

Distribution systems and protection against indirect contact and earth fault

1SDC007102G0201



Distribution systems and protection against indirect contact and earth fault

Index

1 Introduction	2
2 Main definitions	3
3 Protection against earth fault	
3.1 General aspects	5
4 Classification of electrical distribution systems	
4.1 TT system	6
4.2 TN system	6
4.3 IT system	7
4.4 Conclusions	7
5 Protection against indirect contact	
5.1 Effects of current on human body	8
5.2 Protection against indirect contact by automatic disconnection of the circuit	10
5.3 Protection against indirect contact in TT systems	13
5.4 Protection against indirect contact in TN systems	16
5.5 Protection against indirect contact in IT systems	20
6 ABB SACE solutions for protection against earth fault	
6.1 General aspects	22
6.2 The solution with residual current devices	23
6.2.1 Miniature circuit-breakers System pro M and System pro M compact with residual current protection	23
6.2.2 Residual current releases for Tmax moulded-case circuit-breakers	28
6.2.3 Electronic releases PR... ranges for molded-case and air circuit-breakers with integrated residual current protection	29
6.2.4 Residual current relay with external transformer	30
6.3 The solution with function G	31
6.4 Protection function G or residual current protection?	33
6.4.1 Typical applications of residual current circuit-breakers	33
6.4.2 Typical applications of moulded-case and air circuit-breakers equipped with function G against earth fault	34
6.5 Advanced protection systems against earth fault	34
6.5.1 General aspects	34
6.5.2 Source Ground Return	35
6.5.3 Restricted Earth Fault Protection	35
7 Discrimination of the protections against earth fault	37
Annex A: Direct current distribution systems	39
Annex B: Protection against direct contact.....	40
Annex C: Protection against indirect contact without automatic disconnection of the circuit	42
Annex D: Combined protection against both direct and indirect contact	44
Annex E: Considerations on the neutral and protective conductor.....	46
Glossary	51

1 Introduction

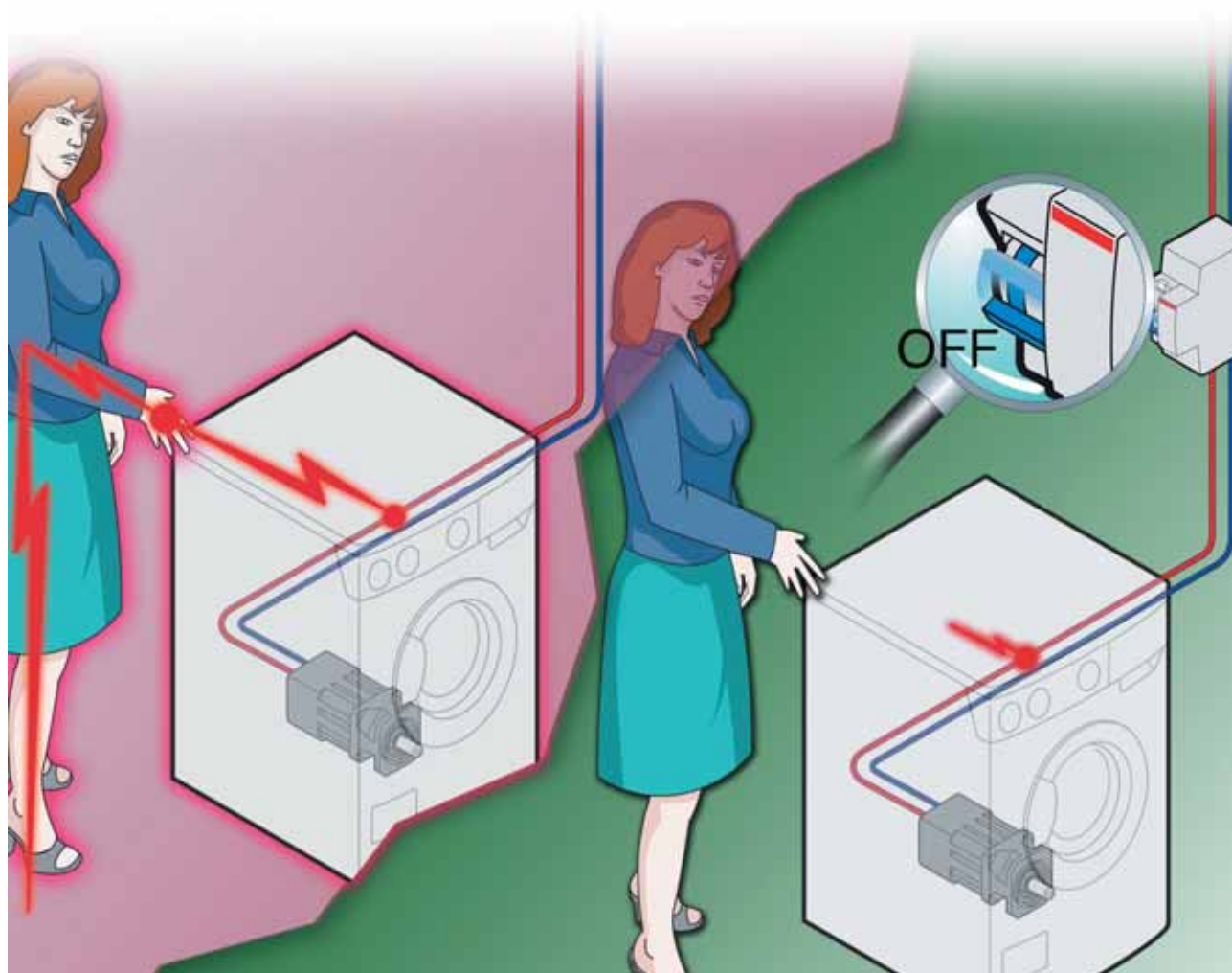
The earth fault, caused by an insulation loss between a live conductor and an exposed conductive part, represents a plant engineering problem which may cause damage to the electrical installations and above all may jeopardize people; as a matter of fact, people could get in touch with an exposed conductive part not normally live but which, due to the fault, might have a dangerous potential to ground.

The scope of this technical paper is providing the reader with the necessary information about the main normative aspects regarding protection against earth fault and indirect contact, clarifying the relevant problems and illustrating the solution proposed by ABB SACE.

This document is divided into three main parts:

- normative aspects (definitions, classification of the distribution systems, prescriptions regarding protection, etc.)
- ABB SACE solutions for protection against earth fault and indirect contact
- discrimination of the protections against earth fault.

In addition, to complete this document, there are some annexes analyzing thoroughly further aspects of the protection against electric shock, in particular protection against indirect contact, combined protection against both direct and indirect contact, considerations on the neutral and protective conductor, etcetera.

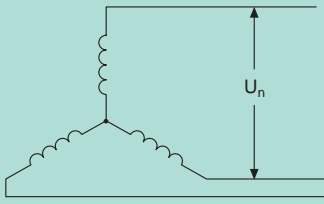
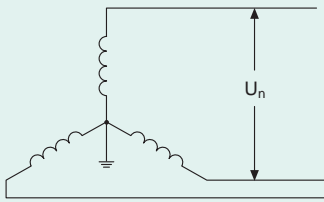
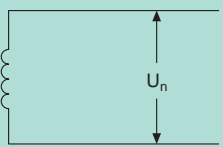
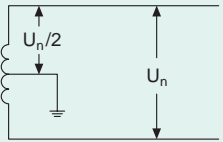


2 Main definitions

The definitions which are fundamental to understand better the content of this paper are reported hereunder; these definitions are extracted from the Standard IEC 60050 - International Electrotechnical Vocabulary:

- *(Effective) touch voltage*: voltage between conductive parts when touched simultaneously by a person or an animal.
- *Prospective touch voltage*: voltage between simultaneously accessible conductive parts when those conductive parts are not being touched by a person.
- *Nominal voltage to earth of a system*: nominal voltage to earth means:
 - the nominal voltage in three-phase systems with insulated neutral or earthed neutral through an impedance;
 - the star voltage corresponding to the nominal voltage in three-phase systems with neutral connected directly to earth;
 - the nominal voltage in single-phase systems, or alternating current systems, without earthed points;
 - half the value of the nominal voltage in single-phase systems, or alternating current systems, with earthed mid-point.
- *Live part*: conductor or conductive part intended to be energized in normal operation, including a neutral-conductor, but by convention not a PEN.
- *Hazardous-live-part*: live part which, under certain conditions, can give a harmful electric shock.
- *Exposed-conductive-part*: conductive part of equipment which can be touched and which is not normally live, but which can become live when basic insulation fails².
- *Direct contact*: electric contact of persons with live parts.
- *Indirect contact*: electric contact of persons with exposed-conductive-parts which have become live under fault conditions.
- *Arm's reach*: zone of accessibility to touch extending from any point on a surface where persons usually stand or move about to the limits which a person can reach with the hand, in any direction, without assistance.
- *Simultaneously accessible parts*: conductors or conductive parts which can be touched simultaneously by a person.

Table 1

three-phase systems with insulated neutral or earthed neutral through an impedance $U_{ne} = U_n$	
three-phase systems with neutral connected directly to earth $U_{ne} = \frac{U_n}{\sqrt{3}} = U_0^1$	
single-phase systems, or a.c. systems, without earthed points $U_{ne} = U_n$	
single-phase systems, or a.c. systems, with earthed mid-point $U_{ne} = \frac{U_n}{2}$	

¹ U_0 indicates the voltage between phase and neutral

² A conductive part which can become live only because it is in touch with an exposed-conductive-part shall not be considered an exposed-conductive-part.

- *Earth leakage current*: current which – in the absence of any fault - flows to earth or to the exposed conductive part.
- *Residual current*: algebraic sum of the values of the electric currents in all live conductors, at the same time at a given point of an electric circuit in an electrical installation.
- *Protective enclosure*: electrical enclosure surrounding internal parts of equipment to prevent access to hazardous-live-parts from any direction.
- *Protective barrier*: part providing protection against direct contact from any usual direction of access.
- *Protective obstacle*: part preventing unintentional direct contact, but not preventing direct contact by deliberate action.
- *Basic insulation*: insulation of hazardous-live-parts which provides basic protection.
- *Supplementary insulation*: independent insulation applied in addition to basic insulation for fault protection.
- *Double insulation*: insulation comprising both basic insulation and supplementary insulation.
- *Reinforced insulation*: insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation.
- *Insulating floors and walls*: floors and walls of rooms with such a high resistance that the current is limited to non-hazardous values.
- *Reference earth*: part of the Earth considered as conductive, the electric potential of which is conventionally taken as zero.
- *Earth electrode*: conductive part, which may be embedded in a specific conductive medium, e.g. concrete or coke, in electric contact with the Earth.
- *Earthing resistance*: resistance between the main earth collector (or node) and the Earth.
- *Independent earth electrode*: earth electrode located at such a distance from other earth electrodes that its electric potential is not significantly affected by electric currents between Earth and other earth electrodes.
- *Protective conductor (identification: PE)*: conductor provided for purposes of safety, for example protection against electric shock:
 - exposed-conductive-parts;
 - extraneous-conductive-parts;
 - main earth collector (or node);
 - earth electrode;
 - earthed point of the source or artificial neutral.
- *PEN conductor*: conductor combining the functions of both a protective earthing conductor and a neutral conductor.¹
- *Earthing arrangement*: all the electric connections and devices involved in the earthing of a system, an installation and equipment.
- *Fault current*: current which flows across a given point of fault resulting from an insulation fault.
- *Earth fault*: occurrence of an accidental conductive path between a live conductor and the Earth.
- *Skilled person*: person with relevant education and experience to enable him or her to perceive risks and to avoid hazards which electricity can create.
- *Instructed person*: person adequately advised or supervised by electrically skilled persons to enable him or her to perceive risks and to avoid hazards which electricity can create.
- *Trained person*: person with relevant education and experience (skilled person) or adequately instructed to enable him or her to perceive risks and to avoid hazards which electricity can create, in relation to particular operations carried out under specified conditions (instructed person). Therefore the term "trained" is an attribute relative to:
 - type of operation;
 - type of installation on which, or near to which, operations are to be carried out;
 - environmental and contingent conditions, and supervision from more qualified personnel.
- *Ordinary person*: person who is neither a skilled person nor an instructed person.

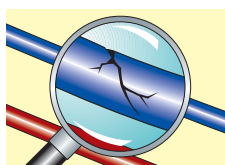
¹ The symbol PEN results from the combination of the symbol PE (for protective conductor) with the symbol N for neutral conductor.

3 Protection against earth fault

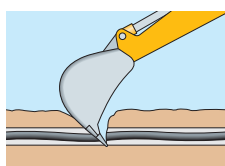
3.1 General aspects

The loss of insulation between normally live conductors and exposed-conductive-parts may generate a fault, which is generally called earth fault.

The main causes of the loss of insulation are:



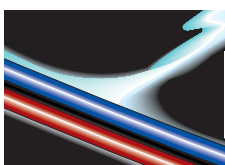
- time decay of dielectric properties (cracks in the insulating rubbers, etc.);



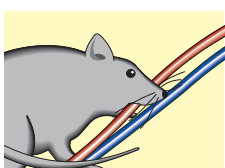
- mechanical breaking (e.g. shearing of a cable in the ground by an excavator);



- particularly aggressive environments (presence of dusts, humidity, pollution, etc.);



- overvoltages of atmospheric origin or due to switching;

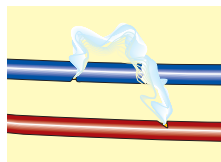


- rodent action.

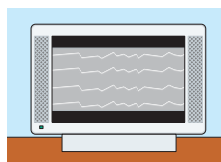
The main effects of the earth fault current are:



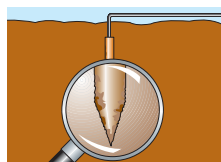
- energizing of exposed-conductive-parts;



- localized electric arcs and consequent overheatings;



- disturbances to telecommunication systems;



- erosion phenomena of earth electrodes.

The earth fault current starts as a localized arc at the point where the insulation has failed; this arc is characterized by a rather modest current level of the order of tens of milliamps. Subsequently, the fault evolves, more or less rapidly, to become a true earth-phase fault. If not rapidly interrupted by protection devices, this fault may end up affecting all the phases, creating a three-phase short-circuit with earth contact.

Therefore, the first consequence of the earth fault current is the damage caused to the plant, whether due to the modest initial arc currents which, because of the difficulty in detection by the overcurrent releases may continue for long periods of time and start a fire, or due to the short-circuit that develops after the integrity of the entire plant has been jeopardized.

Another important consequence of the earth fault current involves the danger to persons caused by indirect contact, i.e. following the contact with exposed-conductive-parts that have been energized accidentally due to a decay in the insulation.

4 Classification of electrical distribution systems

The extent of the earth fault and the consequences deriving from the touching of live exposed-conductive-parts are specifically related to the neutral condition of the power system and to the types of system earthing.

As a consequence, to select the proper device for the protection against earth faults, it is necessary to know the installation distribution system. The International Standard IEC 60364-3 classifies the electrical systems with the combination of two letters.

The first letter indicates the relationship of the power system to earth¹:

- T = direct connection to earth of one point, usually the neutral, in a.c. systems;
- I = all live parts isolated from earth or one point, usually the neutral, connected to earth through an impedance.

The second letter indicates the relationship of the exposed-conductive-parts of the installation to earth:

- T = direct electrical connection of exposed-conductive-parts to earth;
- N = direct electrical connection of the exposed-conductive-parts to the earthed point of the power system.

Subsequent letters, if any, indicates the arrangement of neutral and protective conductors:

- S = neutral and protective functions provided by separate conductors
- C = neutral and protective functions combined in a single conductor (PEN conductor).

With reference to the definitions above, here are described the main type of power systems.

¹ Earthing of a point at MV/LV transformer level is necessary to prevent transferring of dangerous voltages to ground, e.g. voltages due to a fault between MV and LV windings. In IT systems the use of transformers built so as not to transfer dangerous voltages for man and equipment is strongly recommended.

4.1 TT system

In TT systems the neutral and the exposed-conductive-parts are connected to earth electrodes electrically independent (Figure 1); therefore the earth fault current returns to the power supply node through the soil (Figure 2).

Figure 1: TT system

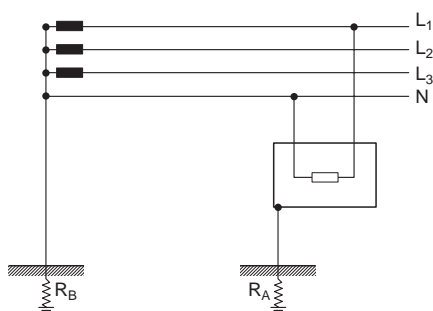
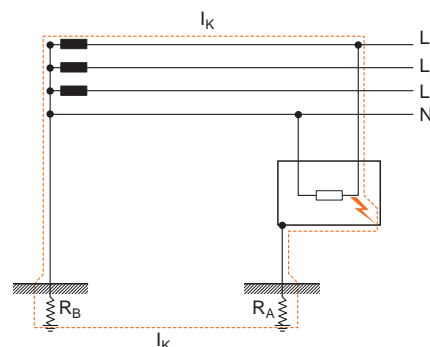


Figure 2: Earth fault in a TT system



In this type of electrical installations the neutral is usually distributed and its function is making the phase voltage (e.g. 230 V) available for the supply of the single-phase loads of civil installations.

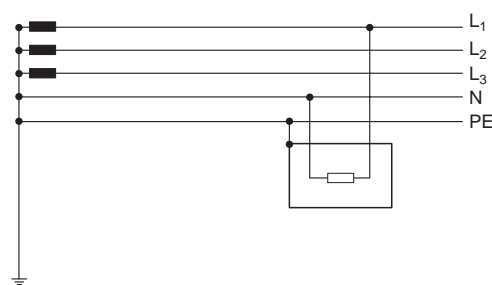
4.2 TN system

In TN systems, the neutral is directly earthed, whereas the exposed-conductive-parts are connected to the same earthing arrangement of the neutral.

TN electrical systems can be divided into three types based on the fact that the neutral and protective conductors are separate or not:

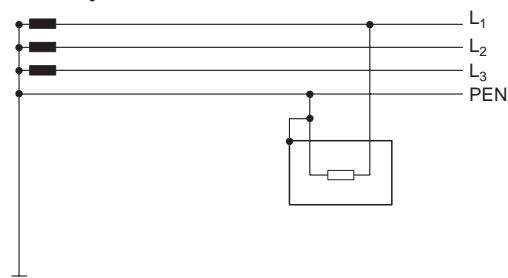
1. TN-S: the neutral conductor N and the protective conductor PE are separated (Figure 3)

Figure 3: TN-S system



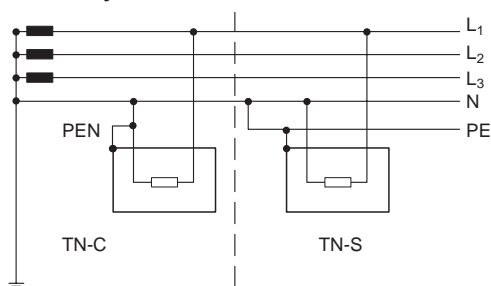
2. TN-C: the neutral and protective functions are combined into a single conductor, called PEN (Figure 4)

Figure 4: TN-C system



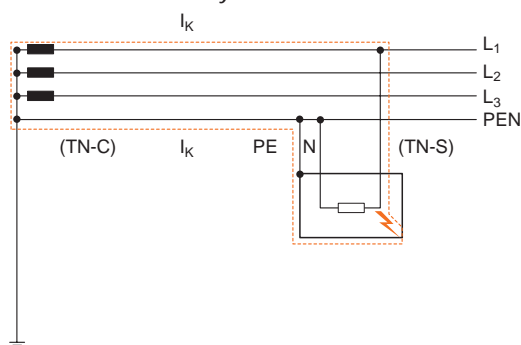
3. TN-C-S: the neutral and protective functions are partially combined into a single PEN conductor and partially separated PE + N (Figure 5).

Figure 5: TN-C-S system



In TN systems the earth fault current returns to the power supply node through a direct metal connection (PE or PEN conductor) without practically affecting the earth electrode (Figure 6).

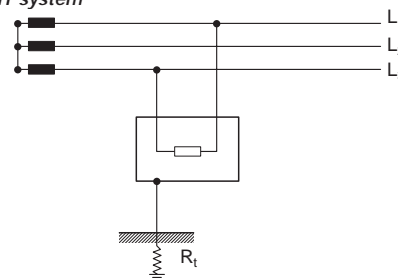
Figure 6: Earth fault in a TN system



4.3 IT system

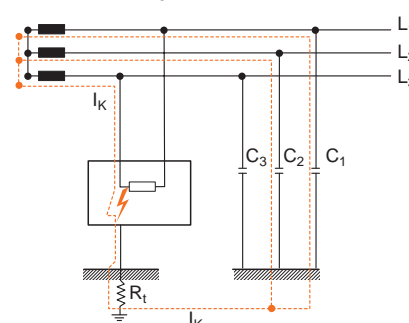
IT systems have no active parts directly earthed, but may have live parts connected to earth through high value impedance (Figure 7). All the exposed-conductive-parts, separately or in group, are connected to an independent earth electrode.

Figure 7: IT system



The earth fault current returns to the power supply node through the earthing arrangement of the exposed-conductive-parts and the capacities to earth of the line conductors.

Figure 8: Earth fault in a TT system



4.4 Conclusions

Distribution system	Main application	Typical value of the fault currents	Remarks
TT	domestic installations and similar; small industries with LV power supply	10+100 A	TT distribution systems are used when assuring the distribution of the protective conductor (PE) is impossible and when it is advisable to leave to the user the responsibility for the protection against indirect contact.
TN	industries and big installations with MV power supply	values similar to those of the single-phase fault	TN distribution systems are the systems through which power supply is distributed to users having their own transformer substation; in these cases, the protective conductor can be easily ensured.
IT	chemical and petrochemical industries, i.e. plants for which service continuity is fundamental	$\mu\text{A} \div 2 \text{ A}$ dependent on the size of the installation; in case of double earth fault, the fault current takes values typical of TT or TN systems depending on the connection of the exposed-conductive-parts to earth	This type of system results to be particularly suitable for the cases in which service continuity must be assured since the presence of a first fault does not cause high currents and/or currents dangerous for the people.

5 Protection against indirect contact

5.1 Effects of current on human body

Dangers to persons due to the contact with a live part are caused by the current flow through the human body. These effects are:

- **tetanzation**: the muscles affected by the current flow involuntary contract and the let-go of conductive parts gripped is difficult. Note: very high currents do not usually induce muscular tetanization because, when the body gets in touch with such currents, the muscular contraction is so sustained that the involuntary muscle movements generally throw the subject away from the conductive part;
- **breathing arrest**: if the current flows through the muscles controlling the respiratory system, the involuntary contraction of these muscles alters the normal respiratory process and the subject may die due to suffocation or suffer the consequences of traumas caused by asphyxia;

- **ventricular fibrillation**: the most dangerous effect is due to the superposition of the external currents with the physiological ones which, by generating uncontrolled contractions, induce alterations of the cardiac cycle. This anomaly may become an irreversible phenomenon since it persists even when the stimulus has ceased;
- **burns**: they are due to the heating deriving, by Joule effect, from the current passing through the human body.

The Standard IEC 60479-1 "Effects of current on human beings and livestock" is a guide about the effects of current flowing through the human body to be used for the definition of electrical safety requirements. This Standard shows, on a time-current diagram, four zones (Figure 1) to which the physiological effects of alternating current (15 – 100 Hz) passing through the human body have been related. Such zones are illustrated in Table 1.

