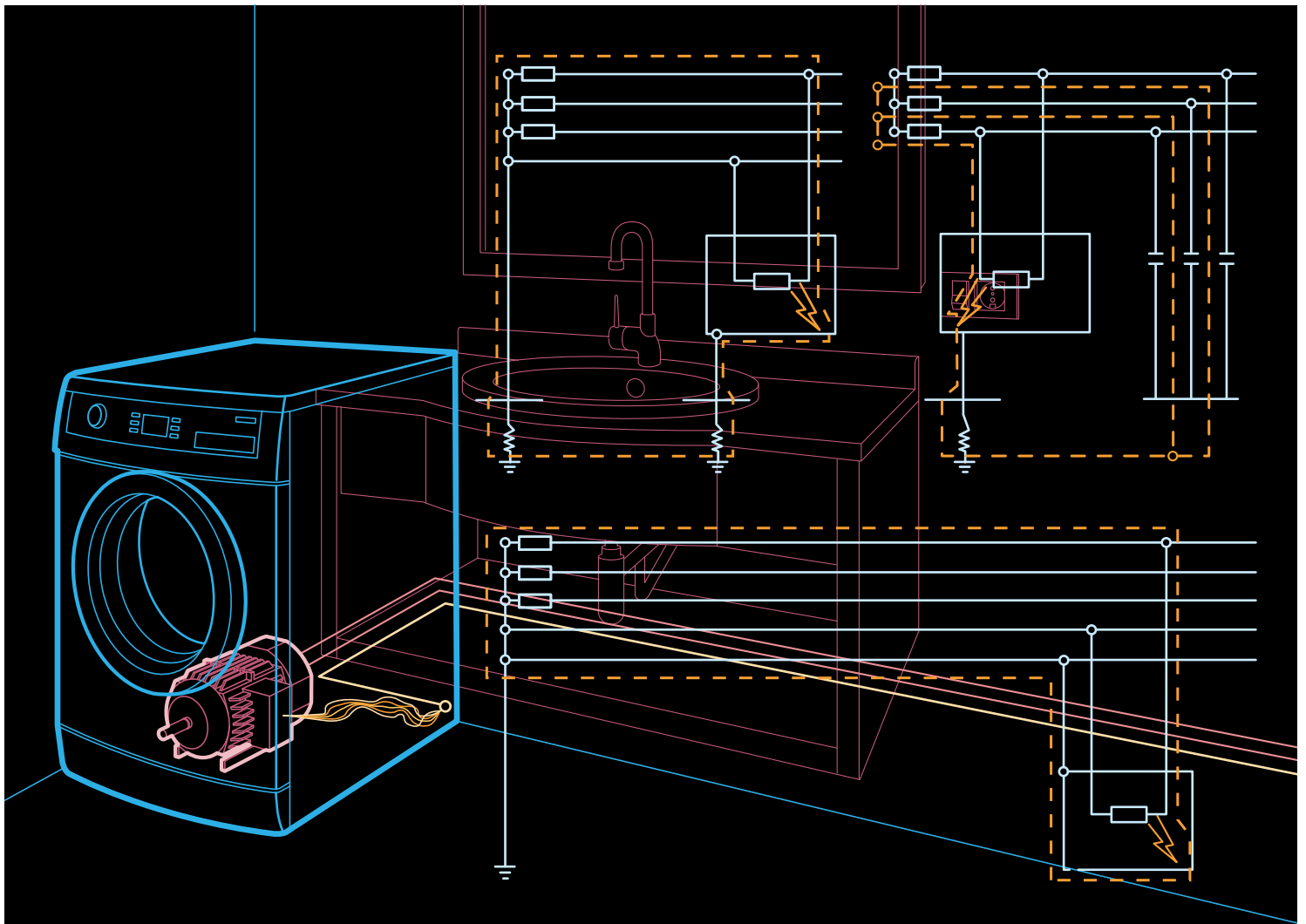




## Technical Application Papers No.3

### Distribution systems and protection against indirect contact and earth fault



# Distribution systems and protection against indirect contact and earth fault

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# 1 Introduction

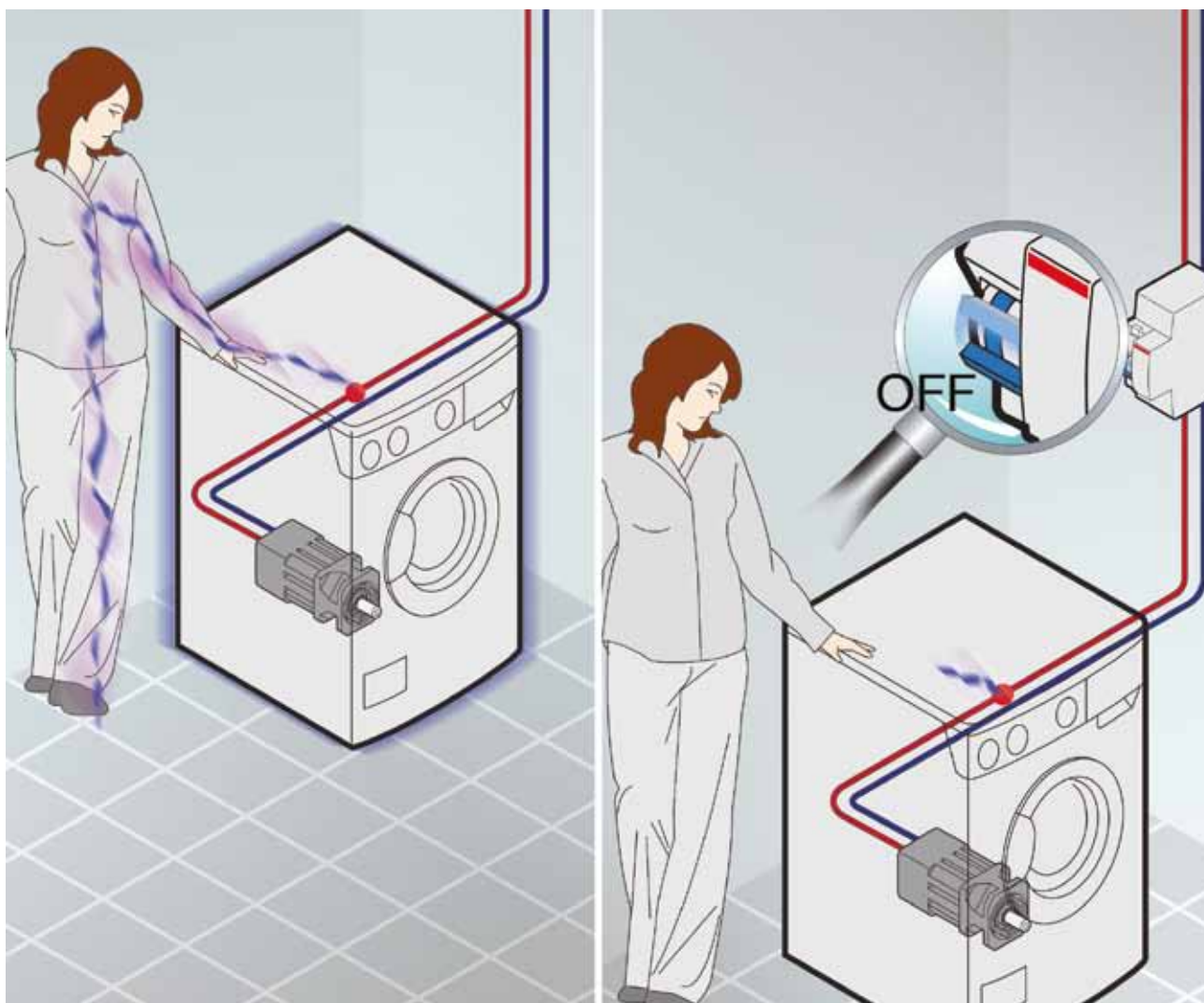
The earth fault, caused by an insulation loss between a live conductor and an exposed conductive part, represents a plant engineering problem which may cause damage to the electrical installations and above all may jeopardize people; as a matter of fact, people could get in touch with an exposed-conductive-part 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, etc.

