn (3)
Service capacity	Ics	Ics (3)
Isolation	yes	under study

(1)

IEC 947-2 does not provide an upper or lower limit. 947-2 circuit breakers are used in the range of « a few amps to a few thousand amps ».

■ standard EN 60 898 defines the ratings (rated current: In): 10, 13, 16, 20, 25, 32, 40, 50, 63, 100 and 125 A

(2)

■ standard IEC 947-2 does not fix the range of operation and leaves the manufacturer to define the magnetic trip threshold, which must then fall within ± 20%.
For Merlin Gerin Compact circuit breakers of ratings higher than 250 A, the magnetic thresholds are:

□ G type adjustable from 2 to 5 Irth,
□ D type adjustable from 5 to 10 Irth,
□ MA type adjustable from 6.3 to 12.5 Irth.

■ standard EN 60 898 modifies standard practice (curves L, U, D) and introduces some new curves:

□ curve B: 3 to 5 In (2.6 to 3.85 for L),
□ curve C: 5 to 10 In (3.85 to 8.8 for U),
□ curve D: 10 to 20 In (10 to 14 for D and MA).

(3)

■ standard IEC 947-2 gives an « ultimate breaking capacity » corresponding to an O-CO test and a « service breaking capacity » of which the value, as a percentage of Icu, is fixed by the manufacturer and corresponds to an O-CO-CO test (see table 1 in **figure 4**).

■ standard EN 60 898 gives a rated breaking capacity Icn corresponding to an O-CO test and a service performance of which the value, as a percentage of Icn, is fixed by the standard and corresponds to an O-CO-CO test for:

□ Icn ⩽ 6 kA Ics = Icn
□ Icn > 6 kA Ics = 0.75 Icn (mini 6 kA)
□ Icn ⩽ 10 kA Ics = 0.75 Icn (mini 6 kA)
□ Icn > 10 kA Ics = 0.5 Icn (mini 7.5 kA)

Moreover this standard limits its field of application to circuit breakers of breaking capacity ⩽ 25 kA: short-circuit current which there is little chance of observing in a domestic or commercial installation.

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