Figure 1: Time-current zones of the effects of alternating current on the human body

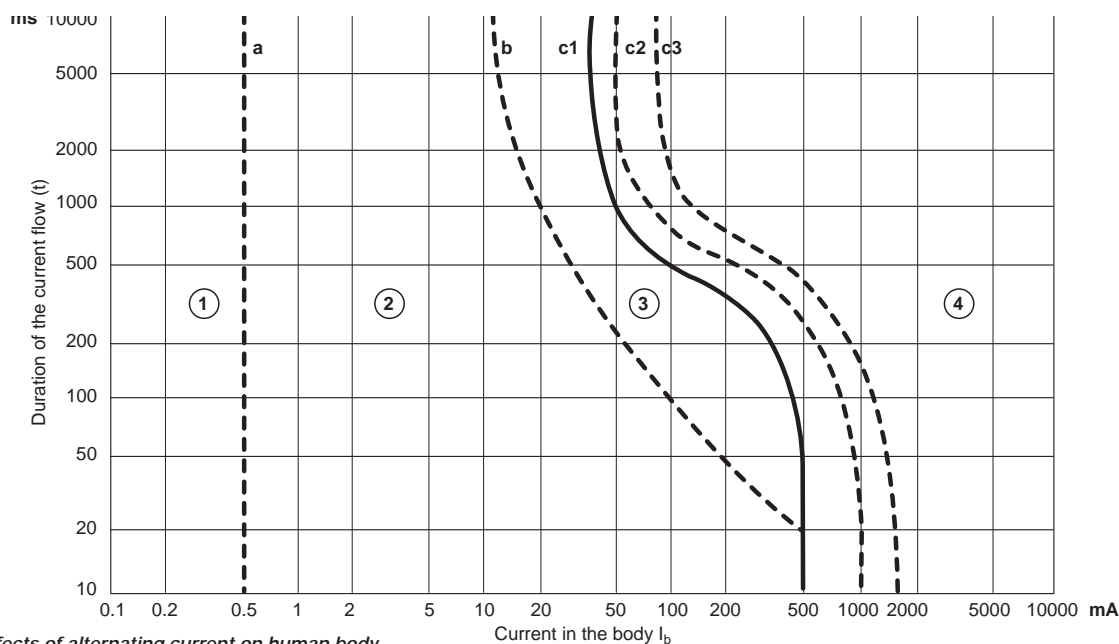


Table 1: Effects of alternating current on human body

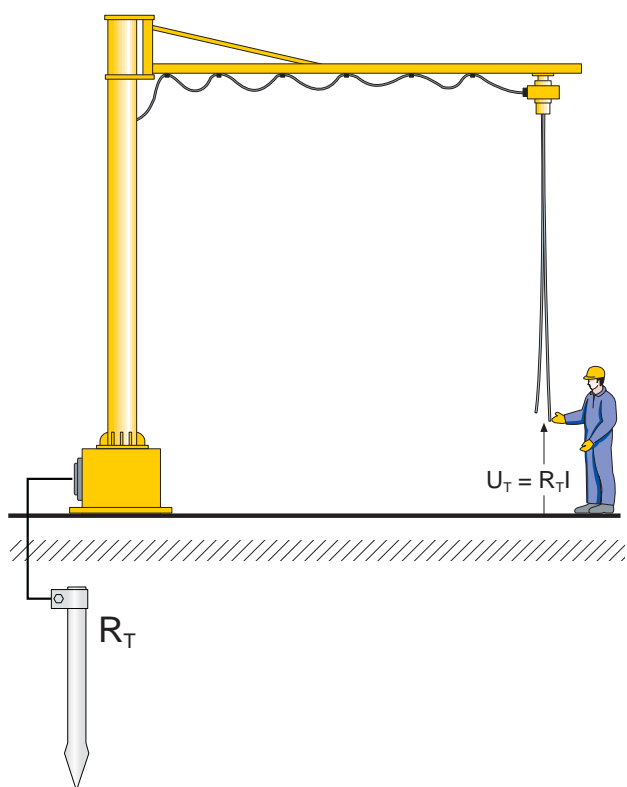
Zone	Effects
1	usually no reaction
2	usually no harmful physiological effects
3	usually no organic damage to be expected. Likelihood of cramplike muscular contractions and difficulty in breathing; reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time
4	in addition to the effects of zone 3, the probability of ventricular fibrillation increases up to about 5% (curve c2), 50% (curve c3) and above 50% beyond the curve c3. Pathophysiological effects such as cardiac arrest, breathing arrest and severe burns may occur increasing with current magnitude and time

The Standard IEC 60479-1 gives also an analogous diagram for direct current.

The curves of Figure 1 cannot be easily applied to the definition of the maximum allowable current limits for people's safety. Therefore, once the human body impedance is known, it is possible to define the safety curves for the allowable voltages by applying Ohm's law.

The electrical impedance of the human body offered to the passage of the current flowing between two of its extremities is very variable. The Standard IEC 60479-1 gives different values of the impedance as a function of the touch voltage and of the current path.

Taking into consideration the precautionary values for the impedance reported in the diagram of the Standard,



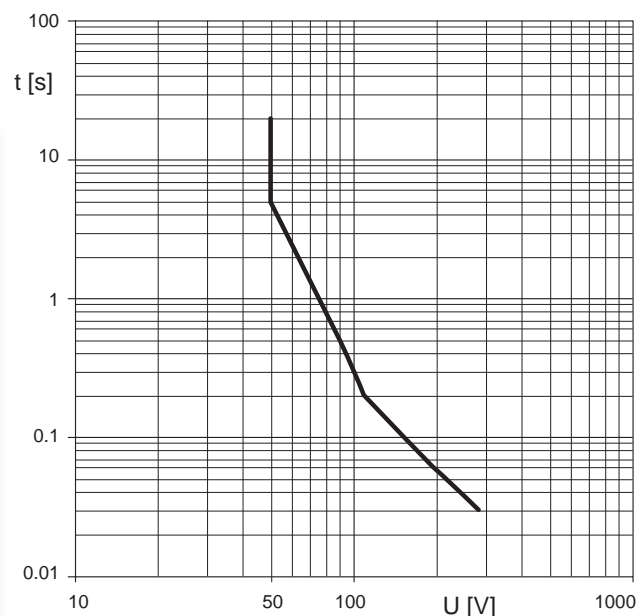
The prospective touch voltage U_T is the voltage which is present between an exposed-conductive-part and a point of the ground sufficiently far.

it is possible to get the time-voltage safety curve which gives some indications relevant to the time for which the human body can withstand the fault current, as a

function of the prospective touch voltage U_T (Figure 2). The prospective touch voltage is the voltage which, due to an insulation failure, is present between a conductive part and a point of the ground sufficiently far, with zero potential. It represents the maximum effective touch voltage value; thus, the most unfavorable condition is taken into consideration for the safety's sake.

From the safety curve of Figure 2, it results that, for all voltage values below 50 V, the tolerance time is indefinite; at 50 V the tolerance time is 5 s.

Figure 2: Time-voltage safety curve



The curve shown in the figure refers to an ordinary location; in particular locations, the touch resistance of the human body towards earth decreases and consequently the tolerable voltage values for an indefinite time is lower than 25 V. Therefore, if the protection against indirect contacts is obtained through the automatic disconnection of the circuit, it is necessary to ensure that such breaking is carried out in compliance with the time-voltage safety curve for any distribution system. In practice, it is not easy to evaluate in advance the touch voltage since it depends upon the configuration of the plant; besides, also after the realization of a plant, the evaluation of this voltage type is quite complex. For these reasons some conventional methods have been defined which allow to determine the disconnecting times of the protection devices not as a function of the effective touch voltage, but as a function of the rated voltage of the installation for TN systems and of the prospective touch voltage for TT systems.

5.2 Protection against indirect contact by automatic disconnection of the circuit

The Standard IEC 60364 prescribes automatic disconnection of the supply for protection against indirect contact.

The protective device shall automatically disconnect the supply so that, in the event of a fault between a live part and an exposed-conductive-part or a protective conductor, a prospective touch voltage exceeding 50 V a.c. (25 V in special environments) does not persist for a time sufficient to cause a risk of harmful physiological effect in a person in contact with simultaneously accessible conductive parts.

This protective measure requires co-ordination between the connection to earth of the system and the characteristics of the protective conductors and devices.

The devices suitable for the automatic disconnection of the supply and able to detect earth fault currents are:

- automatic circuit-breakers with thermomagnetic release;
- automatic circuit-breakers with microprocessor-based electronic relay;
- automatic circuit-breakers with microprocessor-based electronic relay with integrated protection against earth fault (function G);
- thermal magnetic or electronic circuit-breakers with integrated residual current releases;
- pure residual current circuit-breakers;
- residual current releases.

Hereunder there is a description of such protective devices.

Automatic circuit-breakers with thermomagnetic release

The protections ensured by the automatic circuit-breakers equipped with thermomagnetic release are:

- protection against overloads;
- protection against short-circuits;
- protection against indirect contacts.

The protection against overload is provided by the thermal release with inverse time-delay curve, i.e. the higher the overload current, the faster the tripping time.

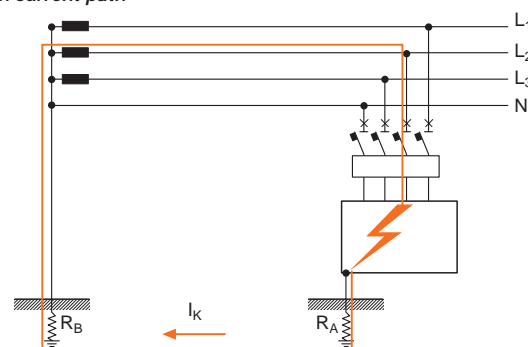
The protection against short-circuit is provided through the magnetic release with an independent time trip curve, i.e. with disconnecting time independent from the short-circuit current.

The protection against indirect contacts can be carried out both by the thermal release as well as by the magnetic release since the earth fault current involves at least one phase; if this current is high enough, it can cause the tripping of the circuit-breaker. As explained farther in this paper, it is necessary that the protective device is coordinated with the distribution system and the earth-

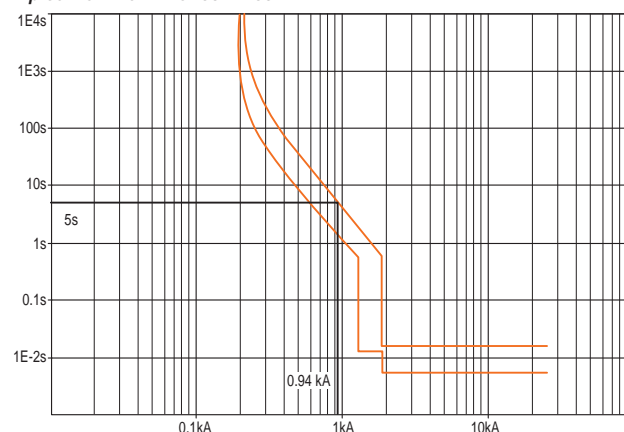
ing modality of the exposed-conductive-parts, so that tripping is guaranteed to occur in such times to limit the persistence of the dangerous touch voltages present in the exposed-conductive-parts further to the fault.

Figure 3 shows an example of the earth fault current path in a system with the neutral and the exposed-conductive-parts connected to two independent earth electrodes (TT system) and the trip curve of a thermal magnetic circuit-breaker type Tmax T1B160 R125.

Figure 3
Earth current path



Trip curve Tmax T1C160 In160



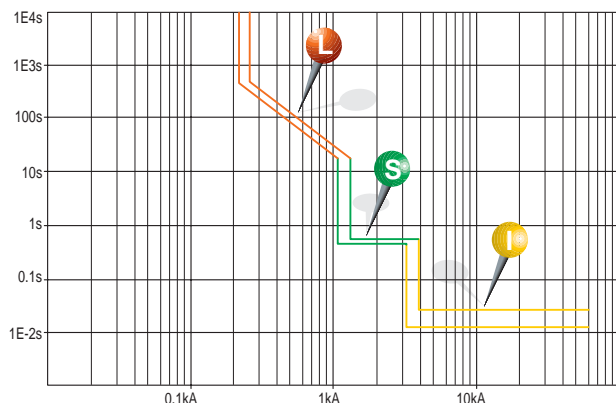
As the diagram shows, by assuming an earth fault current of 940 A, the circuit-breaker shall trip in maximum 5s (value read on the curve with the higher tolerance).

Automatic circuit-breakers with microprocessor-based electronic relay

The protections provided by the automatic circuit-breakers with electronic relays are completely analogous to those assured by the circuit-breakers with thermomagnetic release. The protection functions implemented by microprocessor-based electronic relay allow protection

against overload (protection L), short-circuit (protection S and I) and indirect contact to be realized.

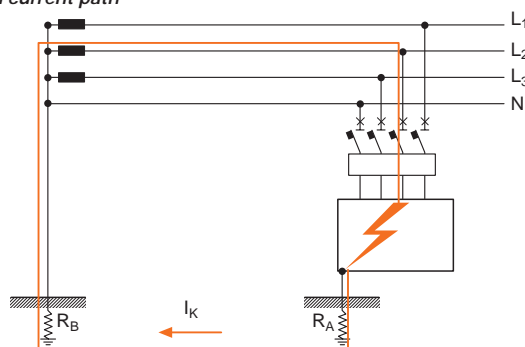
Figure 4



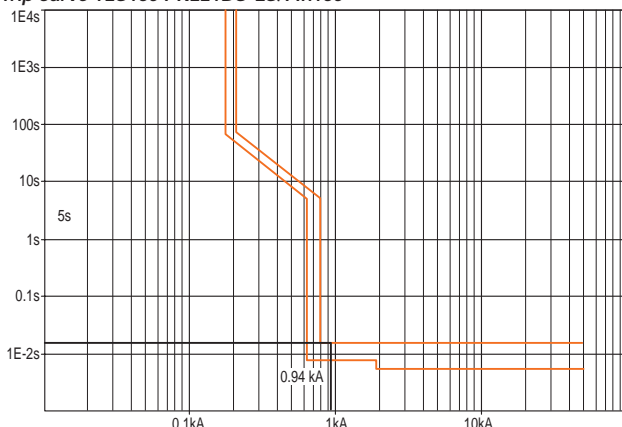
Electronic releases allow to get an accurate settings both as regards the trip times as well as the current thresholds so that the installation requirements are fully satisfied. Figure 5 shows the same example as before, but a circuit-breaker type Tmax T2S160 PR221DS-LS/I In160 with electronic release is installed as protective device.

Figure 5

Earth current path



Trip curve T2S160 PR221DS-LS/I In160



The possibility of setting a low magnetic threshold (at about 750 A) allows to achieve a trip time corresponding to the magnetic tripping (some tens of milliseconds),

which is remarkably quicker than the time obtainable under the same conditions with a thermal magnetic circuit-breaker of the same size.

Automatic circuit-breakers with microprocessor-based electronic relay with integrated protection against earth fault (function G)

The microprocessor-based electronic relays in their advanced version offer, in addition to the protection functions against overload (L) and short-circuit (S and I), a dedicated protection function - called function G - against earth fault.

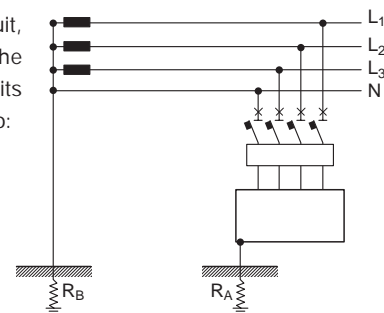
Protection function G can evaluate the vectorial sum of the currents flowing in the live conductors (the three phases and the neutral). In a sound circuit, this sum is equal to zero, but in the presence of an earth fault, part of the fault current shall return to the supply source through the protective conductor and/or the earth without affecting the live conductors.

If this current is higher than the tripping value set for the function G, the circuit-breaker shall trip within the relevant setting time. Figure 6 shows the operating principle.

Figure 6: Operating principle of function G

In case of a sound circuit, the vectorial sum of the currents in the live circuits (phases + neutral) is zero:

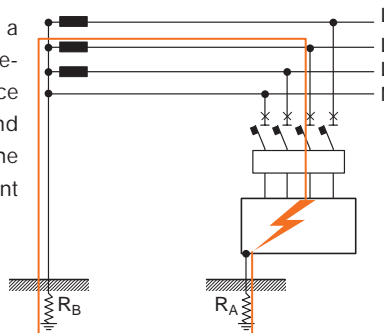
$$I_A = I_{L1} + I_{L2} + I_{L3} + I_N = 0$$



In case of earth fault, a part of the fault current returns to the supply source through the ground and the vectorial sum of the currents shall be different from zero:

$$I_A = I_{L1} + I_{L2} + I_{L3} + I_N \neq 0$$

$$I_A \geq I_{tripping \text{ of function G}}$$

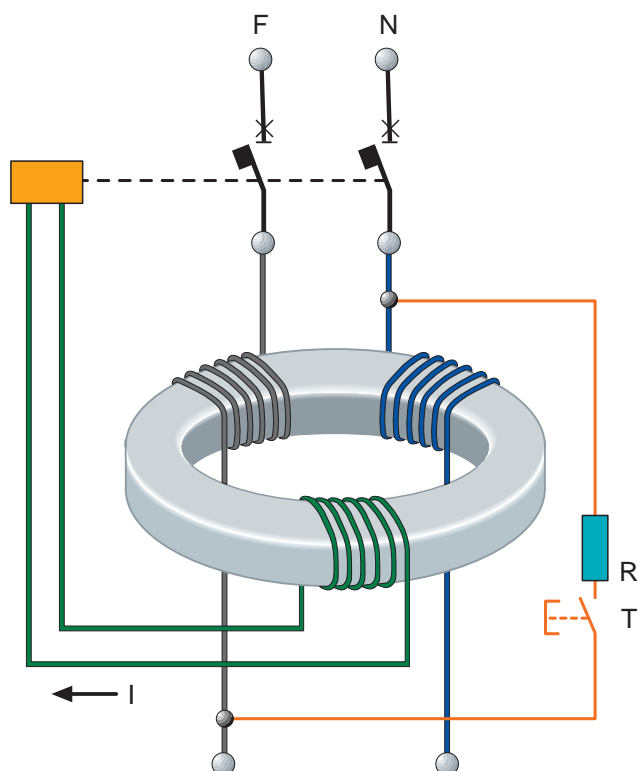


Thermal magnetic or electronic circuit-breakers with integrated residual current release

The automatic circuit-breakers with integrated residual current release combine the residual current release and the overcurrent protection release into a single apparatus and trip due to both current earth leakage as well as overcurrent/short-circuit.

The operating principle of the residual current release consists in detecting the earth fault current through a toroidal transformer including all the live conductors and the neutral, if distributed.

Figure 7: Operating principle of the residual current release



In absence of an earth fault, the vectorial sum of the currents I_A is equal to zero; in case of an earth fault, if the value I_A exceeds the rated residual operating current $I_{\Delta n}$, the circuit at the secondary side of the toroid sends a command signal to a dedicated trip coil causing the tripping of the circuit-breaker.

A first classification of the residual current circuit-breakers is possible according to their sensitivity to the fault current types:

- type AC: tripping is ensured in case of residual sinusoidal alternating currents;

- type A: tripping is ensured for residual sinusoidal alternating currents and for residual pulsating unidirectional currents;
- type B: tripping is ensured for residual continuous currents besides residual sinusoidal alternating currents as well as residual pulsating unidirectional currents.

Table 2: Types of residual current devices

	Form of residual current	Correct functioning of residual devices Type		
		AC	A	B
Sinusoidal ac	suddenly applied	+	+	+
	slowly rising			
Pulsating dc	suddenly applied			
	with or without $\uparrow 0.006A$		+	+
Smooth dc	slowly rising			
				+

A further classification is established based on the tripping delay;

- non-delayed type
- time-delayed type S.



Pure residual current circuit-breakers

Pure residual current circuit-breakers are equipped with a residual current release only and therefore ensure protection only against earth fault. They must be coupled with thermo-magnetic circuit-breakers or fuses for the protection against thermal and dynamical stresses. Their operating principle is the same as previously described.

Residual current releases

Residual current releases, also called switchboard residual current releases, carry out the function of detection of the earth fault current through a separated toroid to be installed externally on the live conductors of the circuit. Should the residual current exceed the set threshold, the release activates a contact which is used to command the tripping mechanism of a circuit-breaker.

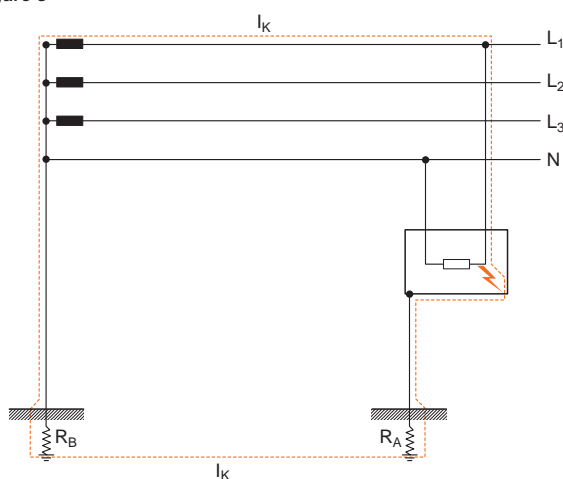
They are devices used in the industrial plants, where the installation conditions are particularly restrictive, such as for example circuit-breakers already installed or limited space in the circuit-breaker cell.

Their operating principle is the same as that previously described.

5.3 Protection against indirect contact in TT systems

An earth fault in a TT system involves the circuit represented in Figure 8.

Figure 8



The fault current flows through the secondary winding of the transformer, the phase conductor, the fault resistance, the protective conductor and the earth electrode resistances (R_A , of the user's plant, and R_B , of the neutral). According to IEC 60364-4 prescriptions, the protective devices must be coordinated with the earthing arrangement in order to

rapidly disconnect the supply if the touch voltage reaches harmful values for the human body.

Assuming 50V (25V for particular locations) the condition to be fulfilled in order to limit the touch voltage on the exposed-conductive-parts under this limit is:

$$R_A \leq \frac{50}{I_a} \quad \text{or} \quad R_A \leq \frac{50}{I_{\Delta n}}$$

where:

R_A is the resistance of the earth electrode (in ohm)¹;

I_a is the current causing the automatic operation of the protective device within 5s, read from the tripping curve characteristic of the device itself (in ampere); when the protective device provides protection against overcurrents, the Std. CEI 64-8, paragraph 413.1.4.2 specifies that:

- if it is a device with inverse time delay characteristic I_a , the current itself shall operate tripping in 5s;
- if it is a device with instantaneous trip time characteristic I_a , the minimum current shall cause circuit-breaker opening;

$I_{\Delta n}$ is the rated residual operating current of the residual circuit-breaker within 1s (in ampere).

From the above, it is clear that the resistance value R_A , which the earthing arrangement shall have, is considerably different when using automatic circuit-breakers instead of residual current devices, because the order of magnitude of the current in the denominator of the above relationship is different. The following paragraph illustrates what already said, underlining the different values that R_A may take in relation to the protective devices used.

The choice of the automatic device for the purpose of protection against earth fault and indirect contact shall be made by coordinating properly the trip time with the R_A value. In TT systems the following devices for the protection against indirect contact can be used:

- circuit-breakers with thermomagnetic releases;
- circuit-breakers with electronic releases;
- residual current devices.

Protection against indirect contact by circuit-breakers with thermomagnetic releases

The use of an automatic circuit-breaker equipped with a thermomagnetic release for the protection against indirect contact in a TT system makes it quite difficult to comply with the earthing arrangement resistance.

¹ The resistance of the earth electrode R_A is in series with that of the protective conductor, which is negligible if compared with the resistance R_A ; as a consequence, in the formula it is possible to take into consideration only the resistance of the earth electrode of the user's plant.

Actually, for these circuit-breakers, the current causing tripping in 5s or instantaneous tripping is usually a multiple of the rated current; as a consequence, to verify the prescriptions of the Standard it is necessary to use earth electrodes with resistance values under the unit, which are hardly feasible in the practice.