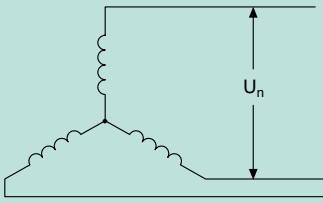
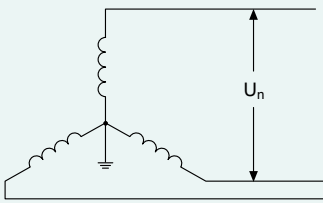
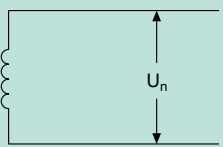
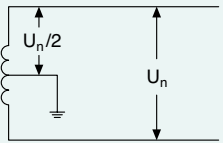


## 2 Main definitions

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 fails<sup>2</sup>.
- *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<br>$U_{ne} = U_n$    |   |
| three-phase systems with neutral connected directly to earth<br>$U_{ne} = \frac{U_n}{\sqrt{3}} = U_0^1$ |   |
| single-phase systems, or a.c. systems, without earthed points<br>$U_{ne} = U_n$                         |  |
| single-phase systems, or a.c. systems, with earthed mid-point<br>$U_{ne} = \frac{U_n}{2}$               |  |

<sup>1</sup>  $U_0$  indicates the voltage between phase and neutral

<sup>2</sup> 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*: vectorial 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.<sup>1</sup>
- *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.

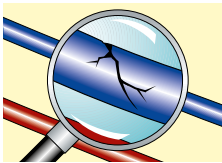
<sup>1</sup> The symbol PEN results from the combination of the symbol PE (for protective conductor) with the symbol N for neutral conductor.

## 3 Protection against earth fault

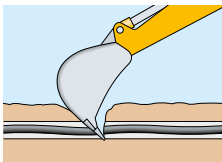
### 3.1 General aspects

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:



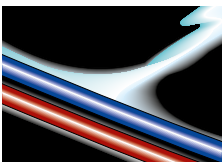
- time decay of dielectric properties (cracks in the insulating rubbers, etc.);



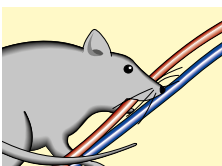
- mechanical breaking (e.g. shearing of a cable in the ground by an excavator);



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



- overvoltages of atmospheric origin or due to switching;

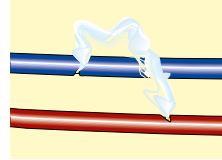


- rodent action.

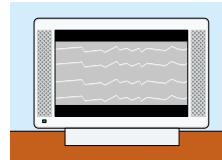
The main effects of the earth fault current are:



- 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 earth<sup>1</sup>:

- 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.

### 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

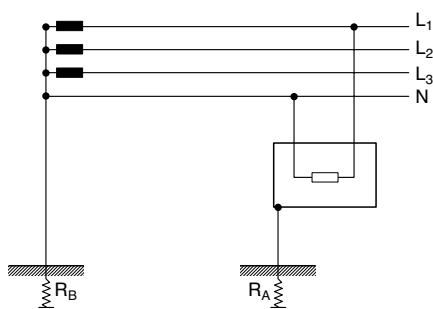
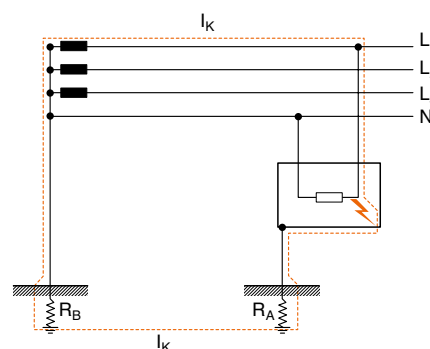


Figure 2: Earth fault in a TT system



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.

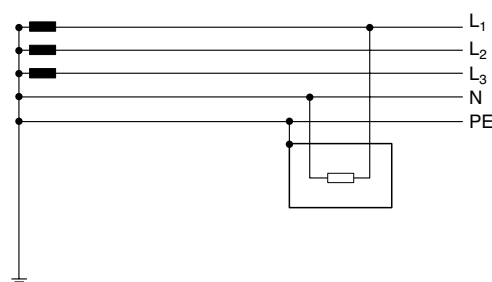
### 4.2 TN system

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:

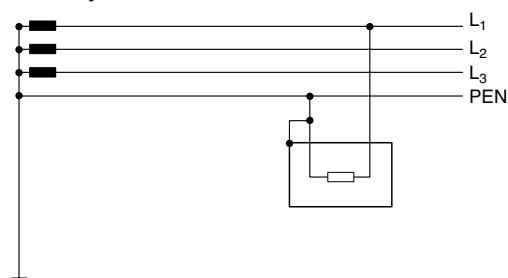
1. TN-S: the neutral conductor N and the protective conductor PE are separated (Figure 3)

Figure 3: TN-S system



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

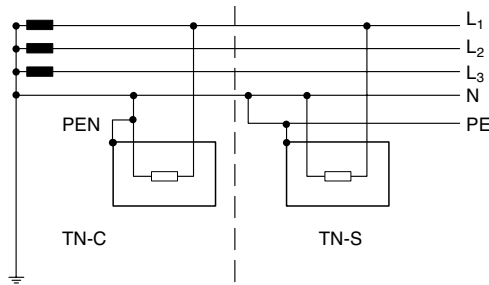
Figure 4: TN-C system





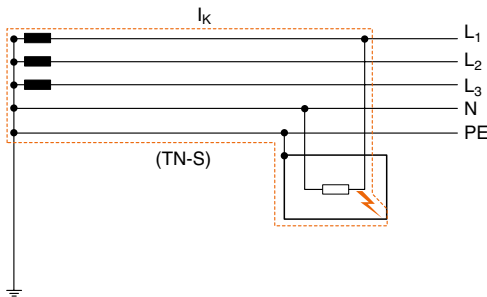
3.TN-C-S: the neutral and protective functions are partially combined into a single PEN conductor and partially separated PE + N (Figure 5).

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).

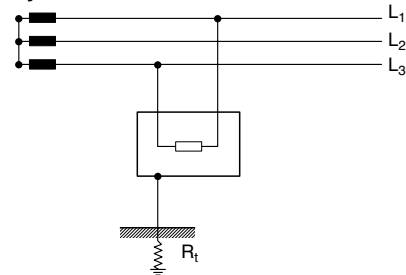
Figure 6: Earth fault in a TN system



## 4.3 IT system

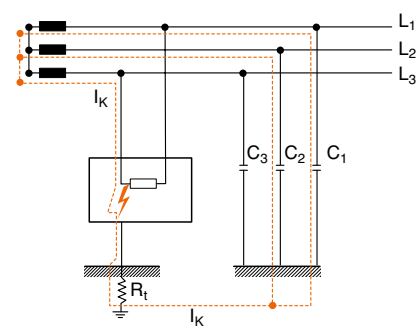
IT systems have no active parts directly earthed, but may have live parts connected to earth through high value impedance (Figure 7). All the exposed-conductive-parts, separately or in group, are connected to an independent earth electrode.

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;<br>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 | $\mu A \div 2 A$ 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