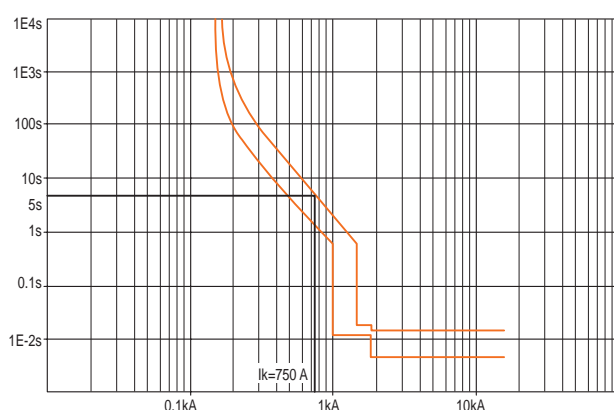
As an example, let's assume to provide protection by using the automatic circuit-breaker of ABB SACE series Tmax T1B160 In125.

Starting from cold conditions, which is the worst case for thermal releases, from the tripping curve it results that the current for which the circuit-breaker trips in 5s is about 750A (Figure 9). Thus:

$$R_A \leq \frac{50}{750} = 0.06\Omega$$

In order to guarantee the necessary protection, it shall be necessary to realize an earthing arrangement with resistance $R_A \leq 0.06\Omega$, which is a difficult value to obtain in the practice.

Figure 9



On the contrary, by using the same apparatus equipped with a residual current release type ABB SACE RC221 with residual current $I_{\Delta n} = 30\text{ mA}$, the following resistance value must be obtained:

$$R_A \leq \frac{50}{0.03} = 1666.6\Omega$$

As it shall be explained further on, using a residual device allows to realize an earthing arrangement with an earth resistance value easily obtainable, whereas automatic circuit-breakers shall be used provided that low earth resistance values R_A are present.

Protection against indirect contact by circuit-breakers with electronic releases

For the electronic releases, the indications given for the previous cases can be followed as well as regards functions L (overload protection), S (short-circuit protection with adjustable release) and I (short-circuit protection with instantaneous trip). The electronic releases allow to realize an accurate setting both in terms of times as well

as in terms of current thresholds, but, as in the above mentioned case, they can be used only when it is possible to implement an earthing arrangement with a very low resistance value, often lower than the unit.

Particular attention must be paid to the protection function G (earth fault protection with adjustable delay) available for the more advanced electronic releases. It must be remembered that this protection is able to evaluate the vectorial sum of the currents flowing in the live conductors (the three phases and the neutral). In a sound circuit this sum is equal to zero, but in the presence of an earth fault a part of the fault current shall return to the supply source through the protective conductor and the ground, without affecting the live conductors. If this current is higher than the value set for the function G, the circuit-breaker shall trip within the time set on the electronic release.

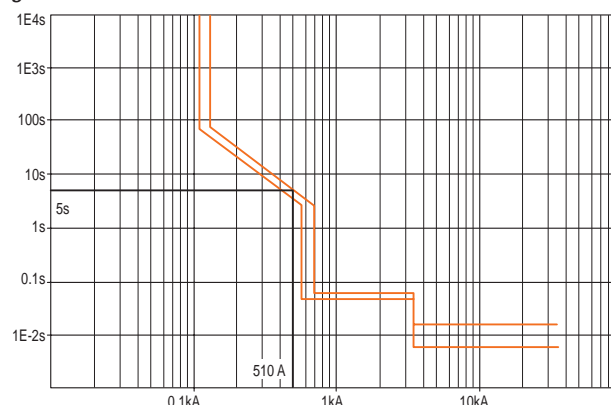
By using the protection function G, the relationship to comply with to realize protection against indirect contact becomes:

$$R_A \leq \frac{50}{I_4}$$

where I_4 is the value in ampere of the trip threshold of the protection function against earth faults. Since this value can be set from 0.2 to $1 I_n$ (according to the type of release), it is easy to understand how, by using function G, a value R_A higher than in the case of use of the functions against overcurrents only (L, S and I) shall be obtained.

For example, taking into consideration the realization of the protection against indirect contact with the circuit-breaker type Tmax T4N250 In 100 A equipped with electronic release type PR222DS/P LSIG (Figure10), it results that the phase protections cannot guarantee an adequate and practical co-ordination with the earthing arrangement, since the tripping current within 5s with the settings of Figure 9 is 510A and this would cause a maximum earth resistance equal to 0.1Ω .

Figure 10

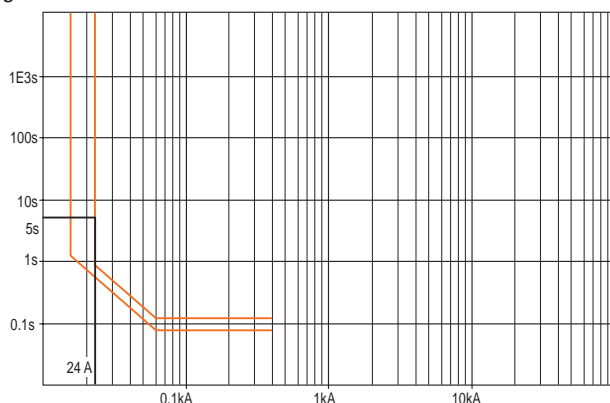


T4N 250 PR222DS/P-LSIG In100

L:	$I_1 = 1 \times I_n$	$t_1 = 3s$
S:	$t = \text{const}$	$I_2 = 6.4 \times I_n$ $t_2 = 0.05s$
I:	OFF	

By using protection function G set at $0.2 \times I_n$, the current threshold beyond which the circuit-breaker trips in 5s is 24 A (value including the higher tolerance); thus, a maximum earth resistance equal to 2.1Ω is obtained.

Figure 11



T4N 250 PR222DS/P-LSIG In100

G: $I^2t = \text{const}$ $I_A = 0.2 \times I_n$ $t_A = 0.1 \text{ s}$

As regards the applications for which it is impossible to provide an earthing arrangement with a low R_A value, it is necessary to take other measures for the protection against indirect contacts (see Annex C); in these cases function G, even if it does not guarantee the protection against indirect contacts, guarantees a partial protection against earth faults, in order to avoid localized arcs which could cause overheating and fire risks.

Protection against indirect contact by residual current devices

The operating principle of the residual current device is basically the detection of an earth fault current by means of a toroidal transformer which encloses all the live conductors, included the neutral, if distributed. In absence of an earth fault the vectorial sum of the currents I_A is equal to zero; in case of an earth fault, if the value of I_A exceeds the value of the trip threshold, called $I_{\Delta n}$, the circuit at the secondary of the toroid sends a command signal to a dedicated opening device causing the circuit-breaker tripping.

In addition to the coordination with the earthing arrangement, to select the rated residual operating current $I_{\Delta n}$, also the total leakage current of the installation under normal operating conditions shall be taken into consideration and, to avoid unwanted trips, such current shall not exceed $0.5 \times I_{\Delta n}$.

In compliance with the relation for the protection against indirect contact, the use of residual current circuit-breakers allows to obtain an R_A value considerably different from that obtained when using automatic circuit-break-

ers. Table 3 shows the maximum values of the earth resistance which can be obtained with residual currents and with reference to a common environment (50V).

Table 3

$I_{\Delta n}$ [A]	R_A [Ω]
0.01	5000
0.03	1666
0.1	500
0.3	166
0.5	100
3	16
10	5
30	1.6

In an electrical plant with a common earthing arrangement and with loads protected by devices with different tripping currents, the worst case relevant to the device with the highest tripping current must be considered to co-ordinate all the loads with the earthing arrangement. This means that, in case of shunts protected in part by means of overload devices and in part by residual current devices, since the resistance R_A of the earthing arrangement shall be calculated on the ground of the current of the overload device which guarantees tripping in 5s and since this is the higher rated tripping current between the two types of device, all the advantages deriving from the use of residual current releases are nullified.

From the above it results that, in a TT system, it is advisable to protect all the loads by means of residual current circuit-breakers combined with the earthing arrangement so as to have the advantage of a proper interruption when the fault arises and an earthing arrangement easy to realize.

Conclusions

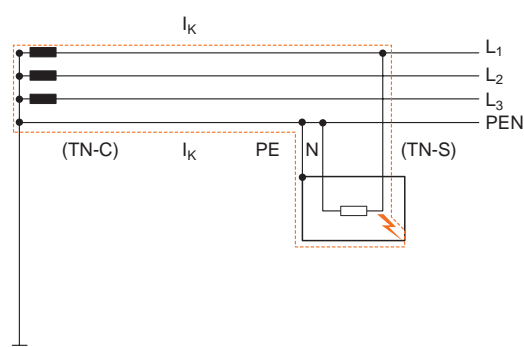
To summarize, in TT systems the Standards allow the use of:

- automatic devices against overload currents, specifying that:
 - for devices with inverse time tripping characteristics, the tripping current I_A must be the current which causes trip in 5s;
 - for devices with instantaneous tripping characteristics, the tripping current I_A must be the minimum current which causes the instantaneous trip;
- residual current devices, specifying that the tripping current $I_{\Delta n}$ is the rated residual operating current of the residual current circuit-breaker with a maximum allowed delay of one second.

5.4 Protection against indirect contact in TN systems

An earth fault in a TN system involves the circuit represented in Figure 12.

Figure 12



As shown in the figure, the fault loop does not affect the earthing arrangement and is basically formed by the connection in series of the phase conductors with the protective conductor (PE or PEN).

To provide a protection for TN systems with automatic disconnection of the circuit, according to IEC 60364-4 prescriptions, the following condition shall be fulfilled:

$$Z_s \cdot I_a \leq U_0$$

where:

Z_s is the impedance of the fault loop comprising the source, the live conductor up to the point of the fault and the protective conductor between the point of the fault and the source (in ohms);

U_0 is the nominal a.c. r.m.s. voltage to earth (in volts)

I_a is the current causing the automatic operation of the disconnecting protective device within the time stated in Table 4 as a function of the nominal voltage U_0 or, for distribution circuits (and under other conditions stated by the standards) within a conventional time not exceeding 5s; if protection is provided by means of a residual current circuit-breaker, I_a is the rated residual operating current $I_{\Delta n}$.

Table 4

U_0 [V]	Disconnecting time [s]
120	0.8
230	0.4
400	0.2
>400	0.1

In practice, the Standard divides the circuits into two types:

- final circuit: it is a circuit which usually supplies equipment;
- distribution circuit: it is a circuit which supplies a distribution board to which other final circuits are connected.

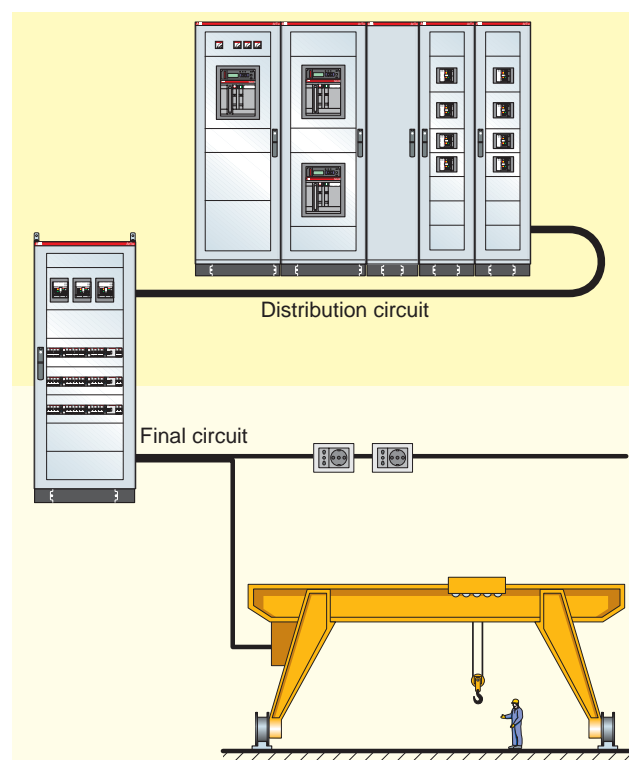
Then, final circuits can supply different loads, such as:

- a stationary equipment (e.g. an aspirator),
- a hand-held or portable equipment;
- a socket-outlet.

The probability of occurrence of an earth fault in a final circuit supplying a portable equipment or a socket-outlet is deemed by the Standard to be higher, since higher are the mechanical stresses to which they are subject; in the same way it is more likely that a person may get in touch with the exposed-conductive-part of a hand-held or portable equipment than with the exposed-conductive-part of a distribution circuit (e.g. the metallic frame of a distribution switchboard). That is the reason of the prescriptions of the Standard: the higher the phase-to-earth voltage of the system for final circuits, the quicker the disconnecting time.

Starting from the considerations above, the Standard prescribes:

- the disconnecting times of Table 4 for final circuits which supply hand-held or portable equipment and socket-outlets;
- disconnecting times not higher than 5s for final circuits supplying stationary electrical equipment and for distribution circuits.



As already stated, disconnecting times not exceeding 5s are permitted by the Standard also for final circuits which supply stationary equipment; but, if in the same distribution board there are other final circuits supplying socket-outlets or portable equipment, it is possible that, due to a fault on the stationary equipment, the exposed-conductive-parts of the portable equipment or of the equipment supplied through socket-outlets become live.

This voltage would be eliminated within 5s, whereas the Standard would require disconnection within 0.4 s (for U_0 equal to 230V).

To maintain a disconnecting time of 5s for final circuits supplying stationary equipment, in the presence of other final circuits supplying portable equipment or socket-outlets, it is necessary to provide equipotential bonding between the distribution board and the extraneous conductive parts; further reference must be made to IEC 60364-4-41 413.1.3.5.

The choice of the automatic device for protection against faults between phase-PE conductors and against indirect contact shall be made by coordinating properly the disconnecting times with the impedance of the fault loop. In TN systems a bolted fault to earth on the LV side usually generates a current similar to that of a short-circuit and the earth fault current flowing through the phase conductor (or conductors) and the protective one does not absolutely affect the earthing arrangement.

The relationship may be expressed as:

$$I_a \leq \frac{U_0}{Z_s} = I_{kLPE}$$

where I_{kLPE} is the fault current between phase-PE conductors. Therefore, it is possible to state that protection against indirect contact is verified when the tripping current I_a of the protective device (within 0.4s, for $U_0=230V$, or 5s under particular conditions) is lower than the fault current between phase-PE conductors (I_{kLPE}) at the exposed-conductive-part to be protected.

In TN systems the following devices are used for protection against indirect contact:

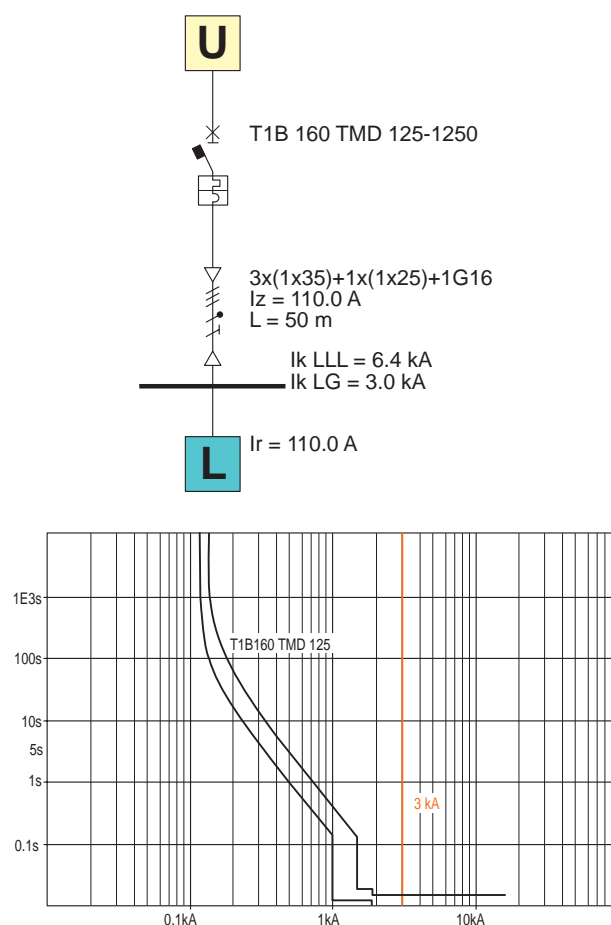
- circuit-breakers with thermomagnetic releases;
- circuit-breakers with electronic releases;
- residual current devices (TN-S only).

Protection against indirect contact by thermomagnetic releases

As previously explained, in TN distribution systems the earth fault currents result to be quite higher due to the low impedance value of the fault loop; as a consequence, in the most cases, protection against indirect contact can be guaranteed by automatic circuit-breakers, provided that the current causing disconnection within the specified times is lower than the fault current.

The following example (Figure 13) is aimed at verifying protection against indirect contact in a final circuit which supplies a portable equipment in a TN-S system at 400V. To this purpose it shall be sufficient to verify that the fault current phase-PE conductors with respect to the exposed-conductive-part considered is greater than the current causing disconnection in 0.4s.

Figure 13



In the example under consideration, the current which causes the automatic operation in a disconnecting time not exceeding 0.4s is lower than the fault current phase-PE conductors, which is 3 kA.

Protection against indirect contact by electronic releases

As regards the electronic releases, the same prescriptions as in the previous case can be followed for protection functions L (against overload), S (against delayed short-circuit) and I (instantaneous short-circuit). Of course, the electronic releases allow accurate settings both in terms of disconnecting times as well as in terms of current thresholds.

Function G against earth faults improves the protection conditions since it allows to face all the situations in

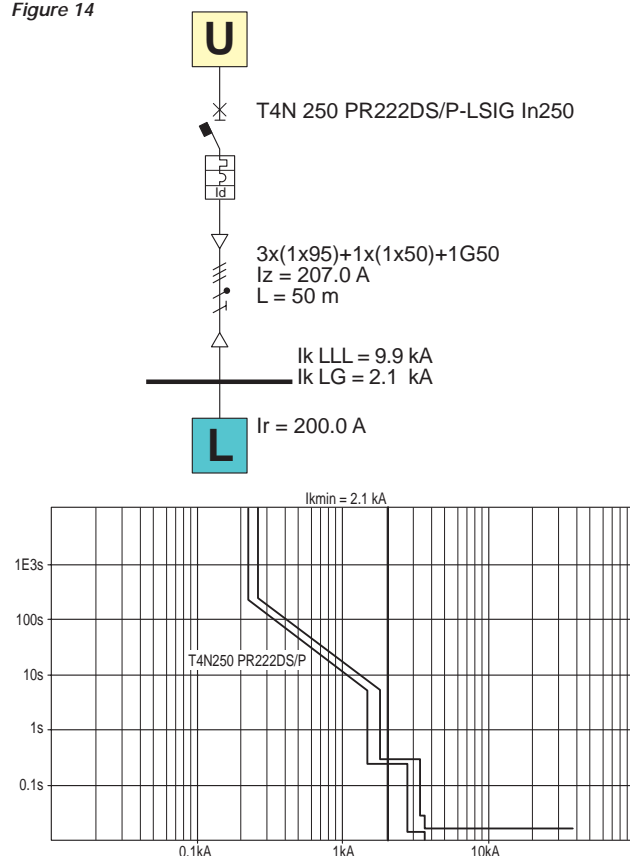
which the impedance of the fault loop takes values so small that the phase protections are not allowed to disconnect within the times prescribed by the Standard, or it is necessary to set the functions S and I at high values due to discrimination. By using function G, the condition to be fulfilled to obtain protection against indirect contact becomes:

$$Z_s \cdot I_4 \leq U_0$$

where I_4 is the value in amperes of the setting of the protection function against earth fault. Since this value can be set from 0.2 to 1 I_n (according to the release type), it is easy to realize how, by using function G, protection against indirect contact can be provided for impedance values of the fault loop higher (e.g. in case of longer cables) than the phase protection.

The following example (Figure 14) shows the possible settings of a circuit-breaker Tmax T4N250 In 250 A equipped with an electronic release type PR222DS/P LSI.

Figure 14



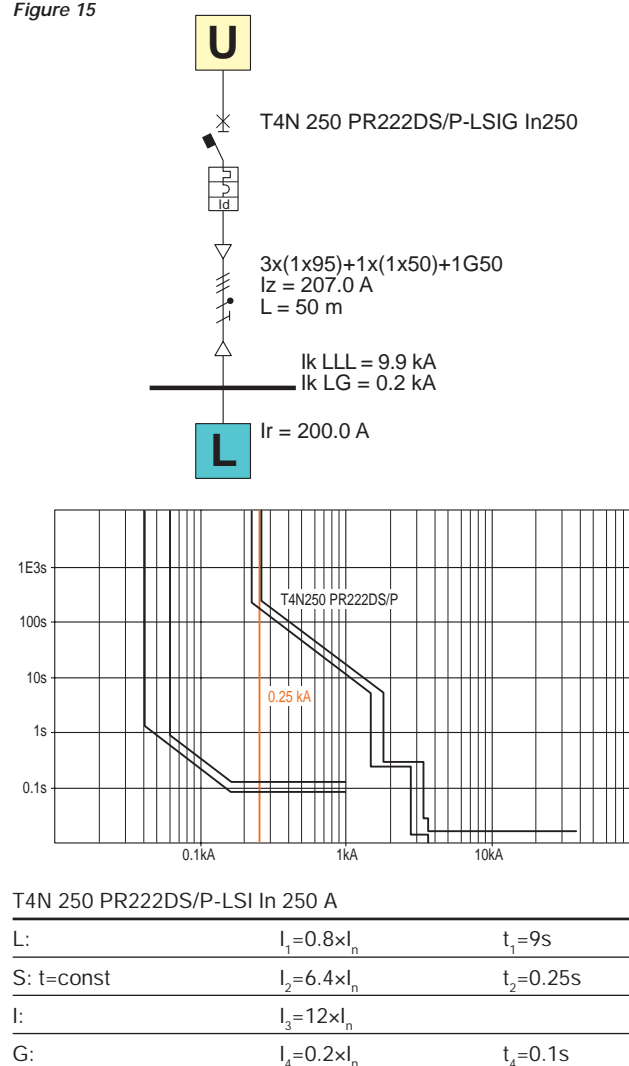
T4N 250 PR222DS/P-LSI In 250 A

L:	$I_1 = 0.8 \times I_n$	$t_1 = 9s$
S: $t = \text{const}$	$I_2 = 6.4 \times I_n$	$t_2 = 0.25s$
I:	$I_3 = 12 \times I_n$	

In particular, threshold I_2 of function S has been set so as to extinguish the fault in less than 0.25s. However, this value represents only one of the possible settings, since also function I could be used for the protection against indirect contact.

If, in the same installation, the fault current phase-PE had been very low, for example equal to 0.25 kA, it would have been impossible to use the phase protections for the protection against indirect contact since the minimum current of function S causing tripping within 0.4s is $I_2 = 1.2 \times 250$ plus the tolerance, i.e. 330 A (value lower than the current I_{KLPE}). Besides, too low settings for protection against phase-PE faults could affect the selectivity for overload currents (overload and short-circuit). Therefore, in this case function G shall be used with the settings shown in Figure 14:

Figure 15



T4N 250 PR222DS/P-LSI In 250 A

L:	$I_1 = 0.8 \times I_n$	$t_1 = 9s$
S: $t = \text{const}$	$I_2 = 6.4 \times I_n$	$t_2 = 0.25s$
I:	$I_3 = 12 \times I_n$	
G:	$I_4 = 0.2 \times I_n$	$t_4 = 0.1s$

In TN-S systems, function G allows the solution of all the situations where the phase protective devices cannot provide the necessary protection.

It should be borne in mind that in TN-C systems it is impossible to use function G in a line supplying a three-phase load plus neutral. As a matter of fact, the micro-processor-based release would not be able to detect the earth fault current, since, under such conditions, the sum of the currents in the phase conductors and in the neutral would always be equal to zero because the fault current belongs to the neutral conductor which is also the

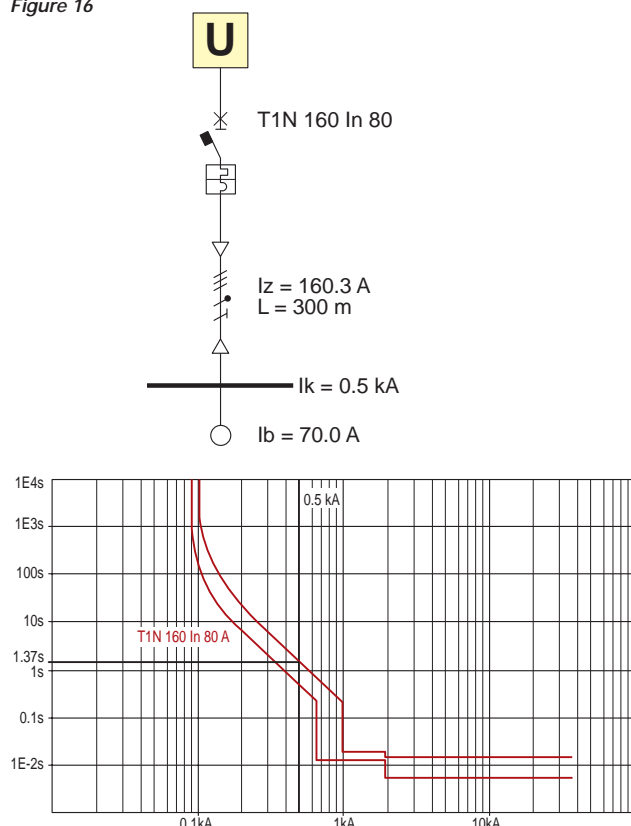
protective conductor PEN (reference is to be made to the next paragraph for a more detailed explanation).

Protection against indirect contact by residual current devices

The use of residual current circuit-breakers improves further the protection conditions, in particular when there is no bolted fault or in case of a fault at the end of a very long line where a remarkable impedance limiting the short-circuit current is present; this can persist for sufficiently long times thus resulting in temperature rises and fire hazard.

To explain the above, Figure 16 shows an example of a final circuit supplied by a cable of 330m length and protected by a thermal magnetic circuit-breaker type Tmax T1N160 In 80 A. Due to the high impedance of the cable, the value of the phase-PE fault current is equal to 0.5 kA. At this value, the circuit-breaker trips in about 1.4 s, not complying with the disconnecting times required by the Standard. In this case, the residual current circuit-breaker allows detection of the fault current and disconnection in quick times, in compliance with the Standard's requirements.

Figure 16



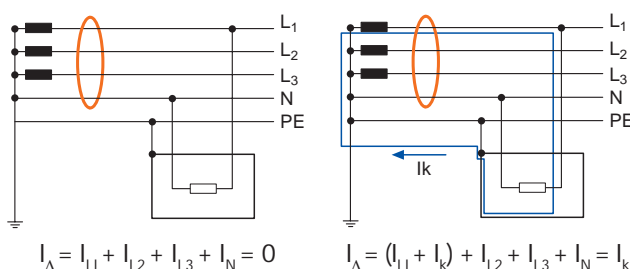
Also residual current circuit-breakers cannot be used in TN-C systems since the neutral and protection functions are provided by a single PEN conductor which prevents these devices from operating.

To understand the above, it is necessary to remember the operating principle of a residual current circuit-breaker,

which essentially detects the earth fault current through a toroidal transformer including all the live conductors and the neutral, if distributed.

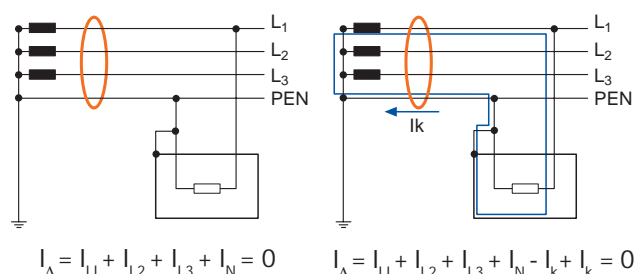
In a TN-S system, the earth fault current returns through the PEN protective conductor without affecting the toroid (Figure 17); in this case, the vectorial sum of the currents is different from zero and, if higher than the set threshold, it may cause the operation of the residual current device.

Figure 17: Residual current device in TN-S systems



In a TN-C system, the earth fault current returns through the PEN protective conductor, thus flowing again through the toroid¹ (Figure 18); in this case the vectorial sum of the currents is still equal to zero and thus the residual current device shall not be able to disconnect.

Figure 18: Residual current device in TN-C systems



On the other hand, in the same system, if the neutral conductor did not pass through the toroid, the presence of a single-phase load (unbalanced load) would be enough to cause the unwanted tripping of the residual current device, even if the circuit were not under fault conditions.

Conclusions

To sum up, in TN systems, the Standards permit the use of:

- automatic devices against overcurrents, able to disconnect the circuit in times depending on the rated voltage or not exceeding 5s under specified conditions
- residual current devices.

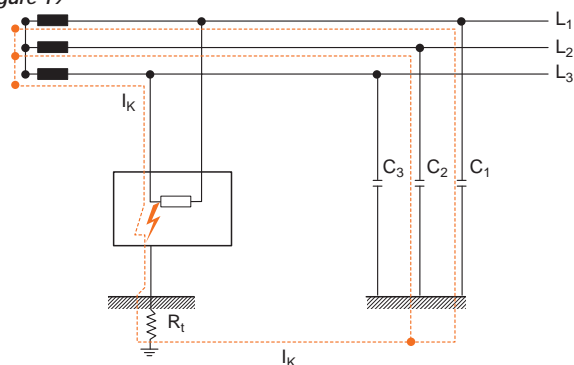
In TN-C systems disconnection of the neutral and use of the residual current devices or of devices with similar operating principle (function G against earth faults) are not possible.

¹ In fact the toroid encloses all the live conductors (phase and neutral).

5.5 Protection against indirect contact in IT systems

As represented in Figure 19, the earth fault current in an IT system flows through the line conductor capacitances to the power supply source. For this reason, the first earth fault shall be characterized by such an extremely low value to prevent the protection from disconnecting; the deriving touch voltages shall be very low.

Figure 19



According to IEC 60364-4, the automatic disconnection of the circuit in case of a single earth fault¹ is not necessary, provided that the following condition is fulfilled:

$$R_t \cdot I_d \leq U_L$$

where:

R_t is the resistance, in ohms, of the earth electrode for exposed-conductive-parts;

I_d is the fault current, in amperes, between a phase conductor and an exposed-conductive-part

U_L is 50V for ordinary locations (25V for particular locations).

If this condition is fulfilled, after the first fault, the touch voltage on the exposed-conductive-part is lower than 50V tolerable by the human body for an indefinite time, as shown in the safety curve (Figure 2).

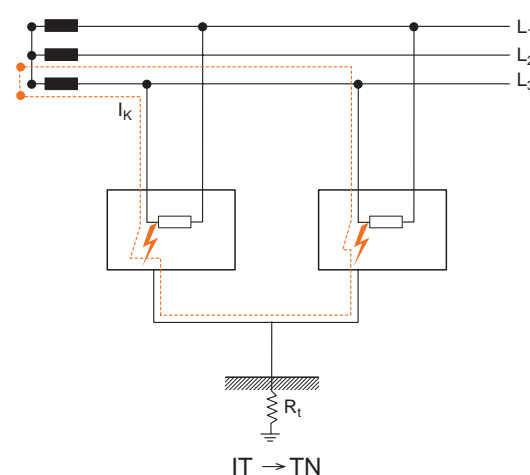
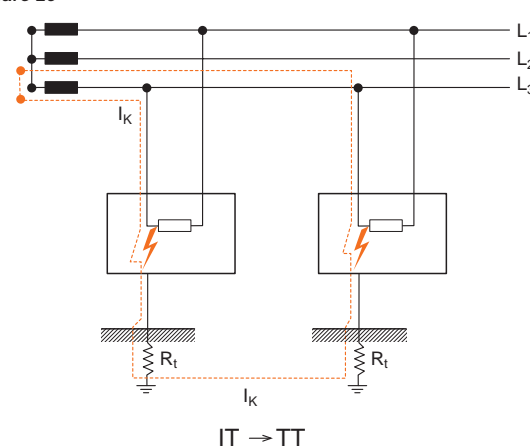
In IT system installations, an insulation monitoring device shall be provided to indicate the presence of an anomalous condition after the occurrence of a first fault. An insulation monitoring device complying with Std. IEC 61557-8, is a device constantly monitoring the insulation of an electrical installation. It is aimed at signaling any remarkable reduction of the insulation level of an installation in order to find the cause of this reduction before a second fault occurs, thus preventing disconnection of the power supply.

The occurrence of a first earth fault modifies the distribution system by limiting the advantages of a network

insulated from earth. In particular, two situations may occur in the event of a first fault to earth (Figure 20):

1. where the exposed-conductive-parts of the equipment are earthed individually, then the IT system becomes a TT system;
2. where the exposed-conductive-parts of the equipment are interconnected by a protected conductor collectively earthed, then the IT system becomes a TN system.

Figure 20



The Standards prescribe that, in the event of a second fault, the supply shall be disconnected according to the following modalities:

- a) where exposed-conductive-parts are earthed in groups or individually, the conditions for protection are as those given for IT TT systems

¹ This is referred to by the Standard as first fault to earth; the occurrence of two simultaneous faults on two different phases is called double fault to earth.

b) where exposed-conductive-parts are interconnected by a protective conductor collectively, the conditions of a TN system apply; in particular the following conditions shall be fulfilled:

where the neutral is not distributed

$$Z_s \leq \frac{U}{2 \cdot I_a}$$

where the neutral is distributed

$$Z'_s \leq \frac{U_0}{2 \cdot I_a}$$

where:

U_0 is the nominal voltage between phase and neutral;

U is the nominal voltage between phases;

Z_s is the impedance of the fault loop comprising the phase conductor and the protective conductor of the circuit;

Z'_s is the impedance of the fault loop comprising the neutral conductor and the protective conductor of the circuit;

I_a is the operating current of the protection device in the disconnecting times specified in Table 5 or within 5s, according to the circuit typology (the prescriptions for TN systems as specified in Chapter 5.4 apply).

Table 5

Installation nominal voltage U_0/U [V]	disconnecting time [s]	
	neutral not distributed	neutral distributed
120/240	0.8	5
230/400	0.4	0.8
400/690	0.2	0.4
580/1000	0.1	0.2

The Standard suggests not to distribute the neutral conductor in IT systems. One of the reasons is the real difficulty in fulfilling the condition prescribed for the impedance of the double fault loop Z'_s . As a matter of fact, in the presence of a neutral conductor distributed, the impedance must be 58% smaller than the impedance Z_s , which is verified in the event of a double fault between the phases; in this way, it becomes evident that there is a greater difficulty in the co-ordination with the automatic device which must trip to guarantee protection against indirect contact.

Moreover, above all for quite complex industrial installations, the presence of the neutral distributed may involve the risk of an accidental connection of it at any point to earth, thus eliminating the advantages offered by IT systems.

The Standard IEC 60364-4 states that, if the requirements at point b) cannot be fulfilled by using overcurrent protective devices, the protection of every supplied load shall be provided by means of a residual current circuit-breaker; therefore, by means of residual current circuit-breakers, the protection conditions can be improved in IT systems too, provided that these distribution systems are used in particular plants for which continuity of supply is a fundamental requirement, or for installations where service breakdown may cause dangerous situations for human beings or significant economic damages. In such cases, the plant shall be equipped with a device constantly monitoring the insulation and signaling with audible or visual signals any possible earth fault in the network or any fault of the supplied equipment.

Conclusions

To sum up, as regards IT systems the Standards:

- do not require automatic disconnection of the circuit supply when a fault occurs;
- prescribe automatic disconnection of the circuit supply if a second fault occurs when the first is not extinguished, by applying prescriptions analogous to TT or TN systems, depending on the type of connection to earth of the exposed-conductive-parts;
- require monitoring of insulation to earth of the network, so that the occurrence of any fault is signalled.

6 ABB SACE solutions for protection against earth fault

6.1 General aspects

As already seen in the previous chapters, in most electrical systems a reliable and safe protection is realized by combining the protection functions against overcurrent with those against earth faults, together with an effective earthing arrangement.

This choice allows to obtain, besides protection against indirect contact, also a reliable and timely protection against earth faults of small value where prevention from fire risks is absolutely necessary.

The proper choice of the protection devices must permit also the realization of tripping selectivity against earth faults besides that against overcurrents.

In order to fulfill the requirements for an adequate protection against earth faults ABB SACE has designed the following product categories:

- Miniature circuit-breakers (Table 1)

- RCBOs (residual current operated circuit-breakers with integral overcurrent protection) DS9 series with rated current from 6 A up to 40 A;
- RCD blocks (residual current blocks) DDA 200 type to be coupled with the thermal magnetic circuit-breakers type S200 with rated current from 0.5 A to 63A;
- RCD blocks (residual current blocks) DDA 60, DDA 70, DDA 90 series to be coupled with thermal magnetic circuit-breakers type S290 with rated current from 80 A to 125 A;
- RCD blocks - DDA 560, DDA 570, DDA 590 series to be coupled with thermal magnetic circuit-breakers type S500 with rated current from 6 A to 63 A;
- RCCBs (residual current circuit-breakers) F200 type, with rated current from 16 A to 125 A.

Table 1: Thermal-magnetic miniature circuit-breakers System pro M with residual current protection

	In [A]	DDA 200	DDA 60	DDA 70	DDA 90	DDA 560	DDA 570	DDA 590
S200	0.5÷63	•	-	-	-	-	-	-
S290	80÷125	-	•	•	•	-	-	-
S500	6÷63	-	-	-	-	•	•	•

- Molded-case circuit-breakers (Table 2)

- RC221 residual current release, to be coupled with circuit-breakers Tmax T1, T2, T3 with rated currents from 16 A to 250 A;
- RC222 residual current release to be coupled with circuit-breakers Tmax T1, T2, T3, T4, T5 with rated uninterrupted currents from 16 A to 400 A;
- RC223 residual current release to be coupled with the circuit-breaker Tmax T4 with rated currents up to 250 A;
- electronic release type PR222DS/P, PR223DS/P LSIG for circuit-breakers Tmax T4, T5, T6 with rated uninterrupted currents from 100 A to 1000 A;

- electronic release type PR331, PR332 LSIG for the circuit-breaker Tmax T7 with rated uninterrupted currents from 800 A to 1600 A;
- PR332 and PR333 electronic releases with residual current integrated protection for the circuit-breaker type Tmax T7 with rated uninterrupted currents from 800 A to 1600 A.

Table 2: Molded-case circuit-breakers type Tmax with protection against residual current and earth faults

	In [A]	RC221	RC222	RC223	PR222 LSIG	PR223 LSIG	PR331 LSIG	PR332 LSIG	PR333 LSIRc
T1	16 ÷ 160	•	•	-	-	-	-	-	-
T2	10 ÷ 160	•	•	-	-	-	-	-	-
T3	63 ÷ 250	•	•	-	-	-	-	-	-
T4	100 ÷ 320	-	•	• ¹	•	•	-	-	-
T5	320 ÷ 630	-	•	-	•	•	-	-	-
T6	630 ÷ 1000	-	-	-	•	•	-	-	-
T7	800 ÷ 1600	-	-	-	-	-	•	•	•

¹ Only for T4 250

- Air circuit-breakers (Table 3)

- electronic release type PR331, PR332, PR333 LSIG for the circuit-breaker Emax X1 with rated uninterrupted currents from 630 A to 1600 A;
- air circuit-breakers equipped with electronic release type PR121, PR122, PR123 LSIG for circuit-breakers Emax E1 to E6 with rated uninterrupted currents from 400 A to 6300 A;
- PR332 and PR333 electronic releases with residual current integrated protection for circuit-breaker Emax X1 with rated uninterrupted currents from 630 A to 1600 A;
- PR122 and PR123 electronic releases with residual current integrated protection for circuit-breakers Emax E1 to E6 with rated uninterrupted currents from 400 A to 6300 A.

Table 3: Air circuit-breakers type Emax with protection against residual current and earth faults

	In [A]	PR331 PR332 LSIG	PR121 PR122 PR123 LSIG	PR122 LSIRc
X1	630 ÷ 1600	•	-	-
E1	400 ÷ 1600	-	•	•
E2	400 ÷ 2000	-	•	•
E3	400 ÷ 3200	-	•	•
E4	1250 ÷ 4000	-	•	-
E6	3200 ÷ 6300	-	•	-

- Residual current releases with external transformer:

- RCQ: switchboard electronic residual current release;
- RD2: residual current monitor for fixing on DIN rail.

6.2 The solution with residual current devices

6.2.1 Miniature circuit-breakers System pro *M* and System pro *M* compact with residual current protection

RCBOs DS9... series

The range of thermal magnetic residual current circuit-breakers (MCBs) DS 9... series, single pole plus neutral, by ABB SACE satisfies the requirement for circuit-breakers able to provide a protection aimed at the different typologies of single-phase circuits of modern electrical engineering.

All the circuit-breakers are characterized by a single red/green operating lever and a residual current tripping flag on the front part of the apparatus.

The DS 9... range satisfies all the protection requirements of single-phase circuits by offering in two modules the possibility of choosing among three different breaking

capacity values, five different residual current tripping values and, for each of them, the possibility of choosing between residual current protection type A or AC.

The range DS 9... consists of three series:

- DS 941 with 4.5 kA breaking capacity
- DS 951 with 6 kA breaking capacity
- DS 971 with 10 kA breaking capacity.

Overload and short-circuit protection is provided by the same thermomagnetic component as the S9... MCBs range; see the technical catalogue for further information.

For each series all sensitivity values required by these circuit-breaker types are available: 30 mA - 100 mA - 300 mA - 500 mA - 1000mA. In addition, 10mA sensitivity is available for DS 941 series only.

The possibility of choosing between type A or type AC residual current protection for each series allows to realize a dedicated protection against indirect contact, according to the load connected to the protected line.

Residual current operated circuit-breakers (RCBOs) DS9...series

		DS941	DS951	DS971
Reference Standard		IEC/EN 61009, IEC/EN 60947-2		
Type (waveform of the leakage current sensed)		AC, A		
Tripping characteristics		instantaneous		
Rated current	I_n [A]	$6 \leq I_n \leq 40$	$6 \leq I_n \leq 40$	$6 \leq I_n \leq 32$
Poles		1P+N		
Rated voltage	U_e [V]	230		
Insulation voltage	U_i [V]	500		
Rated frequency	[Hz]	50...60		
Rated breaking capacity IEC/EN 61009	I_{cn} [A]	4500	6000	10000
Rated breaking capacity IEC/EN 60947-2 two poles - 230 V	I_{cu} [kA]	6	10	10
	I_{cs} [kA]	4.5	6	10
Thermomagnetic release characteristics	B: $3 I_n \leq I_m \leq 5 I_n$	•		
	C: $5 I_n \leq I_m \leq 10 I_n$	•		
Rated sensitivity $I_{\Delta n}$ [A]		0.01-0.03-0.1-0.3-0.5-1	0.03-0.1-0.3-0.5-1	0.03-0.1-0.3-0.5-1

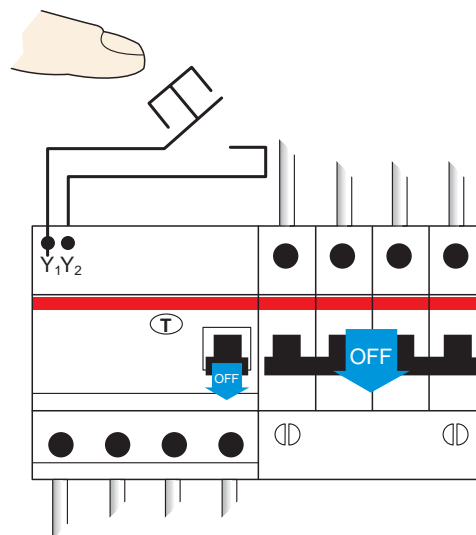
Thermal-magnetic residual current circuit-breakers (RCCBs) DS200 series

The thermal-magnetic residual current circuit-breakers series DS200 L, DS200, DS200 M and DS200 P, in two-, three- and four-pole versions, offer both the function of protection against indirect contact as well as the thermomagnetic functions typical of automatic circuit-breakers (disconnection due to overload or short-circuit).

The series of thermal-magnetic RCCBs are derived by the corresponding series of automatic CBs S200 compact of which they maintain the same characteristics in terms of breaking capacity, tripping curve and rated current. In particular, in DS200 L series the part for the protection against overcurrent is constituted by a thermomagnetic release S200L series, in DS200 series by a release S200 series, in DS200 M series by a release S200M series and in DS200 P series by a release S200 P series.

The residual current releases DS200 and DS200 M series are type AC and type A, while in DS200 L and DS200 P series they are respectively type AC and type A.

In the versions size 50 and 63 A there are two additional terminals Y1 Y2 for remote tripping of the residual current release through external pushbutton, as the following picture shows.



The operating voltage range for the circuit-breakers DS200 series is:

- 110-254V for the two-pole version
- 195-440V for the three- and four-pole versions.

Thermal magnetic residual current circuit-breakers (RCCBs) DS200 series

		DS200L	DS200	DS200 M	DS200 P	
Reference Standard		IEC/EN 61009, IEC/EN 60947-2				
Type (waveform of the leakage current sensed)		AC	AC, A	AC, A	A	
Tripping characteristic		instantaneous				
Rated current	In [A]	6...32	6...63	6...63	6...25	32
Poles		2P	2P, 3P, 4P	2P, 3P, 4P	2P	
Rated voltage	Ue [V]	110-254 (2P)/195-440 (3P, 4P)				
Insulation voltage		Ui [V] 500				
Rated frequency		[Hz] 50...60				
Rated breaking capacity IEC/EN 61009		Icn [A] 4500	6000	10000	25000	15000
Rated breaking capacity * IEC/EN 60947-2		Icu [kA] 6	10	15	25	15
		Ics [kA] 4.5	7.5	11.2	12.5	10
Thermomagnetic release characteristics	B: 3 In ≤ Im ≤ 5 In		•	•		
	C: 5 In ≤ Im ≤ 10 In	•	•	•		
	K: 8 In ≤ Im ≤ 14 In		•		•	•
Rated sensitivity	IΔn [A]	0.03	0.03, 0.3 (only type AC car. C - 2P, 4P)	0.03, 0.3 (only type AC car. C - 4P)	0.03	

*1P+N@230Vac, 2P, 3P, 4P @400Vac

Residual current blocks DDA 200 series to be coupled with the thermal magnetic circuit-breakers (MCBs) type S200

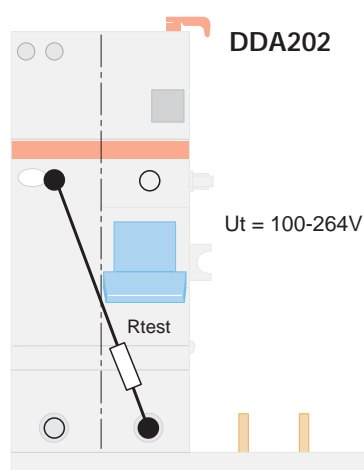
The residual current blocks (RCD blocks) are coupled with MCBs having corresponding or lower rated currents, so that protection is provided against both earth fault currents as well as overload and short-circuit currents.

The DDA 200 blocks are suitable for assembly with S 200 MCBs by means of fixed coupling elements and plastic pins.

They are available in the following types: AC, A and AP-R (selective and antidisturbance versions) and AE type with emergency stop function; the range includes all the sizes up to 63 A for all sensitivity values and pole configuration.