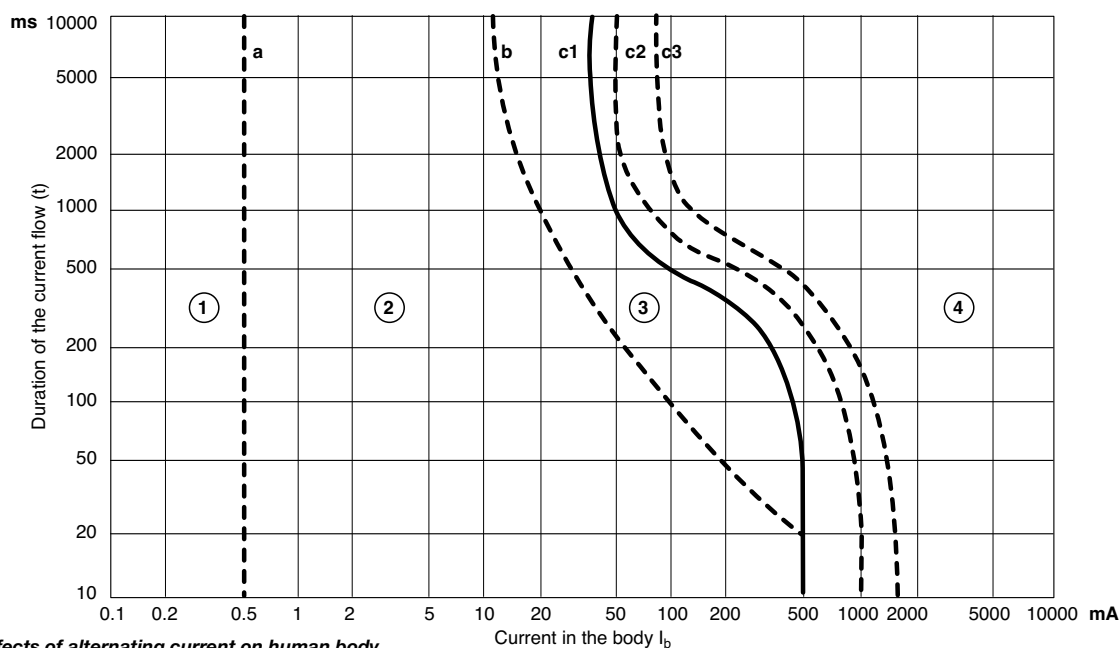


Table 1: Effects of alternating current on human body

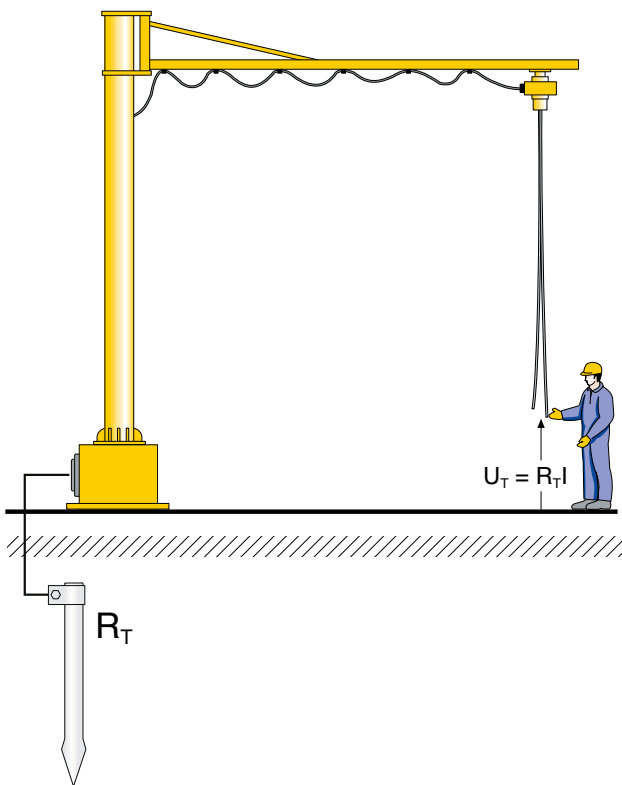
| Zone | Effects                                                                                                                                                                                                                                                                                                                                   |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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.

## 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.

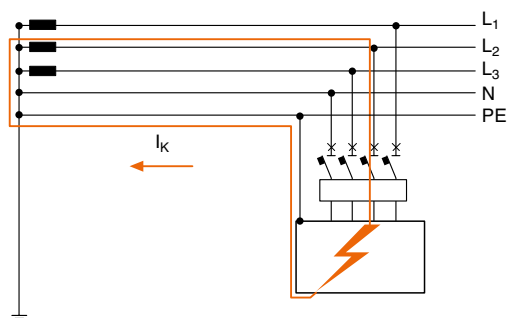
The protection against short-circuit is provided through the magnetic release with an independent time trip curve, i.e. with disconnecting time independent from the short-circuit current.

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.

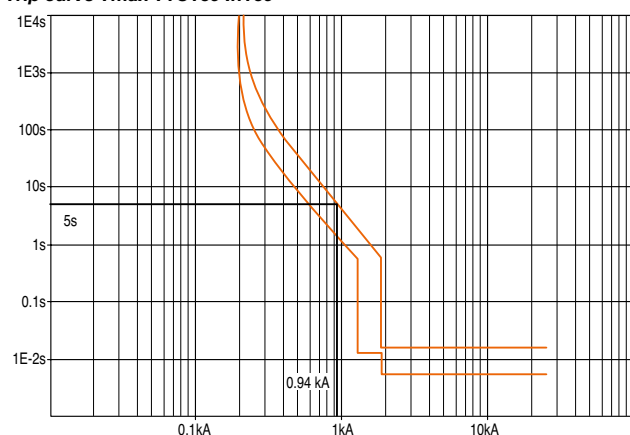
As explained farther in this paper, it is necessary that the protective device is coordinated with the distribution system and the earthing modality of the exposed-conductive-parts, so that tripping is guaranteed to occur in such times to limit the persistence of the dangerous touch voltages present in the exposed-conductive-parts further to the fault.

Figure 2 shows an example of the earth fault current path in a system with the neutral is directly earthed and the exposed-conductive-parts are connected to the same earthing arrangement of the neutral (TN system) and the trip curve of a thermal magnetic circuit-breaker type Tmax T1C160 R160.

**Figure 2**  
Earth current path



**Trip curve Tmax T1C160 In160**



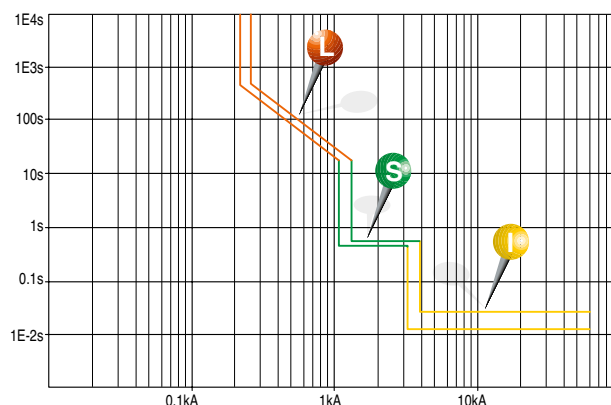
As the diagram shows, by assuming an earth fault current of 940 A, the circuit-breaker shall trip in maximum 5s (value read on the curve with the higher tolerance).

#### 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

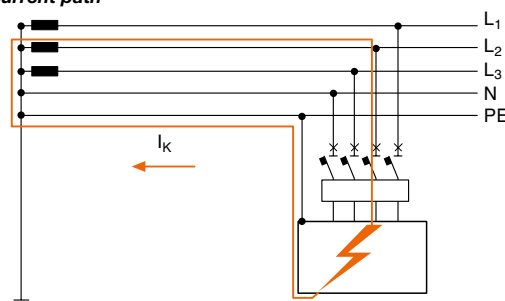
against overload (protection L), short-circuit (protection S and I) and indirect contact to be realized.

**Figure 3**

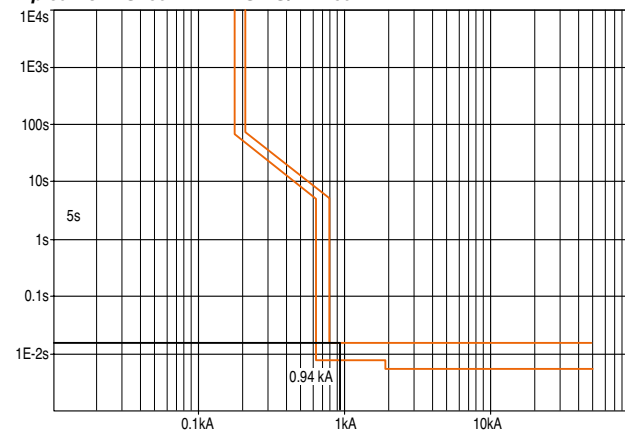


Electronic releases allow to get an accurate settings both as regards the trip times as well as the current thresholds so that the installation requirements are fully satisfied. Figure 4 shows the same example as before, but a circuit-breaker type Tmax T2S160 PR221DS-LS/I In160 with electronic release is installed as protective device.