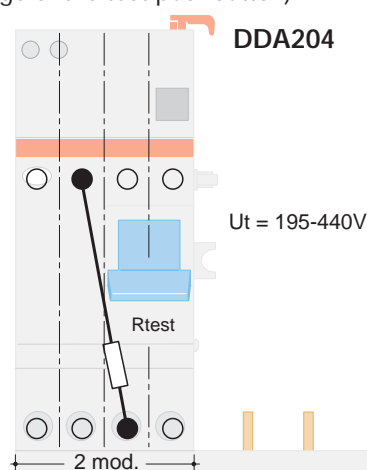
Besides, 63 A sizes are provided with terminals allowing remote opening control by means of NO pushbuttons. The DDA 200 blocks, 25-40 A standard version, thanks to their design and to the choice of the operating range for the test pushbutton are suitable to be used in electrical and naval installations (where the voltage phase-neutral is 115-125V).

In fact, the two-pole residual current blocks are available with operating range 100-264V for the test pushbutton as shown in the figure:

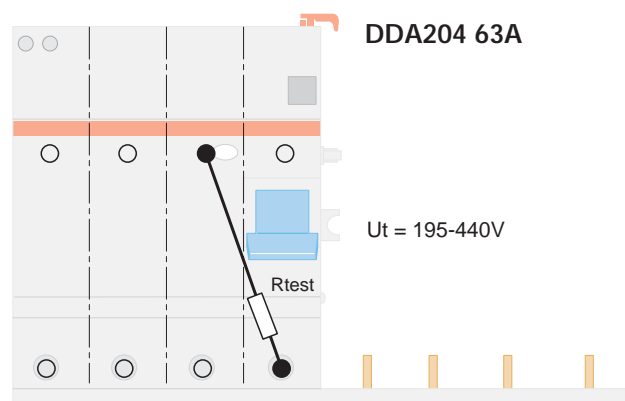


In the compact four-pole blocks with two modules (available size 25-40A), the test pushbutton is connected at a point between the two central phases, with operating range from 195 to 440V; for this configuration in particular, it results to be suitable both for systems with 400V between the phases (as in the standard situations) as well as for electrical installations with 115-125V voltage between phase and neutral conductor (in this case the

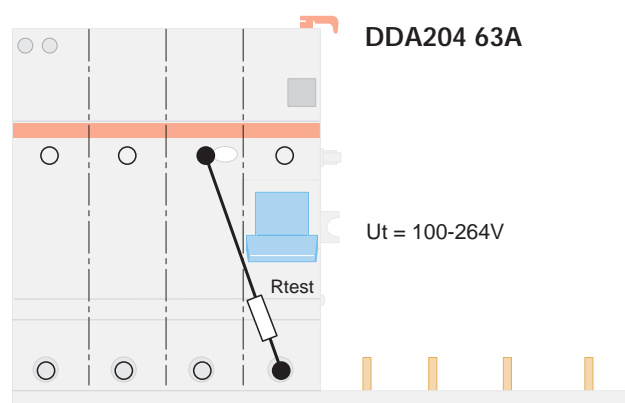
voltage between phases would be $115-125V \times 1.73 = 200/215V$ which are voltage values included in the operating range of the test pushbutton).



In the four-pole blocks, 63A size, the test pushbutton has an operating range from 195 to 440V and is connected as shown in the following figure:



However, there are the blocks DDA 200 115V for which the operating range of the test pushbutton is from 100 to 264V; thus, also for this size, the blocks DDA 200 can be used in naval installations with 115-125V voltage between phase and neutral.



RCD blocks DDA 200 type

		DDA200 AC	DDA200 A	DDA200 A AE	DDA200 AC AP-R	DDA200 A AP-R	DDA200 AC-S	DDA200 A S
Reference Standard		IEC/EN 61009 Annex G						
Type (waveform of the leakage current sensed)		AC	A	A	AC	A	AC	A
Tripping characteristic		instantaneous					selective	
Rated current I_n [A]		25, 40, 63	25, 40, 63	63	25, 40, 63	25, 40, 63	63	63
Poles		2P, 3P, 4P						
Rated voltage U_e [V]		230/400 – 240/415						
Insulation voltage U_i [V]		500						
Rated frequency [Hz]		50...60						
Rated breaking capacity IEC/EN 61009 I_{cn} [A]		I_{cn} of the associated MCB						
Rated breaking capacity IEC/EN 60947-2 2 I_{cu} [kA] I_{cs} [kA]		I_{cu}/I_{cs} of the associated MCB						
Rated sensitivity $I_{\Delta n}$ [A]		0.01...1	0.01...1	0.03...1	0.03	0.03	0.1...1	0.1...1

RCD blocks DDA 60, DDA 70, DDA 90 series to be coupled with MCBs S290

For assembly with MCBs type S 290 the following RCD blocks are available: DDA 60 type AC, DDA 70 type A and DDA 90 type S.

RCD blocks DDA 60, DDA 70, DDA 90 series

		DDA60	DDA70	DDA90
Reference Standard		IEC/EN 61009 Annex G		
Type (waveform of the leakage current sensed)		AC	A	A
Tripping characteristic		instantaneous	instantaneous	selective
Rated current I_n [A]		100		
Poles		2P, 4P		
Rated voltage U_e [V]		230/400		
Insulation voltage U_i [V]		500		
Rated frequency [Hz]		50...60		
Rated breaking capacity IEC/EN 61009 I_{cn} [A]		I_{cn} of the associated MCB		
Rated breaking capacity IEC/EN 60947-2 2 I_{cu} [kA] I_{cs} [kA]		I_{cu}/I_{cs} of the associated MCB		
Rated sensitivity $I_{\Delta n}$ [A]		0.03 - 0.3	0.03 - 0.3	0.3 - 1

RCD blocks DDA 560, DDA 570, DDA 590 series to be coupled with MCBs S500

For assembly with MCBs S 500 the following RCD blocks are available: DDA 560 type AC, DDA 570 type A and DDA 590 type S.

RCD blocks DDA 560, DDA 570, DDA 590 series

		DDA560	DDA570	DDA590
Reference Standard		IEC/EN 60947-2 Annex B		
Type (waveform of the leakage current sensed)		AC	A	A
Tripping characteristic		instantaneous		selective
Rated current	I_n [A]	63		
Poles		2P, 3P, 4P		
Rated voltage	U_e [V]	230/400		
Insulation voltage	U_i [V]	690		
Rated frequency	[Hz]	50...60		
Rated breaking capacity IEC/EN 61009	I_{cu} [kA] I_{cs} [kA]	I_{cu}/I_{cs} of the associated MCB		
Rated sensitivity	$I_{\Delta n}$ [A]	0.03 - 0.3	0.03 - 0.3	0.3 - 0.5 - 1

Residual current circuit-breakers (RCCBs) F200 series

The new range of residual current circuit-breakers System pro M compact offers a large number of RCCBs F200. The types AC and A, both in instantaneous as well as in selective versions, are integrated with some configurations for special applications, such as the type AP-R antidisturbance and the version with the neutral on the left.

All sizes up to 63 A are available, with all sensitivity values up to 1 A, in two-pole and four-pole versions.

There are also RCCBs with 80-100-125A rated currents, and sensitivity from 0.03 to 0.5A, type A, AC, A antidisturbance and A selective.

The range of RCCBs F200 includes also the types B, with size 63A and sensitivity 0.03- 0.3 A, and B selective, 63A with sensitivity 0.3A.

Residual current circuit-breakers (RCCBs) F200 series

	F200 AC	F200 A	F200 AC AP-R	F200 A AP-R	F200 A S
Reference Standard	IEC/EN 61008				
Type (waveform of the leakage current sensed)	AC	A	AC	A	A
Tripping characteristic	instantaneous				selective
Rated currentIn [A]	16, 25, 40, 63		25, 40, 63		40, 63
Poles	2P, 4P				
Rated voltageUe [V]	230/400 - 240/415				
Insulation voltageUi [V]	500				
Rated frequency[Hz]	50...60				
Rated sensitivity IΔn [A]	0.01...0.5		0.03		0.1...1

6.2.2 Residual current releases for Tmax moulded-case circuit-breakers

All Tmax circuit-breakers are preset for combined assembly with residual current releases. In particular, Tmax T1, T2 and T3 circuit-breakers, three-pole and four-pole versions, can be combined with RC221 or RC222 series, four-pole T4 and T5 with RC222 to be installed below the circuit-breaker, whereas T4 can be combined with the residual current release of RC223 series.

Apart from the protection against overloads and short-circuits typical of automatic circuit-breakers, the residual current circuit-breakers derived from them guarantee also protection of people and protection against earth fault currents, thereby assuring protection against indirect contact and fire hazards. The residual current releases can also be mounted on Tmax T1D, T3D, T4D and T5D switch-disconnectors; in that case, the derived apparatus is a "pure" residual current-circuit breaker, i.e. one which guarantees residual current protection only and not the protections typical of automatic circuit-breakers. "Pure" residual current circuit-breakers are sensitive to the earth fault current only and are generally applied as main switch-disconnectors in small distribution switchboards towards terminal loads.

The use of "pure" or "impure" residual current circuit-breakers allows continuous monitoring of the insulation status of the plant, thus ensuring effective protection against indirect contact, fire and explosion hazards and, in case of devices with $I_{\Delta n} = 30 \text{ mA}$, they provide additional protection of people against direct contact.

The residual current releases comply with the following Standards:

- IEC 60947-2, Annex B
- IEC 60255-3 (RCQ and RC223) and IEC 61000: for protection against unwanted tripping
- IEC 60755 (RCQ): for insensitivity to direct current components.

RC221 and RC222 residual current releases for T1, T2 and T3

The residual current releases type RC221 and RC222 can be installed both on the automatic circuit-breakers series Tmax T1, T2, T3, as well as on T1D and T3D switch-disconnectors. The versions available make their use possible both with three-pole as well as four-pole circuit-breakers, in the fixed version.

They are constructed applying electronic technology and act directly on the circuit-breaker by means of a trip coil, supplied with the residual current release, to be housed in the special slot made in the left-hand pole area. They do not require an auxiliary power supply source as they are supplied directly by the network and their operation is

guaranteed even with a single phase plus neutral or with two phases supplied with voltage and in the presence of unidirectional pulsating currents with direct components (type A).

The residual current release RC222 allows remote opening control of the circuit-breaker through an external pushbutton NC, thus realizing a positive safety circuit (AE).

RC222 residual current releases for T4 and T5

With T4 and T5, in the four-pole version, it is possible to use an RC222 residual current release mounted below the circuit-breaker.

This RC222 residual current release, in the fixed version, can be easily converted into a plug-in device by adding the special conversion kit.

The RC222 release is constructed using electronic technology and acts directly on the circuit-breaker by means of a trip coil, supplied with the residual current release, to be housed in the special slot made in the left-hand pole area. It does not require an auxiliary power supply source as it is supplied directly by the network and its operation is guaranteed even with only a single phase plus neutral or two phases supplied with voltage and in the presence of unidirectional pulsating currents with direct components.

The RC222 residual current release can be supplied either from above or from below. A disconnection device from the power supply during the insulation test is available. The residual current release RC222 allows remote opening control of the circuit-breaker through an external pushbutton NC, thus realizing a positive safety circuit (AE).

RC223 residual current releases (type B)

Along with the family of residual current releases previously described, ABB SACE is developing the RC223 residual current device (type B), which can be combined with Tmax T4 four-pole circuit-breaker, in the fixed or plug-in version.

It is characterized by the same types of reference as the release type RC222, but it can also boast the compliance with type B operation, which guarantees sensitivity to residual fault currents with alternating, alternating pulsating and direct current components.

The residual current release RC223 allows remote opening control of the circuit-breaker through an external pushbutton NC, thus realizing a positive safety circuit (AE).

The reference Standards are: IEC 60947-1, IEC 60947-2 Annex B and IEC 60755.

Apart from the signals and settings typical of the residual current release RC222, the RC223 allows also

the selection of the maximum threshold of sensitivity at the residual fault frequency (3 steps: 400 – 700 – 1000 Hz). It is therefore possible to adapt the residual current release to the different requirements of the industrial plant according to the prospective fault frequencies generated on the load side of the release. Typical installations which may require frequency thresholds different from the standard ones (50 – 60Hz) are the welding installations for the automobile industry (1000Hz), the textile industry (700Hz), airports and three-phase drives (400Hz).

6.2.3 Electronic releases PR...series for molded-case and air circuit-breakers with integrated residual current protection

Emax and Tmax T7 circuit-breakers can be equipped with a toroid mounted on the back of the circuit-breaker so that protection against earth faults with detection of the residual current is ensured.

In particular, the types of electronic release which can guarantee this function are:

- PR122/P LSI Rc and PR332 LSI Rc
- PR122/P LSIg and PR332/P LSIg with "measurement module"
- PR123/P LSIg and PR333/P LSIg.

The releases PR332 and PR333, which provide residual current protection, can be supplied with the circuit-breakers type Tmax T7, Emax X1 in three-pole and four-pole version, whereas the releases PR122 and PR123, which provide the same function, can be supplied with the circuit-breakers type Emax E2 and E3, in three-pole and four-pole version and Emax E4 (three-pole version only).

Thanks to the wide range of settings, these electronic releases are suitable for applications where a system with residual current protection co-ordinated with the various distribution levels - from the main switchboard to the end user - is required.

Table 4

		RC221	RC222		RC223
Circuit-breaker size		T1-T2-T3	T1-T2-T3	T4 and T5 4p	T4 4p
Type		"L" shaped	"L" shaped	placed below	placed below
Technology		microprocessor-based	microprocessor-based	microprocessor-based	microprocessor-based
Action		with solenoid	with solenoid	with solenoid	with solenoid
Primary service voltage ⁽¹⁾	[V]	85...500	85...500	85...500	110...440
Operating frequency	[Hz]	45...66	45...66	45...66	0-1000
Self-supply		■	■	■	■
Test operation range ⁽¹⁾		85...500	85...500	85...500	110...500
Rated service current	[A]	up to 250 A	up to 250 A	up to 500 A	up to 250 A
Rated residual current trip	[A]	0.03 - 0.1 - 0.3	0.03 - 0.05 - 0.1 - 0.3	0.03 - 0.05 - 0.1	0.03 - 0.05 - 0.1
		0.5 - 1 - 3	0.5 - 1 - 3 - 5 - 10	0.3 - 0.5 - 1 - 3 - 5 - 10	0.3 - 0.5 - 1
Time limit for non-trip	[s]	instantaneous	instantaneous - 0.1 - 0.2 - 0.3 - 0.5 - 1 - 2 - 3	instantaneous - 0.1 - 0.2 - 0.3 - 0.5 - 1 - 2 - 3	instantaneous - 0 - 0.1 - 0.2 - 0.3 - 0.5 - 1 - 2 - 3
			±20%	±20%	±20%
Tolerance over trip times			±20%	±20%	±20%
Local trip signalling		■	■	■	■
Trip coil with changeover contact for trip signalling		■	■	■	■
Input for remote opening			■	■	■
NO contact for pre-alarm signalling			■	■	■
NO contact for alarm signalling			■	■	■
Indication of pre-alarm from 25% I _{Δn} (tolerance ± 3%)		■	■	■	
Indication of alarm timing at 75% I _{Δn} (tolerance ± 3%)		■	■	■	
Automatic residual current reset		■	■	■	■
Type "A" for pulsating alternating current, "AC" for alternating current		■	■	■	■
Type "AE" for remote release device			■	■	■
Type "B" for pulsating current and direct current					■
Type "S" selective			■	■	■
Button for insulation test		■	■	■	■
Power supply from above and below		■	■	■	■
Assembly with three-pole circuit-breakers		■	■	■	■
Assembly with four-pole circuit-breakers		■	■	■	■
Kit for conversion of circuit-breaker with residual current release from fixed to plug-in			■	■	

⁽¹⁾ Operation up to 50 V phase-neutral (55 V for RC223)

These electronic releases for residual current protection are suitable to be used in the presence of:

- alternating earth currents (type AC)
- alternating and/or pulsating earth currents with direct components (type A).

The following table shows the main technical characteristics of residual current protection:

Table 5

Sensitivity $I_{\Delta n}$	[A]	0.3 - 0.5 - 0.7 - 1 - 2 - 3 (dip in position 0.1) 3 - 5 - 7 - 10 - 20 - 30 (dip in position 1)
Tripping times	[s]	0.06 - 0.1 - 0.2 - 0.3 - 0.4 - 0.5 - 0.8 - 1 - 3 - 5
Type		AC and A

6.2.4 Residual current relay with external transformer

ABB SACE circuit-breakers can be combined also with the residual current relays RCQ and RD2 with separate toroid (to be installed externally on the line conductors) in order to fulfill the requirements when the installation conditions are particularly restrictive, such as with circuit-breakers already installed, limited space in the circuit-breaker compartment etc.

Thanks to the setting characteristics of the residual current and of the trip times, the residual current relays with external transformer can be easily installed also in the final stages of the plant; in particular, by selecting the rated residual current $I_{\Delta n} = 0.03$ A with instantaneous tripping, the circuit-breaker guarantees protection against indirect

contact and represents an additional measure against direct contact also in the presence of particularly high earth resistance values (for example in TT systems). Such residual current relays are of the type with indirect action: the opening command given by the relay must cause the tripping of the circuit-breaker through a shunt opening release (to be provided by the user).

SACE RCQ switchboard electronic residual current relay

System pro M compact MCBs, Tmax moulded-case circuit-breakers and Emax air circuit-breakers can be combined also with SACE RCQ switchboard electronic residual current relay with separate toroid (to be installed externally on the line conductors) and fulfill requirements with trip thresholds up to 30 A and times up to 5 s.

Thanks to its wide range of settings, SACE RCQ switchboard electronic residual current relay is suitable for applications where a system with residual current protection co-ordinated with the various distribution levels - from the main switchboard to the end user - is required. It is particularly recommended both when low sensitivity residual current protection is required, such as in partial (current) or total (chronometric) selective chains, as well as for high sensitivity applications (physiological sensitivity) to provide additional protection of people against direct contact.

SACE RCQ is a type A residual current relay and detects the residual currents both of alternating as well as of pulsating type with direct components.

Table 6

Residual current relays			SACE RCQ
Power supply voltage	AC [V]		80...500
	DC [V]		48...125
Operating frequency	[Hz]		45÷66
Trip threshold adjustment $I_{\Delta n}$	1st range of settings/adjustments	[A]	0.03 - 0.05 - 0.1 - 0.3 - 0.5
	2nd range of settings/adjustments	[A]	1 - 3 - 5 - 10 - 30
Trip time adjustment	[s]		0 - 0.1 - 0.2 - 0.3 - 0.5 - 0.7 - 1 - 2 - 3 - 5
Pre-alarm threshold adjustment	% x $I_{\Delta n}$		25...75% x $I_{\Delta n}$
Range of use of closed transformers	Toroidal transformer Ø 60[mm]	[A]	0.03...30
	Toroidal transformer Ø 100[mm]	[A]	0.03...30
	Toroidal transformer Ø 185 [mm]	[A]	0.1...30
Range of use of transformers that can be opened	Toroidal transformer Ø 110 [mm]	[A]	0.3...30
	Toroidal transformer Ø 180[mm]	[A]	0.3...30
	Toroidal transformer Ø 230 [mm]	[A]	1...30
Signalling for alarm pre-threshold			Yellow flashing LED 1 NO change-over contact 6 A - 250V AC 50/60 Hz
Residual current relay trip signalling			Yellow magnetic flag change-over contacts (NO, NC; NO) 6 A - 250 V AC 50/60 Hz
Remote opening control			NO contact Trip time 15 ms
Connection to the toroidal transformer			By means of 4 twisted conductors. Maximum length 5m
Dimensions L x H x P	[mm]		96 x 96 x 131.5
Drilling for assembly on door	[mm]		92 x 92

RD2 residual current monitor (RCMs)

As just said, System pro Mcompact MCBs and small size Tmax moulded-case circuit-breakers can be combined also with RD2 residual current monitors with separate toroid (to be installed externally on the line conductors) and fulfill requirements with trip thresholds up to 2 A and times up to 5 s.

The applications of RD2 RCM are similar to those already described as regards the RCQ relay; therefore it is particularly recommended both when low sensitivity residual current protection is required, such as in partial (current) or total (chronometric) selective chains as well as for high sensitivity applications (physiological sensitivity), to provide additional protection of people against direct contact.

RD2 device is a type A residual current relay and detects the residual currents both of alternating as well as of uni-directional pulsating type. Through special minidips, it is possible to select the tripping times and adjust sensitivity. Besides, RD2 can be directly fixed on DIN rail.

Technical characteristics			
Operating voltage	[V]	230÷400 a.c. (RD2) 48÷150 a.c./d.c. (RD2-48)	
Frequency	[Hz]	50/60	
Sensitivity setting $I_{\Delta n}$	[A]	0.03; 0.1; 0.3; 0.5; 1; 2	
Trip time settings	[s]	Fast (instantaneous); 0.3; 0.5; 1; 2; 5	
Contact capacity	[A]	10 at 250 V a.c. (ohmic)	
Contact type		change-over	
Operating temperature	[°C]	-5...+40 ±5	
Modules	[n°]	2	
Standards		IEC/EN 62020	

6.3 The solution with function G

As regards the range of rated currents from 100 A to 6300 A, protection against earth faults is provided by ABB SACE circuit-breakers combined with electronic releases:

- PR222DS/P, PR223DS and PR223EF (PR222DS/PD) for Tmax moulded-case circuit-breakers T4, T5 and T6 with uninterrupted rated currents from 250 A to 1000 A;
- PR331 and PR332 for moulded-case circuit-breakers Tmax T7 with rated currents from 800 A to 1600 A;
- PR331, PR332 and PR333 for air circuit-breakers type Emax X1 with rated currents from 630 A to 1600 A;
- PR121/P, PR122/P and PR123/P for Emax air circuit-breakers with rated currents from 400 A to 6300 A.

The above mentioned releases can be provided with function G for protection against earth faults with inverse time delay or independent time delay tripping characteristics. All the technical characteristics are described in details

in the technical catalogues. The following table shows the available settings:

Table 7

		I_{Δ}	t_{Δ}
PR222	$I^2t=k$	0.2 – 0.25 – 0.45 – 0.55 – 0.75 – 0.8 - $1 \times I_{\Delta}$ manual setting	0.1s, 0.2s, 0.4s, 0.8s manual setting
		0.2... $1 \times I_{\Delta}$ (step $0.1 \times I_{\Delta}$) electronic setting	0.1...0.8s (step 0.01s) electronic setting
PR223	$I^2t=k$	0.2... $1 \times I_{\Delta}$ (step $0.1 \times I_{\Delta}$)	0.1...0.8s (step 0.01s) electronic setting
PR331	$I^2t=k - t=k$	0.2 – 0.3 – 0.4 – 0.6 – 0.8 – 0.9 – $1 \times I_{\Delta}$	0.1s, 0.2s, 0.4s, 0.8s
PR332 – PR333	$I^2t=k - t=k$	0.2... $1 \times I_{\Delta}$ (step $0.02 \times I_{\Delta}$)	0.1...1s (step 0.05s)
PR121	$I^2t=k - t=k$	0.2 – 0.3 – 0.4 – 0.6 – 0.8 – 0.9 – $1 \times I_{\Delta}$	0.1s, 0.2s, 0.4s, 0.8s
PR122 – PR123	$I^2t=k - t=k$	0.2... $1 \times I_{\Delta}$ (step $0.02 \times I_{\Delta}$)	0.1...1s (step 0.05s)

Figure 1

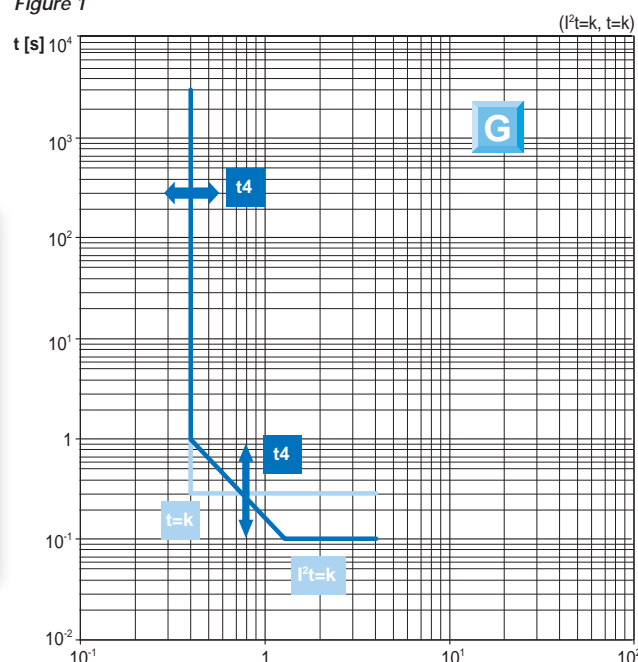


ABB SACE electronic releases have been designed by using microprocessor-based technology. This allows the realization of protection functions guaranteeing high reliability, accuracy of tripping and insensitivity to external environment.

The electronic microprocessor-based releases are self-supplied and guarantee the proper operation of the protection functions also when the current flows through one phase only. The protection release is constituted by current transformers (three or four based on the circuit-breaker polarity) of the protection unit PR... and by one opening solenoid which acts directly on the operating mechanism of the circuit-breaker.

The current transformers supply all the energy necessary for the correct functioning of the protection and the signal necessary for current detection.

Advantages deriving from the use of the electronic releases for protection against indirect contact

As an example, the protection against indirect contact of a terminal load in a TN-S system shall be considered.

The installation characteristics are:

- three-phase system without neutral
- TN-S distribution system
- voltage 400 V
- frequency 50 Hz
- short-circuit current $I_k = 30 \text{ kA}$
- length of the conductor $L = 200 \text{ m}$
- load current $I_b = 187 \text{ A}$
- PVC insulated single-core copper cable
- cross section of the phase conductor $S = 95 \text{ mm}^2$
- cross section of the protective conductor $S_{PE} = 50 \text{ mm}^2$
- current carrying capacity of the cable $I_z = 207 \text{ A}$

Once established the suitability of the circuit-breakers type T3N250 $I_n = 200 \text{ A}$ with thermomagnetic release and type T4N250 $I_n = 250 \text{ A}$ with electronic release type PR222DS/P LSIG, as regards rated current, breaking capacity and cable protection against short-circuit and overload, the maximum protected length against indirect contact¹ is verified by examining as an alternative the performances of the two circuit-breakers with thermomagnetic and electronic release.

The test on the cable length protected against indirect contact is carried out in compliance with the Italian Standard CEI 64-8/5 as regards the check of the timeliness of tripping of the protective devices against short-circuit by taking into account the analogy between the problem of the maximum protected length against short-circuit and that one of the maximum protected length against indirect contact.

The following formula (derived from Ohm's Law applied to the fault circuit) allows to calculate the maximum protected length against indirect contact:

$$L_{\max} = \frac{0.8 \cdot U_0}{1.5 \cdot \rho \cdot (1+m) \cdot \frac{I_a}{S}}$$

where

U_0 is the phase to earth supply voltage in volt (230 V);

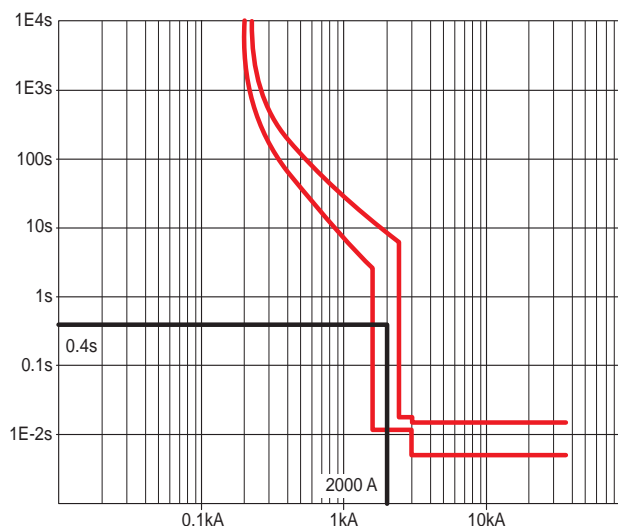
0.8 is a coefficient keeping into account a 80% reduction in the supply voltage due to the effect of the short-circuit current;

- 1.5 is a coefficient keeping into account the increase of the resistance value during the short-circuit;
- ρ is the resistivity of the conductor material at 20°C (0.018 $\Omega \text{ mm}^2/\text{m}$ for copper);
- m is the ratio between the cross section of the phase conductor and the cross section of the protective conductor;
- I_a is the current causing the circuit-breaker to trip within the times prescribed by the Standard plus the tolerance (usually 20%);
- S is the cross section of the phase conductor.

T3N250 In 200 A circuit-breaker with thermomagnetic release

- release $I_n = 200 \text{ A}$
- thermal setting range $I_1 = 140 - 200 \text{ A}$
- tripping current in 0.4s $I_a = 2000 \text{ A}$
- tolerance on the tripping current $\pm 20\%$

Figure 2



From the formula it results:

$$L_{\max} = (0.8 \cdot 230 \cdot 95) / [1.5 \cdot 0.018 \cdot (1 + 95/50) \cdot 1.2 \cdot 2000] = 93 \text{ m}$$

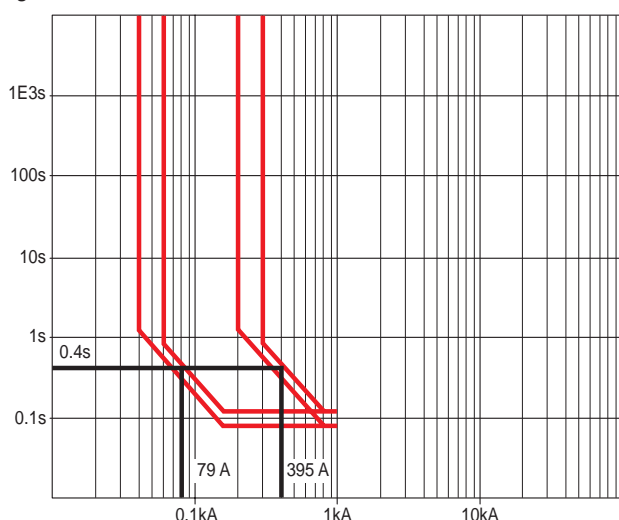
The length of the cable of the plant is 200 m and therefore the protection provided is not complete.

¹ The verification of the maximum protected length results from the relationship for protection against indirect contact in TN systems $Z_x I_a \leq U_0$, expressed as a function of the cable length. By introducing in the formula the minimum value of current which causes the instantaneous tripping of the circuit-breaker, it is possible to obtain a maximum length corresponding to a minimum short-circuit current for phase to earth fault, which can be eliminated by the circuit-breaker in short times, thus guaranteeing protection against indirect contact.

T4N250 circuit-breaker with electronic release PR 222DS/P L SIG

rated current	$I_n = 250 \text{ A}$
setting range of function G	$I_4 = 50 - 250 \text{ A}$
minimum tripping current in 0.4s	$I_a = 79 \text{ A per } I_4 = 50 \text{ A}$
maximum tripping current in 0.4s	$I_a = 395 \text{ A per } I_4 = 250 \text{ A}$
tolerance on the tripping current	$\pm 10\%$

Figure 3



From the formula it results:

$$L_{\max} = (0.8 \cdot 230 \cdot 95) / [1.5 - 0.018 \cdot (1 + 95/50) \cdot 1.1 \cdot 79] = 2567 \text{ m}$$

with $I_4 = 50 \text{ A}$

and

$$L_{\max} = (0.8 \cdot 230 \cdot 95) / [1.5 - 0.018 \cdot (1 + 95/50) \cdot 1.1 \cdot 395] = 513 \text{ m}$$

with $I_4 = 250 \text{ A}$

Therefore it can be concluded that, thanks to the use of the electronic release, the cable is protected for the entire length of 200 m.

Protection is obtained by adjusting the function G with all the values ranging from 50 and 250 A.

This wide range of possibilities and the quite low value of the setting currents contribute to make protection coordination easier, by concretizing the previous statements as regards the advantages deriving from the use of protection against earth faults for people safety and plant reliability.

6.4 Protection function G or residual current protection?

As described in the previous chapters, ABB SACE offers two typologies of products for earth fault protection:

- residual current protection to be coupled with the circuit-breakers;
- earth fault protection function G integrated in the electronic releases of the circuit-breakers.

Residual current protection uses a toroid of ferromagnetic material through which the live conductors of the circuit pass; in the presence of an earth fault, the vectorial sum of the currents flowing in the conductors is different from zero and, when it is higher than the set threshold, it causes the tripping of the protection. ABB SACE residual current releases allow the adjustment of the tripping current threshold from 30 mA to 30 A with delay times from 0 (instantaneous) to 5s (refer to the technical catalogue for further details).

The operating principle of function G is similar to that of the residual current protection but the vectorial sum of the currents is processed by a microprocessor and there are no toroidal transformers. Function G of ABB SACE releases makes it possible to set the tripping current threshold from 0.2 to one time the rated current of the coupled circuit-breaker and the delay times from 0.1 to 1 s (for further details please refer to the technical catalogue).

The decision of which protections to choose has to be made by analysing carefully not only the distribution system, but also the short-circuit current value; compliance with the Standard prescriptions implies that the circuit-breaker must be able to detect and extinguish a fault current within the times necessary to avoid the harmful effects of the current.

6.4.1 Typical applications of residual current circuit-breakers

Residual current circuit-breakers are particularly suitable for protection of people against indirect contact and for additional protection against direct contact.

The use of residual current circuit-breakers for protection against indirect contact is absolutely necessary, for example, in the following cases:

- TT distribution system: as already seen, the fault current returns to the power supply through the ground and takes a small value in comparison with the instantaneous tripping current of a thermal magnetic circuit-breaker;
- earthing of the exposed-conductive-parts is deficient.

However, it may be necessary or useful to implement these protections also in other cases, such as in configurations with a single earthing arrangement (TN-S system) if one of the following conditions is present:

- normal protections are not sufficient to provide protection that falls within the limits set by the Standards;
- dangerous environmental conditions (e.g. excessive humidity);
- faults with impedance values not negligible.

Some of the plants in which these circuit-breakers are particularly useful include:

- all types of construction sites (building, naval, etc.);
- mobile equipment or plants;
- hospital environments and operating rooms;
- excavations and mines;
- campground electric installations;
- pools, saunas, canteens and, generally, environments with high humidity levels;
- aquarium and fountain lighting;
- agricultural premises;
- craftsmen laboratories;
- school laboratories.

Besides, residual current circuit-breakers are suitable for protecting installations with fire or explosion hazards or, in general, where a leakage current could cause economic damages, such as:

- chemical factories;
- dusty environments or with inflammable materials;
- oil refinery plants;
- gas treatment plants;
- battery charger installations.

6.4.2 Typical applications of moulded-case and air circuit-breakers equipped with function G against earth fault

Air and moulded-case circuit-breakers equipped with function G are currently used in MV/LV transformer substations to protect both transformers as well as distribution lines.

Function G is usually provided with short time delay and therefore guarantees selectivity with regard to the residual current releases located on the load side.

Apart from the applications for which the residual current release is explicitly required, function G can be used for protection against indirect contact, when allowed by the installation conditions, and to improve protection against earth faults with regard to the normal phase protections.

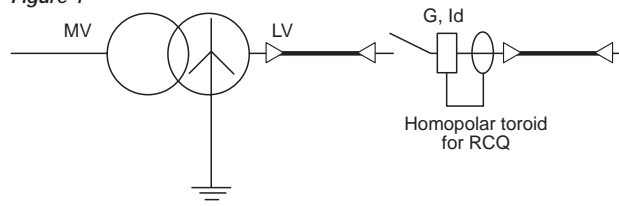
6.5 Advanced protection systems against earth fault

6.5.1 General aspects

Making reference to the typical diagram of a line constituted by transformer, cable and main circuit-breaker, three zones can be singled out, depending on the fault location, and three different types of protections can be identified:

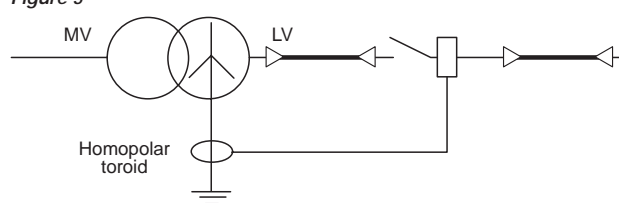
1. The Unrestricted Earth Fault Protection (UEFP) is the protection against the earth faults occurring on the load side of the circuit-breaker terminals at the secondary winding of the transformer. This type of protection (Figure 4), a subject already dealt with in the previous chapters, is obtained by using function G, residual current protection (RC..) or normal phase protections against high earth fault currents.

Figure 4



2. The Source Ground Return, which is also called "Stand-by Earth Fault Protection" (SEFP), is the protection against earth faults occurring both on the load and on the supply side of the circuit-breaker terminals at the secondary winding of the transformer. This protection is implemented by using the homopolar toroid for the earth conductor of the transformer star point, as shown in the figure below:

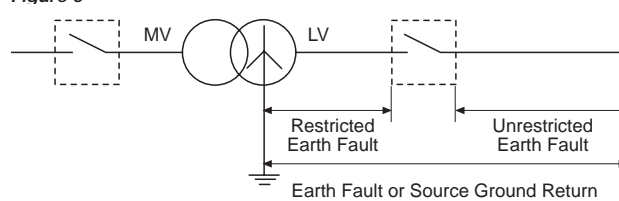
Figure 5



3. The Restricted Earth Fault Protection (REFP) is the protection against the earth faults both of the transformer secondary winding as well as of its connection cables to the circuit-breaker terminals.

The figure below shows the earth fault areas.

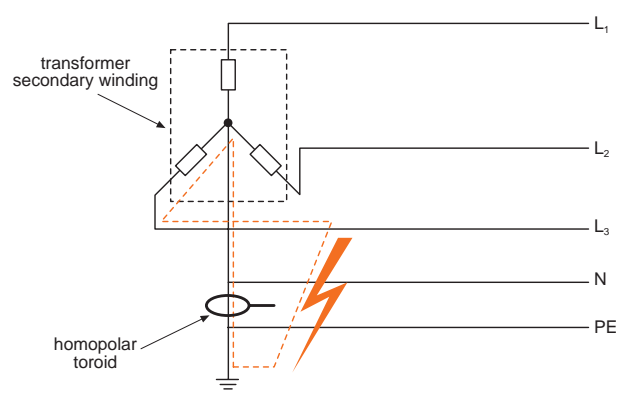
Figure 6



6.5.2 Source Ground Return

The protection "Source Ground Return" represents the protection function against the earth faults which occur on both the load and the supply side of the circuit-breaker terminals at the secondary winding of the MV/LV transformer. This protection is implemented by using a homopolar toroid embracing the conductor which connects the star point of the transformer to earth.

Figure 7



In this way, the toroid shall be able to detect :

- phase-PE fault currents;
- phase-earth fault currents;
- wiring errors (for example, if a single-phase load is connected wrongly between phase and PE conductor);
- connections to earth of the neutral at points different from the star point.

ABB SACE electronic releases type PR122, PR123, PR332 and PR333 for Emax and Emax X1 air circuit-breakers can be used combined with an external toroid located on the conductor connecting the transformer star point to earth. The rated current of the toroid can be adjusted at 100 A, 250 A, 400 A and 800 A thus making the earth fault protection threshold (function G) independent of the size of the primary current transformers installed on the circuit-breaker phases.

6.5.3 Restricted Earth Fault Protection

The Restricted Earth Fault Protection (REFP) is the protection against the earth faults occurring between the transformer secondary winding and the circuit-breaker terminals¹.

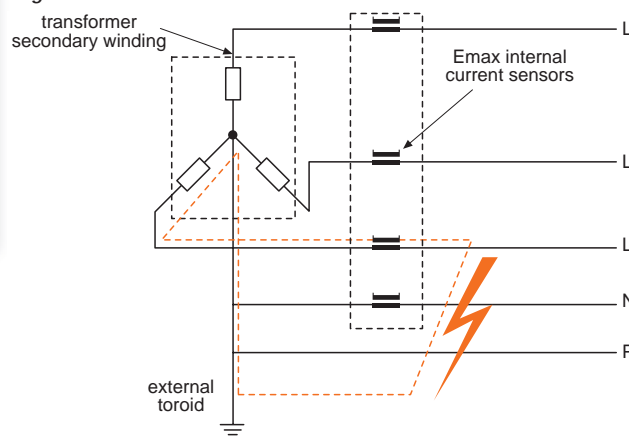
Emax series circuit-breakers equipped with the electronic releases type PR123 and PR333 (Emax X1) allow two independent curves for protection G: one for the internal protection (function G without external toroid) and one for

the external protection (function G with external toroid, as described in the above paragraph).

Function "double G" allows simultaneous protection of the installation both against earth faults of the secondary of the transformer and of its connection cables to the circuit-breaker terminals (restricted earth fault protection), as well as against earth faults on the load side of the circuit-breaker (outside the restricted earth fault protection).

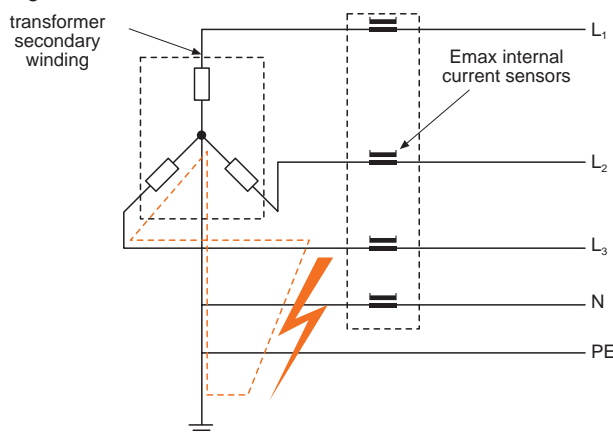
The following figure shows an earth fault on the load side of an Emax circuit-breaker: the fault current flows through one phase only and, if the vectorial sum of the currents detected by the four current transformers (CTs) results to be higher than the set threshold, the electronic release activates function G (and the circuit-breaker trips).

Figure 8



With the same configuration, a fault on the supply side of the circuit-breaker (Figure 9) does not cause intervention of function G since the fault current affects neither the CT of the phase nor that of the neutral.

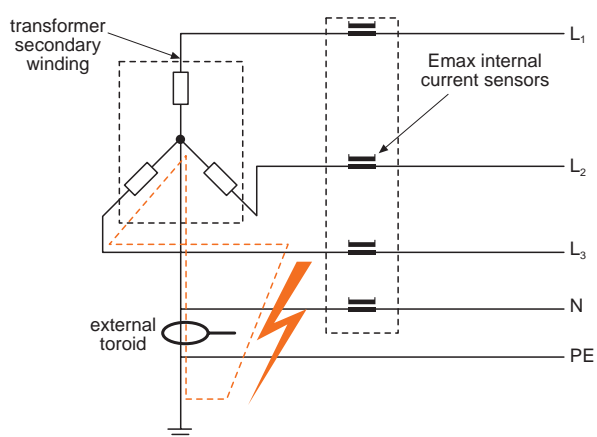
Figure 9



¹ For MV protections it is difficult to eliminate this type of fault, in particular when a delta-star transformer is used, since the fault current phase-earth or phase-neutral at the secondary winding is seen at the primary reduced by $\sqrt{3}$.

The use of function “double G” allows an external toroid to be installed, as shown in the following figure, so that earth faults on the supply side of the Emax circuit-breaker can be detected as well. In this case, the alarm contact of the second G is exploited in order to trip the circuit-breaker installed on the primary and to ensure fault disconnection.

Figure 10



If, with the same configuration as in the figure, the fault occurred on the load side of the Emax circuit-breaker, the fault current would affect both the toroid as well as the current transformers on the phases. To define which circuit-breaker is to trip (MV or LV circuit-breaker), a suitable coordination of the trip times is required: in particular, it is necessary to set the times so that the LV circuit-breaker opening due to internal function G is faster than the realization of the alarm signal coming from the external toroid.

Therefore, thanks to the time-current discrimination between the two protection functions G, before the MV circuit-breaker on the primary of the transformer receives the trip command, the circuit-breaker on the LV side is able to eliminate the earth fault. Obviously, if the fault occurred on the supply side of the LV circuit-breaker, only the circuit-breaker on the MV side would trip.

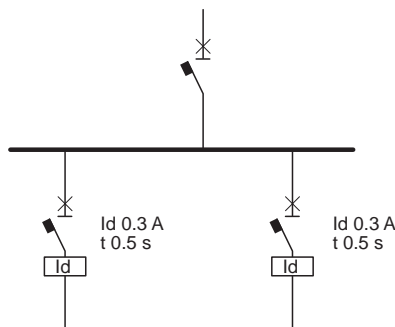
7 Discrimination of the protections against earth fault

For safety reasons, the Standard IEC 60364-5-53 recommends discrimination between residual current protective devices in series to provide continuity of supply to the parts of the installation not involved in the fault. This discrimination can be achieved by installing the residual current devices so that only the device closest to the fault disconnects the supply.

This is called residual current discrimination and can be distinguished into two types:

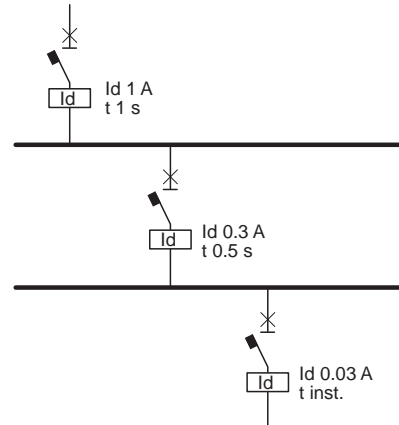
1. horizontal residual current discrimination (Figure 1): it consists in protecting each single line with a residual current circuit-breaker; in this way, in the event of an earth fault, only the outgoing affected by the fault shall be disconnected, since the residual current circuit-breakers are not interested by any fault current. However, it is necessary to take other measures than the residual current device to provide protection against indirect contact in the part of the switchboard and of the installation on the supply side of the residual current release;

Figure 1: Horizontal residual current discrimination



2. vertical residual current discrimination (Figure 2): it is achieved with residual current circuit-breaker in series.

Figure 2: Vertical residual current discrimination



In compliance with IEC 60364-5-53, to ensure discrimination between two residual current protective devices in series, these devices shall satisfy both the following conditions :

- the non-actuating time-current characteristic of the residual current protective device located on the supply side (upstream) shall lie above the total operating time-current characteristic of the residual current protective device located on the load side (downstream);
- the rated residual operating current on the device located on the supply side shall be higher than that of the residual current protective device located on the load side.

The non-actuating time-current characteristic is the curve reporting the maximum time delay during which a residual current higher than the rated non-actuating one (equal to $0.5 I_{\Delta n}$) flows in the residual current circuit-breaker without making it trip.

To summarize, in order to guarantee discrimination between two residual current devices in series, the following conditions shall be satisfied:

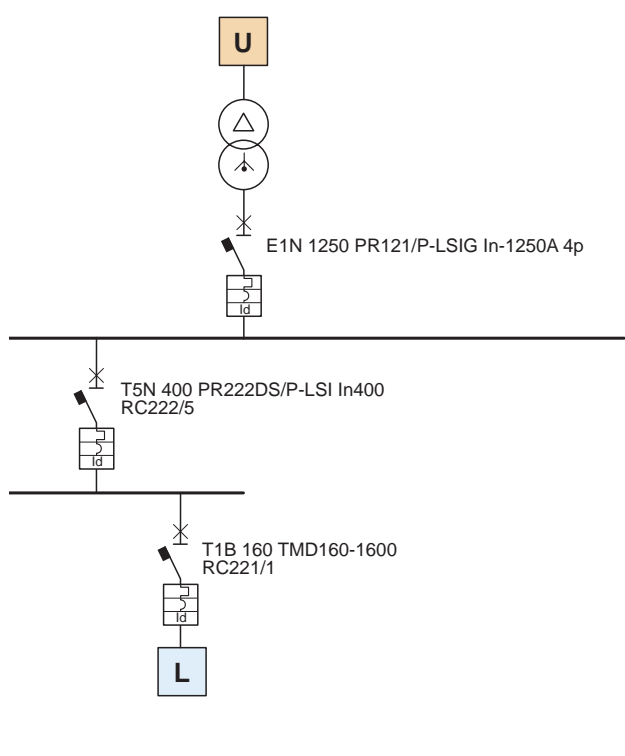
- for delayed time residual current circuit-breakers type S located on the supply side (in compliance with Standards IEC 61008-1 and IEC 61009), it is necessary to choose downstream non-selective circuit-breakers having $I_{\Delta n}$ three times lower;
- for residual current electronic releases (RC 221/222/223, RCQ and RD2), it is enough that the tripping times and currents of the device on the supply side are immediately higher than those of the device on the load side, by taking due account of the tolerances.

Note: as regards the protection against indirect contact in the distribution circuits of TT systems, the maximum tripping time at $I_{\Delta n}$ is 1s.

The following example (Figure 3) shows a part of an installation where there are three circuit-breakers in series equipped with residual current and electronic releases with protection function G against earth fault. The circuit-breakers considered are:

- E1N 1250 PR121/P-LSIG $I_n=1250A$ 4p
- T5N 400 PR222DS/P-LSI $I_n=400A$ with residual current device type RC222
- T1B 160 TMD $I_n=160A$ with residual current device type RC221

Figure 3



To ensure a correct coordination to the purpose of residual current discrimination, it is necessary that tripping current and time thresholds are adjusted properly, by taking into account also the tolerances.

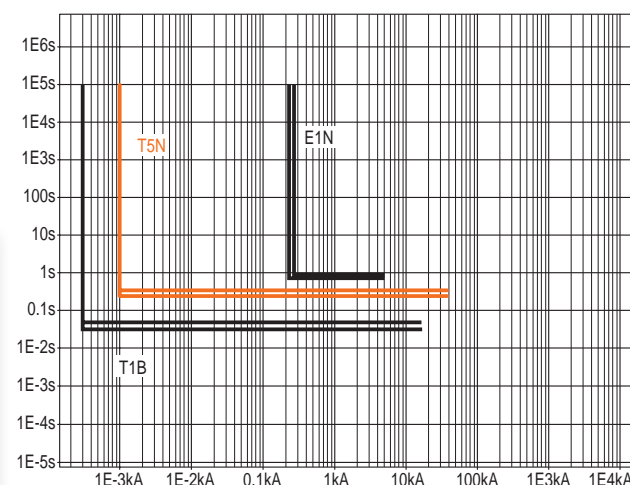
Obviously, the requirement of the Standards shall be verified for each circuit-breaker, as regards protection against indirect contact.

The possible settings to achieve discrimination are:

- E1N 1250
G (Earth fault): $t=const$ - Current - 250 [A] - Time 0.8 [s]
- T5N 400
RC: Current 1 [A] - Time 0.3 [s]
- T1B 160
RC: Current 0.3 [A] - Time instantaneous

The tripping curves relevant to such settings are represented in Figure 4:

Figure 4

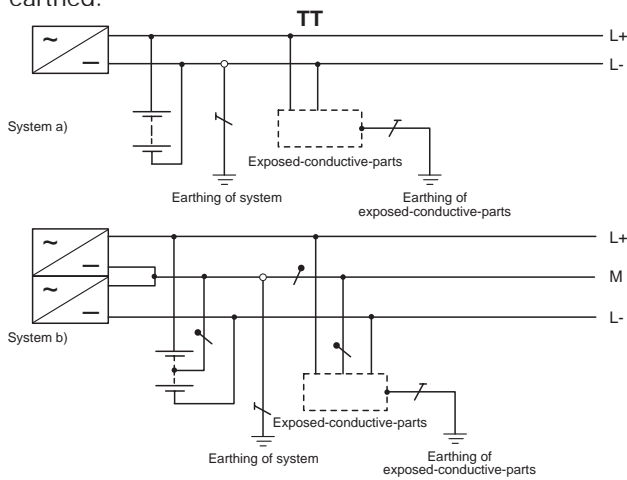


Annex A

Direct current distribution systems

The direct current distribution systems are defined by the Standard IEC60364-1 in an analogous way to those in alternating current:

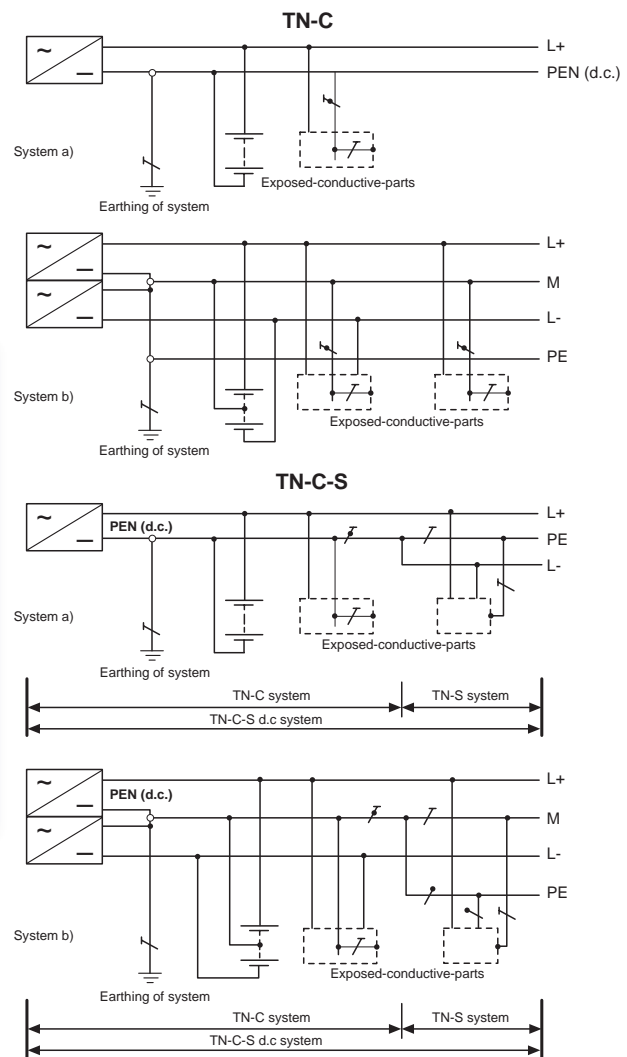
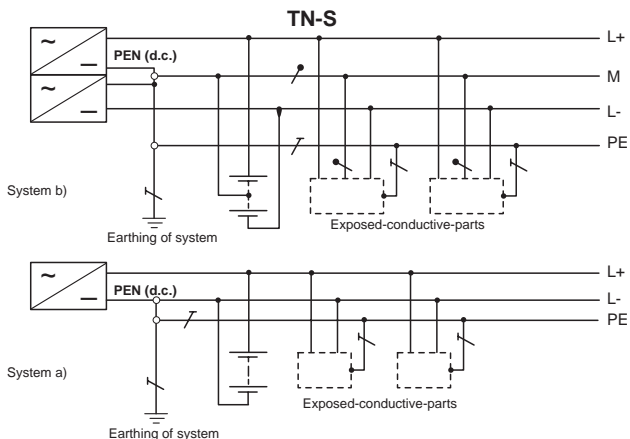
TT System: a polarity of the system and the exposed-conductive-parts are connected to two electrically independent¹ earthing arrangements. If necessary, the middle point of the supply can be earthed.



TN System: a polarity, or the middle point of the supply, is directly earthed; the exposed-conductive-parts are connected to the same earthed point.

Three types of TN system are considered according to whether the earthed polarity and the protective conductor are separated or not, as follows:

1. **TN-C** – the functions of earthed polarity and protective conductor are combined in a single conductor called PEN
2. **TN-S** – the conductor of the polarity connected to earth and the protective conductor PE are separated;
3. **TN-C-S** – the functions of earthed polarity and protective conductor are partially combined in a single conductor PEN and partially separated.



To the purpose of protection against indirect contact, the Standard IEC 60364-4 prescribes that a protective device automatically disconnects the supply to the circuit so that, in the event of a fault between a live part and an exposed-conductive-part or a protective conductor, a prospective touch voltage exceeding 120 V ripple-free d.c. does not persist on the exposed-conductive-parts for a time sufficient to cause a risk of harmful physiological effect in a person².

Disconnecting time and voltage values lower than those just indicated may be required for special installations or locations.

Further requirements for direct current power systems are being studied.

In direct current power systems the main aspects of electromechanical corrosion due to direct leakage currents must be taken into account.

¹ The choice of connecting to earth either the positive or the negative polarity is made for reasons not considered in this annex.

² In IT systems, the automatic disconnection of the circuit is not usually required on the occurrence of a first fault.

Annex B

Protection against direct contact

Protection of persons and live stocks against direct contact implies avoidance of the dangers that may arise from contact with live parts of the installation. In order to avoid direct contact it is necessary to realize an electrical installation having definite characteristics so that the safety of persons is ensured.

This protection can be achieved through one of the following methods:

- preventing a current from passing through the body of any person;
- limiting the current which can pass through a body to a value lower than the shock current, which is physiologically harmful.

It is necessary to remember that the protective measures shall be appropriately integrated between them, according to the installation type and the environmental conditions.

Based on these considerations, the safety measures can be distinguished into:

- total protections;
- partial protections.







Total protections prevent persons from both unintentionally as well as intentionally touching of live parts and are measures usually taken in the case of installations accessible to persons who do not have adequate technical knowledge (ordinary persons).









The measures used in locations accessible only by trained people are defined partial protections, since they provide a protection against accidental but not intentional touching.





The main measures for the protection against direct contact are:

- covering completely the live parts with insulation which can only be removed by destruction (in this case the protection is total);
- placing the live parts inside enclosures or behind

The following table shows the degrees of protection of the enclosures complying with Stds. IEC/CEI EN 60529

FIRST NUMERAL: protection against ingress of solid foreign objects			
IP			Complete description
0		Non-protected	Particular protections not provided
1		Protected against solid foreign objects of 50 mm diam. and greater (unintentional contact with hands)	A large surface of the human body, for example a hand (voluntary protection is not provided) or solid foreign objects of 50 mm diam. and greater shall not fully penetrate
2		Protected against solid foreign objects of 12.5 mm diam. and greater (hand finger)	Fingers or similar objects exceeding 80 mm length or solid foreign objects of 12 mm diam. shall not fully penetrate
3		Protected against solid foreign objects of 2.5 mm diam. and greater (tools, wires)	Tools, wires etc. of 2.5 mm diam. or thickness and greater, or solid foreign objects of 2.5 mm diam. and greater shall not penetrate at all
4		Protected against solid foreign objects of 1.0 mm diam. and greater	Wires or straps 1.0 mm thick or greater or solid foreign objects of 1.0 mm diam. and greater shall not penetrate at all
5		Dust-protected	Ingress of dust is not totally prevented, but dust shall not penetrate in a quantity to interfere with satisfactory operation of the apparatus
6		Dust-tight	No ingress of dust

SECOND NUMERAL: protection against ingress of water with harmful effects			
IP			Complete description
0		Non-protected	Particular protections not provided
1		Protected against vertically falling water drops (condensate)	Vertically falling drops shall have no harmful effects
2		Protected against vertically falling water drops when enclosure tilted up to 15°	Vertically falling drops shall have no harmful effects when the enclosure is tilted at any angle up to 15° on either side of the vertical
3		Protected against spraying water at an angle up to 60° of the vertical	Water sprayed at an angle up to 60° on either side of the vertical shall have no harmful effects
4		Protected against splashing water from any directions	Water splashed against the enclosure from any direction shall have no harmful effects
5		Protected against water jets from any directions (water jetting pumps)	Water projected in jets against the enclosure shall have no harmful effects
6		Protected against powerful water jets (like sea waves)	Ingress of water in quantities causing harmful effects shall not be possible in case of heavy waves or powerful water jets
7		Protected against the effects of temporary immersion in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time
8		Protected against the effects of continuous immersion in water	The enclosure is suitable for continuous immersion in water with no harmful effects under the conditions specified by the manufacturer

Additional letter: protection against access to hazardous parts			
IP			Complete description
0		Protected against access with the back of the hand	The access probe, sphere of 50 mm diam., shall have adequate clearance from hazardous parts
1		Protected against access with a finger	The jointed test finger of 12 mm diam., 80 mm length, shall have adequate clearance from hazardous parts
2		Protected against access with a tool	The access probe of 2.5 mm diam., 100 mm length, shall have adequate clearance from hazardous parts
3		Protected against access with a wire	The access probe of 1.0 mm diam., 100 mm length, shall have adequate clearance from hazardous parts

barriers providing at least the degree of protection IP2X or IPXXB; as regards horizontal surfaces within reach and larger than barriers or enclosures, a degree of protection at least IPXXD or IP4X is necessary (the protection is total);

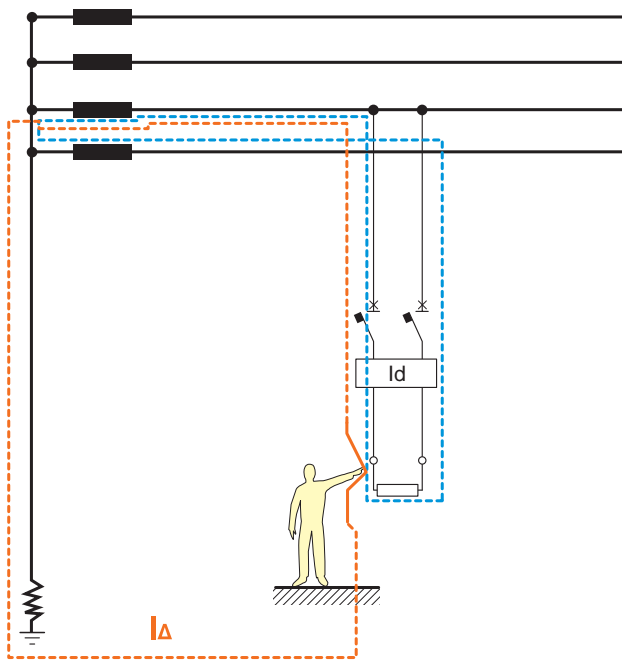
- the use of obstacles intended to prevent unintentional contact with live parts (the protection prevents from unintentionally touching only, but not from intentional one and therefore it is only a partial protection);
- placing live parts out of reach to prevent unintentional contact with these parts (partial protection);
- the use of residual current devices with a rated operating residual current not exceeding 30mA.

Protection by residual current circuit-breakers is defined by the Standards as additional protection intended only to integrate the measures of protection previously described but not to replace them. In order to better understand this, Figure 1 shows the case where the direct contact occurs with one live part only.

The blue dotted line represents the current path under normal conditions, whereas the red line shows the path of the current which might flow through the person under the above mentioned conditions.

Since there is not a fault to earth, the connection status of the exposed-conductive-parts to earth has no influence.

Figure 1

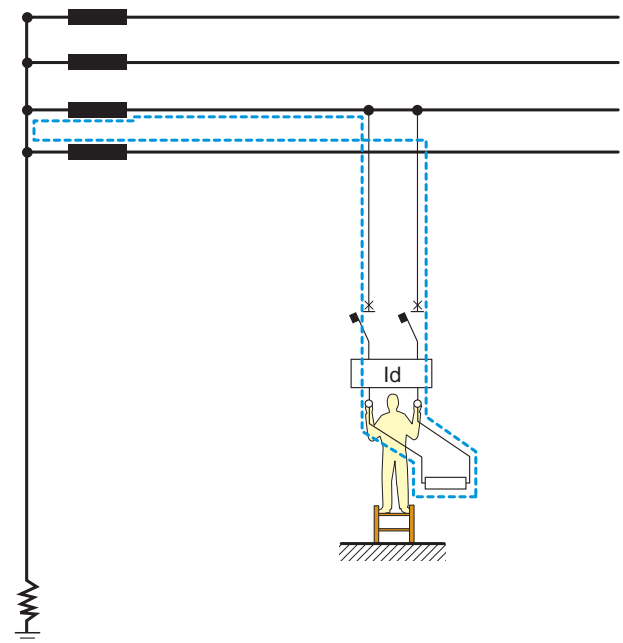


As known, the residual current device operates certainly with $I_{\Delta} \geq I_{\Delta n}$ (where $I_{\Delta n}$ is the sensitivity of the residual current device).

According to the hazard curve (see Chapter 5), a person does not suffer any damage if the current flowing through the human body is lower than or equal to 30mA ($I_{\Delta n} \leq 30\text{mA}$).

Instead, Figure 2 shows the case when direct contact occurs on two polarities with different potential.

Figure 2



The danger could arise when a person is insulated from earth (e.g. a person leaned against a wooden ladder or wearing shoes with rubber sole, etc.) or if his body presents a high electrical resistance value to which the earth resistance is added; in fact, under these conditions, the leakage current I_{Δ} had such a low value that the residual current device would not be activated, but anyway the person might be passed through by a current which could cause hazards.

As a consequence, for these cases (even if quite uncommon) the Standard defines the residual current protection as additional protection to be integrated with the above mentioned means.

Annex C

Protection against indirect contact without automatic disconnection of the circuit

In addition to protection against indirect contact by automatic disconnection of the circuit, the installation Standards allow to realize this type of protection without automatic disconnection with evident advantages for service continuity; these protections are considered as preventive measures since they are used to prevent dangerous conditions from occurring.

The main measures are the following:

- protection by the use of Class II equipment or equivalent insulation;
- protection by provision of a non-conducting location;
- protection by earth-free local equipotential bonding;
- protection by electrical separation.

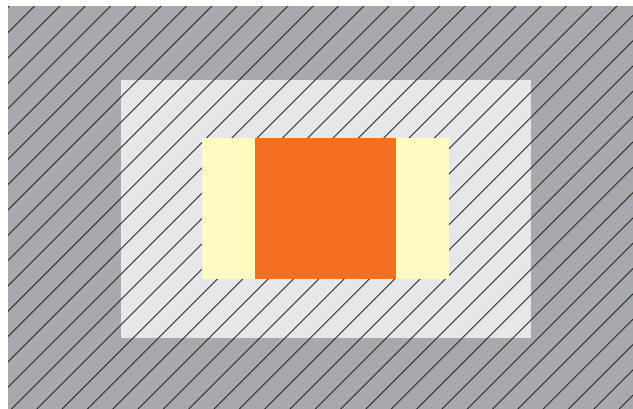
Protection by the use of Class II equipment or equivalent insulation






This protection is provided by the use of electrical equipment having defined – constructional and non constructional - features, which ensure protection against indirect contact.

The main features of these equipment are (Figure 1):

- double insulation or reinforced insulation;
- complete insulation (as regards prefabricated boards);
- supplementary insulation applied to electrical equipment having basic insulation in the process of erecting an electrical installation;
- reinforced insulation applied to uninsulated live parts as a process in the erection of an electrical installation.

Figure 1



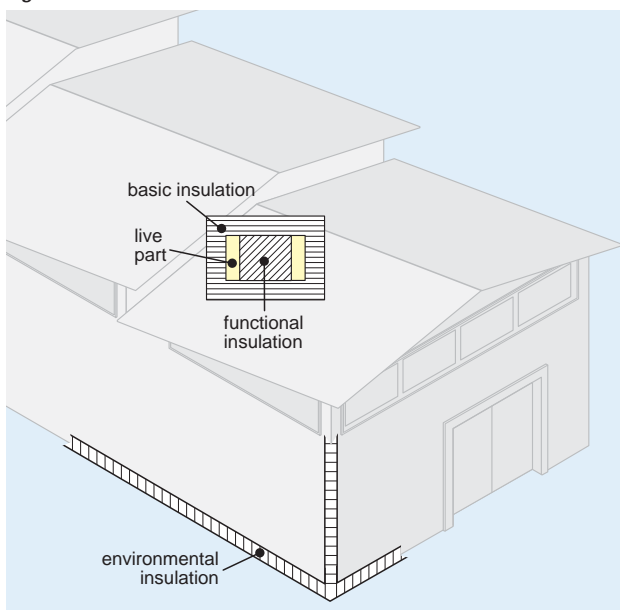
-  = live part
-  = functional isolation: in an electrical device it insulates the parts at different potentials thus enabling operations
-  = basic insulation is the insulation of the normally live parts
-  = supplementary insulation is applied in addition to basic insulation in case of a failure of the last
-  = reinforced insulation, that is a unique insulation which can guarantee the equivalent protection degree which can be provided by basic insulation plus supplementary insulation

Protection by non-conducting locations

Protection by non-conducting locations consists in providing through the environment particular arrangements (spacing, interposition of obstacles and insulation) suitable to prevent simultaneous contacts with parts at different potentials (e.g. caused by a failure in the basic insulation of live parts).

Due to its particular features, this method of protection is never applicable in civil buildings and similars.

Figure 2



Protection by earth-free local equipotential bonding

This type of protection consists in interconnecting all simultaneously accessible exposed-conductive-parts. By using this method, problems might occur in the event of disconnection of an equipotential bonding, which could expose persons to dangerous potential differences in the installation.

This measure of protection is never applicable in civil buildings and similars and, due to the difficulties in fulfilling the required conditions, there are few locations having the appropriate features.

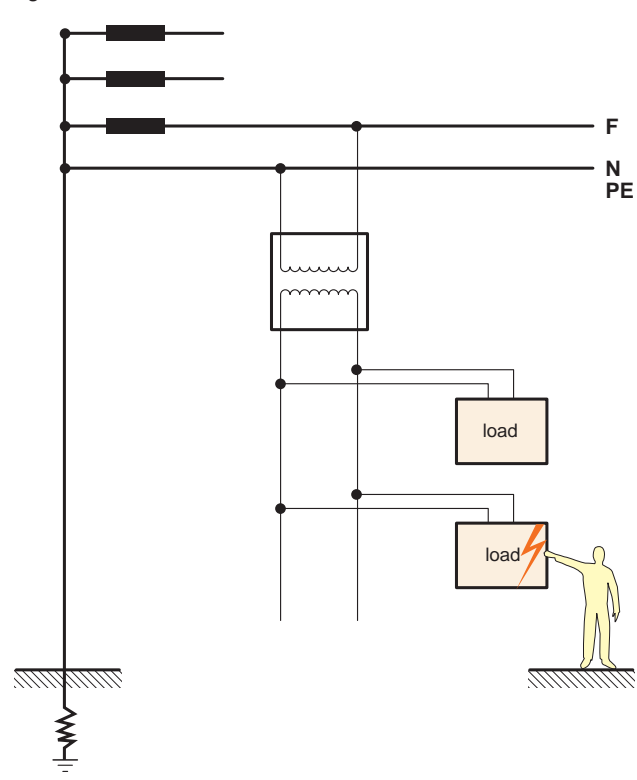
Protection by electrical separation

Protection by electrical separation consists in providing an electrical separation between the supply source and the supplied apparatus by using an isolating transformer or a source of current with an equivalent degree of safety.

The transformer used to obtain this separation cannot be a simple transformer or an autotransformer, but it shall have such characteristics to ensure electrical insulation (double or reinforced insulation or a protective screening between the input and output windings).

With this protection, in case of indirect contact, the voltage on the human body is limited to the impedance of the system to earth¹ since the system is completely insulated (Figure 3).

Figure 3



¹ Disregarding the capacitive currents for cables of short length.

Annex D

Combined protection against both direct and indirect contact

The Standards allow to use a combined protection against both direct and indirect contact. To this purpose, it is necessary to realize a system with well defined characteristics.

The main feature of these systems is having a circuit rated voltage equal to 50Va.c. and 120Vd.c. (extra-low voltage systems).

This type of protection can be ensured by taking appropriate measures so that the rated voltage shall rise in no case, as it could occur in the event of a fault on the secondary winding of a transformer with primary at $U_1 > 50V$ due to an insulation loss between the two windings or due to a contact with other circuits having higher voltage values.

Therefore, the extra-low voltage level can be obtained using the following sources:

- a safety isolating transformer in accordance with the Standards (IEC 61558-2-6);
- a source of current providing a safety degree equivalent to that of the safety isolating transformer;
- an electrochemical source with suitable characteristics;
- small generators;
- certain electronic devices complying with appropriate Standards (where measures have been taken in order to ensure that, even in the case of an internal fault, the voltage at the outgoing terminals cannot exceed the above mentioned values).

These types of system are defined:

- SELV (Safety Extra-Low Voltage);
- PELV (Protection Extra-Low Voltage);
- FELV (Functional Extra-Low Voltage).

Safety Extra-Low Voltage (SELV)

A SELV system has the following characteristics:

1. it is supplied by either one of the independent source or one of the safety source previously mentioned;
2. it is separated from the other electrical systems by a protection, i.e. a double or reinforced insulation or an earthed metallic screen;
3. there are no points connected to earth.

These characteristics are necessary to prevent the system from having a voltage value higher than the rated one.

Protection Extra-Low Voltage (PELV)

A PELV system has the same characteristics of items 1. and 2. above, but it shall have an earthed point necessary for functional reasons or for the safety of the control circuits.

PELV systems result to be less safe than SELV systems because, through the connection to earth, the circuit might acquire a voltage exceeding the secondary rated voltage (extra-low voltage).

This is one of the reasons because the PELV system is not admissible when more severe protective measures are required (e.g. restrictive conductive locations).

Considerations about direct and indirect contacts (in SELV and PELV systems)

By using SELV or PELV protection systems, there are no dangers of indirect contacts since the supply voltage is so low that it does not cause hazards for persons.

As regards direct contact for rated voltages up to 25Va.c. and 60Vd.c., protection is already ensured by SELV (under normal environmental conditions).

For higher voltage values (but, however, not exceeding 50V) insulation shall be provided or live parts shall be made inaccessible to the test finger.

Functional Extra-Low Voltage (FELV)

When the system is extra-low voltage, but it does not fulfill the above mentioned requirements for SELV and PELV circuits, the system is called FELV (Functional Extra-Low Voltage).

Considerations on direct and indirect contacts (in FELV systems)

FELV systems can be supplied by a normal no-safety transformer; therefore it is possible that, due to a fault in the insulation, the voltage of the primary flows through the secondary.

Therefore, safety measures against both direct and indirect contacts must be applied.

Indirect contact

As regards indirect contact it is necessary that:

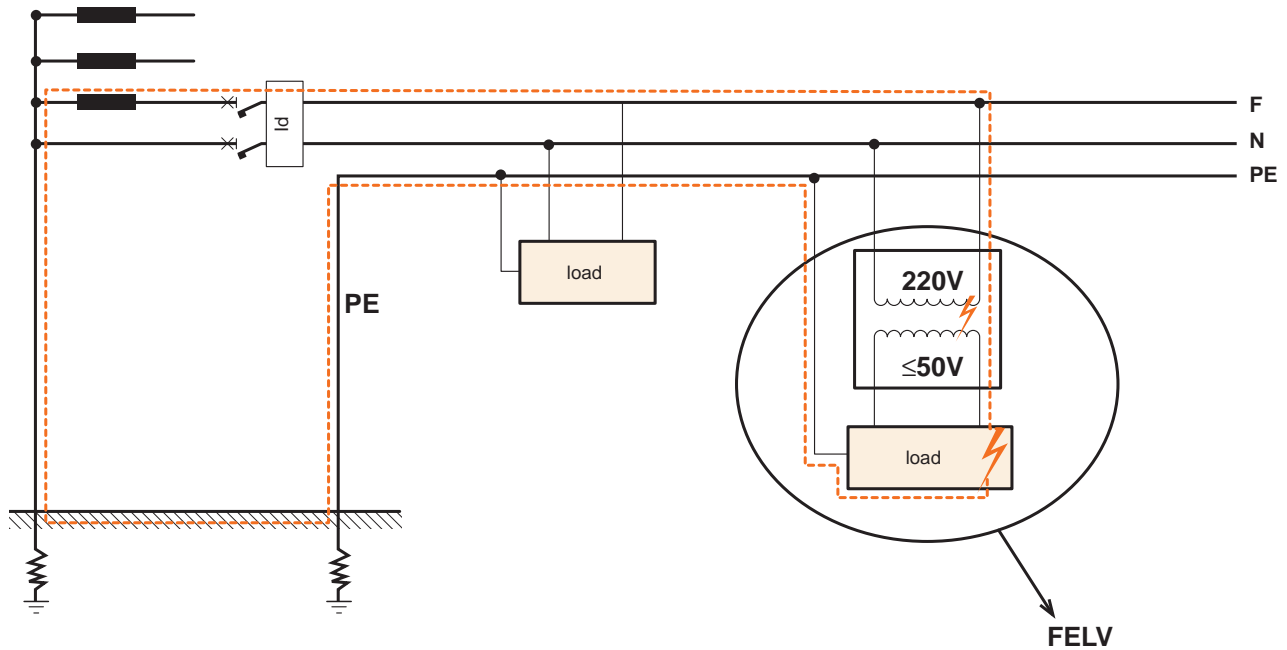
- the exposed-conductive-parts of the FELV circuit are connected to the protective conductor of the primary system, provided that protection by automatic disconnection of the circuit is provided. Thus, in fact, as Figure 1 shows, in case of double fault the residual current device of the primary system shall trip for $I_{\Delta} \geq I_{\Delta n}$
- the exposed-conductive-parts of the FELV circuit are connected to the earth-free equipotential bonding insulated conductor (in a system where protection by electrical separation is provided).

Direct contact

As regards direct contact it is necessary that:

- live parts are placed inside enclosures or behind barriers affording a degree of protection of at least IP2X or IPXXB
- an insulation corresponding to the minimum test voltage required for the primary circuit is guaranteed.

Figure 1



Annex E

Considerations on the neutral and protective conductor

Neutral conductor

General aspects

The neutral conductor is a live conductor that is connected to the neutral point of the system¹ and is able to contribute to the transmission of electric power.

Its other functions are:

- making available a voltage U_0 that is different from the phase-to-phase voltage U (Figure 1);
- making the single phase loads functionally independent one from the other (Figure 2);
- limiting the shifting of the star point in the presence of unbalanced three-phase loads (Figure 3);
- accomplishing also the function of protective conductor (PEN), under specific conditions (Figure 4).

Figure 1

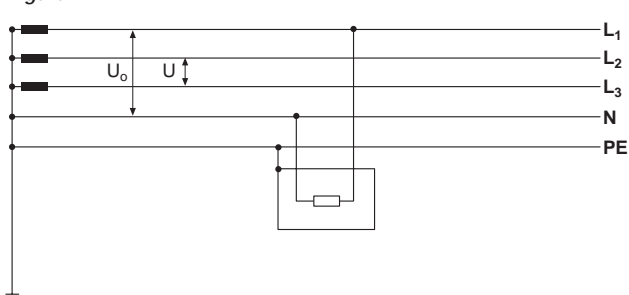
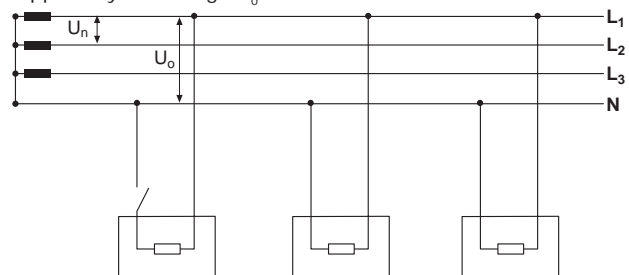


Figure 2

With the neutral distributed the single-phase loads are always supplied by the voltage U_0 .



In absence of the neutral, the disconnection of a load could make the other loads operate at a voltage equal to $U_n/2$.

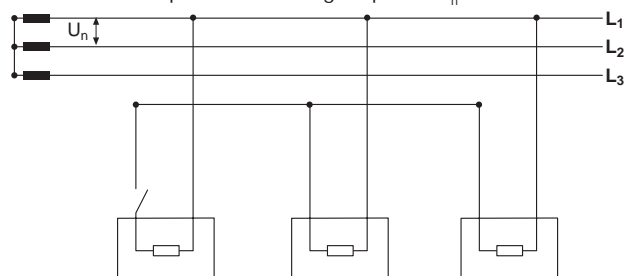
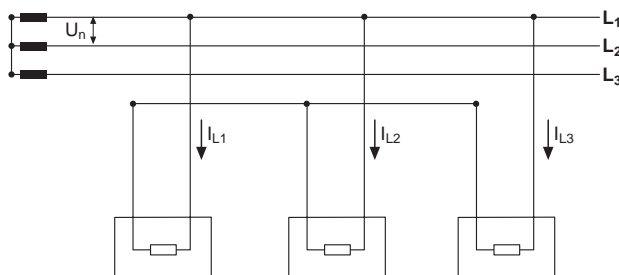


Figure 3

Without the neutral, the sum of the currents must be zero, which results in a strong dissymmetry of the phase voltages.



The presence of the neutral binds the real star point to the ideal one.

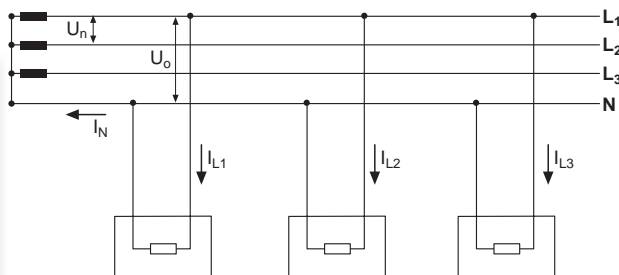
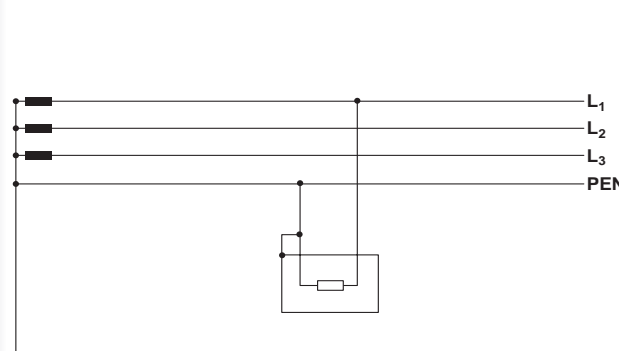


Figure 4

In TN-C system, the neutral conductor is also the protective conductor.



¹ The neutral point is usually - but not necessarily - connected to the starpoint of the transformer or of the generator. In practice, in electrical installations, the neutral point of the system has zero potential. In fact, if the system is balanced, from the vector diagram of the phase-to-phase and of the star voltages, it results that the neutral point coincides with the centroid of the triangle. From a physics point of view, the neutral point becomes available in case of star connection of the phases. Otherwise, if the connection is of delta type, the neutral point can be made accessible by deriving from the phases a set of three star-connected impedances of equivalent value.

Protection and disconnection of the neutral conductor

Under abnormal conditions, the neutral conductor may have a voltage to earth which, for example, may be due to a disconnection caused by an accidental rupture or by the intervention of the single-pole devices (fuses or single-pole circuit-breakers). Attention must be paid to the fact that these anomalies can have heavy consequences if the neutral conductor is used also as protective conductor like in TN-C systems. As regards these distribution systems the Standards prohibit the use of any device (single- as well as multi-pole ones) which could disconnect the PEN conductor and prescribe the minimum cross-sectional areas (see the following paragraph) necessary to consider negligible the possibility of rupture due to accidental causes. As just seen, in a four-pole circuit, the disconnection of the neutral conductor only may alter the supply voltage of the single-phase apparatus which are supplied by a voltage different from the phase voltage. Therefore, protection of the neutral conductor must not be provided by single-pole devices. Protection and disconnection of the neutral conductor are different according to the nature of the distribution systems:

- TT or TN systems;
- IT systems.

TT or TN systems:

- a) where the cross-sectional area of the neutral conductor is at least equal to or greater than that of the phase conductors, it is not necessary to provide overcurrent detection for the neutral conductor or a disconnecting device for that conductor (neutral not protected and not disconnected);
- b) overcurrent detection does not need to be provided for the neutral conductor if the two following conditions are simultaneously fulfilled:
 - the neutral conductor is protected against short-circuit by the protective device for the phase conduc-

tors of the circuit, and

- the maximum current likely to be carried by the neutral conductor is, in normal service, clearly lower than the value of the current-carrying capacity of that conductor;
- c) where the cross-sectional area of the neutral conductor is less than that of the phase conductor, it is necessary to provide overcurrent detection for the neutral conductor, so that the disconnection of the phase conductors, but not necessarily of the neutral conductor, is caused (neutral protected but not disconnected).

In TN-C systems, the neutral conductor serves also as protective conductor and therefore it cannot be disconnected. Besides, in case of disconnection of the neutral conductor, during an earth fault the exposed-conductive-parts would take the rated voltage to earth of the system.

IT systems:

Where the neutral conductor is distributed¹, it is generally necessary to provide overcurrent detection for the neutral conductor of every circuit, which will cause the disconnection of all the live conductors of the corresponding circuit, including the neutral conductor.

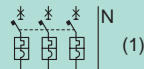
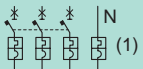
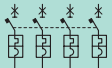
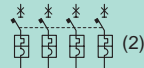
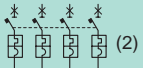
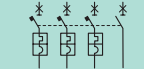
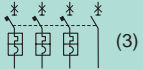



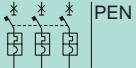
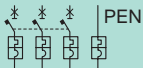
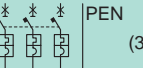
Overload detection on the neutral conductor is not necessary if:

- the neutral conductor is effectively protected against the short-circuits by a protective device placed on the supply side (i.e. located at the origin of the installation);
- the circuit is protected by a residual current device with a rated residual current not exceeding 0.15 times the current-carrying capacity of the corresponding neutral conductor. This device shall disconnect all the live conductors, including the neutral.

¹ The Standard advises against the distribution of the neutral in IT systems, see Chapter 5.

Table 1 summarizes the items above.

Table 1

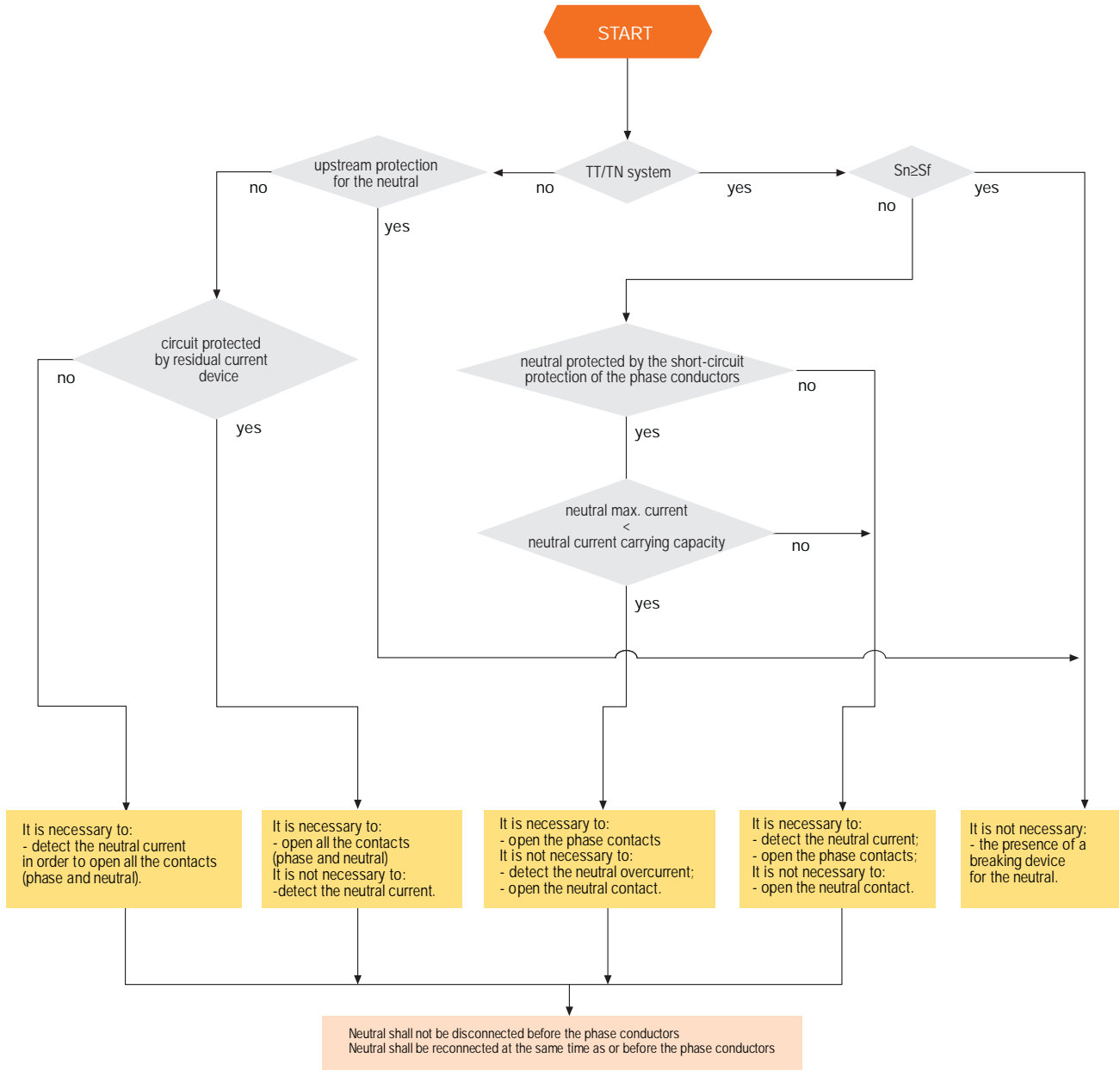
	TT or TN-S systems		TN-C system		IT system
	$S_N = S$	$S_N < S$	$S_{PEN} = S$	$S_{PEN} < S$	
Three-phase + neutral	 (1)	 (1)	-	-	
	 (2)	 (2)			
	 (3)	 (3)			
Phase + neutral	 (1)	-	-	-	
	 (2)				
	 (3)				
Three-phase+ PEN	-	-		 (1)	-
				 (3)	
Phase + PEN	-	-		-	

(1) minimum requirement prescribed by the installation standards

(2) configuration suggested by ABB

(3) feasible configuration if item b) is verified.

Figure 5: Flowchart "protection of the neutral conductor"



Determination of the minimum cross-sectional area of the neutral conductor

The neutral conductor, if any, shall have the same cross-sectional area as the line conductor in the following cases:

- in single or two-phase circuits, whatever the cross section of the line conductor is;
- in three-phase circuits, when the cross section of the line conductor is smaller than or equal to 16 mm² in copper or 25 mm² in aluminum.

The cross section of the neutral conductor can be smaller

than the cross section of the phase conductor when the cross section of the phase conductor is greater than 16 mm² with copper cable or 25 mm² with aluminum cable, if both the following conditions are met:

- the cross section of the neutral conductor is at least 16 mm² for copper conductors and 25 mm² for aluminum conductors;
- there is no high harmonic distortion of the load current. If there is high harmonic distortion, as for example in the case of discharge lamps, the cross section of the neutral cannot be smaller than the cross section of the phase conductors.

To summarize:

Table 2

	Phase cross section S [mm ²]	Min. neutral cross-section S_N [mm ²]
Single-phase/two-phase circuits Cu/Al	any	S^1
Three-phase circuits Cu	$S \leq 16$	S^1
	$S > 16$	16
Three-phase circuits Al	$S \leq 25$	S^1
	$S > 25$	25

¹in TN-C distribution systems, the Standards prescribe for the PEN conductors the minimum cross section of 10 mm² if made by copper and 16 mm² if by aluminum.

Protective conductor

Determination of the minimum cross sections

The minimum cross section of the protective conductor PE can be determined by using Table 3 below:

Table 3

Cross section of the phase conductor S [mm ²]	Cross-sectional area of the protective conductor S_{PE} [mm ²]
$S \leq 16$	S
$16 < S \leq 25$	16
$S > 25$	$S/2$

For a more accurate calculation and assuming that the protective conductor is subjected to adiabatic heating from an initial known temperature to a final specified temperature (therefore applicable for fault extinction times no longer than 5s), the minimum cross section of the protective conductor S_{PE} can be obtained by using the following formula:

$$S_{PE} = \frac{\sqrt{I^2 t}}{K}$$

where:

- S_{PE} is the cross section of the protective conductor in [mm²];
- I is the r.m.s. current flowing through the protective conductor in the event of a fault with low impedance in [A];
- K is a constant which depends on the material of the protective conductor, on the type of insulation and on the initial and final temperature and which can be taken from the tables of the Standards or calculated with the following formula:

$$K = \sqrt{\frac{Q_c (B + 20)}{\rho_{20}} \ln \left(1 + \frac{\theta_f - \theta_i}{B + \theta_i} \right)}$$

where:

- Q_c is the thermal capacity per unit of volume of the conductor material in [J/°C·mm³];
- B is the inverse of the temperature coefficient of the resistivity at 0° C for the conductor;
- ρ_{20} is the resistivity of the conductor material at 20°C in [Ω·mm];
- θ_i is the initial temperature of the conductor in [°C];
- θ_f is the final temperature of the conductor in [°C];
- θ_i and θ_f depend both on the insulating material as well as on the type of cable used; for further details refer to the Standard.

Table 4 shows the most common values of the above mentioned parameters:

Table 4

Material	B [°C]	Q_c [J/°C·mm ³]	ρ_{20} [Ω·mm]	$\sqrt{\frac{Q_c (B + 20)}{\rho_{20}}}$
Copper	234.5	$3.45 \cdot 10^{-3}$	$17.241 \cdot 10^{-6}$	226
Aluminum	228	$2.5 \cdot 10^{-3}$	$28.264 \cdot 10^{-6}$	148
Lead	230	$1.45 \cdot 10^{-3}$	$214 \cdot 10^{-6}$	42
Steel	202	$3.8 \cdot 10^{-3}$	$138 \cdot 10^{-6}$	78

If the table of the Standards or the formula do not provide a standardized cross section, it is necessary to choose a protective conductor with the immediately larger standardized cross-section.

Regardless of whether the table or the formula is used, the cross section of the protective conductor, which is not a part of the supply cable, shall be at least:

- 2.5 mm² if a mechanical protection is provided
- 4 mm² if no mechanical protection is provided.

Glossary

PE	Protection conductor
PEN	Combined conductor (protection and neutral)
I_{Δ}	Residual current
$I_{\Delta n}$	Rated residual current
I_n	Rated current
I_3	Instantaneous trip threshold
RCD	Residual current device
U_0	Phase voltage (phase to neutral)
U_n	Nominal voltage (between phases)
Z	Impedance
I_a	Tripping current of the protection device
R	Resistance
R_t	Resistance of the earthing arrangement
N	Neutral
S	Cross section of the phase conductor
S_N	Cross section of the neutral conductor
S_{PE}	Cross section of the protection conductor
S_{PEN}	Cross section of the PEN conductor



ABB SACE S.p.A.

An ABB Group Company

L.V. Breakers

Via Baioni, 35

24123 Bergamo - Italy

Tel.: +39 035.395.111 - Telefax: +39 035.395.306-433

<http://www.abb.com>

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

1SDC007102G0201 May '06
Printed in Italy
6000 - CAL