**Figure 4**  
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.

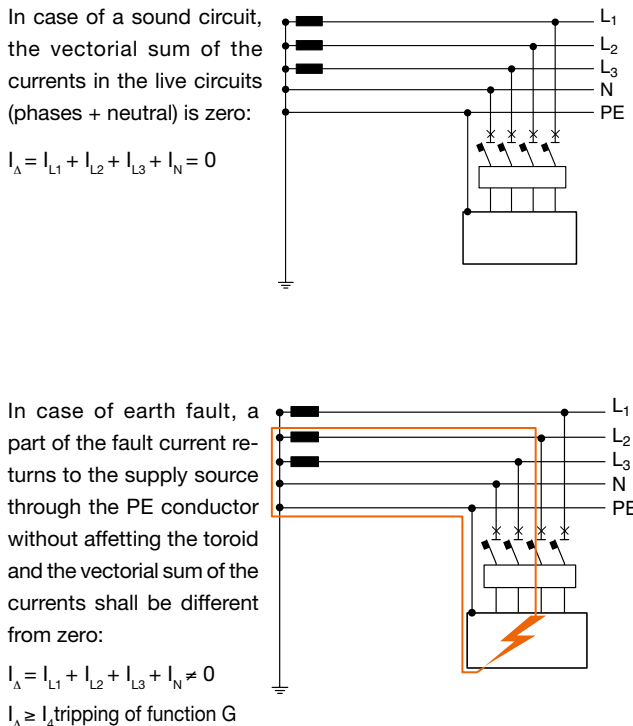
#### Automatic circuit-breakers with microprocessor-based electronic relay with integrated protection against earth fault (function G)

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 5 shows the operating principle.

Figure 5: Operating principle of function G

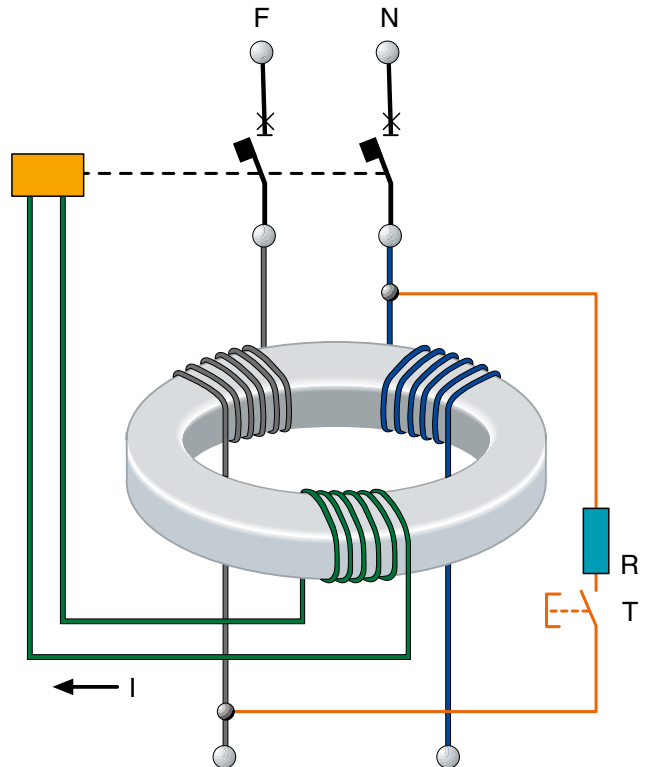


#### Thermal magnetic or electronic circuit-breakers with integrated residual current release

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 6: Operating principle of the residual current release



In absence of an earth fault, the vectorial sum of the currents  $I_{\Delta}$  is equal to zero; in case of an earth fault, if the value  $I_{\Delta}$  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 0.006A<br>slowly rising |                                              |   |   |
| Smooth dc     |                                         |                                              |   | + |

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.

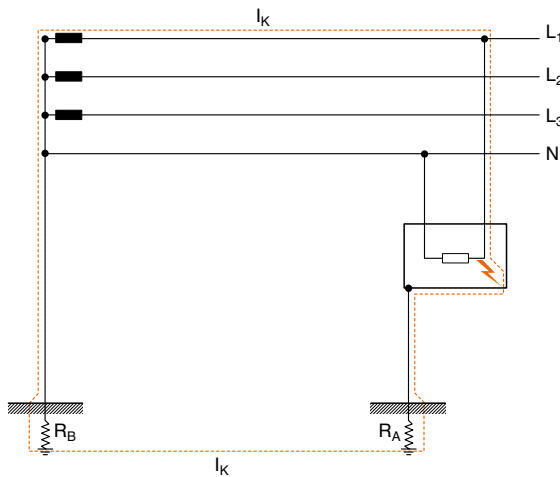
Their operating principle is the same as that previously described.



### 5.3 Protection against indirect contact in TT systems

An earth fault in a TT system originates the circuit represented in Figure 7.

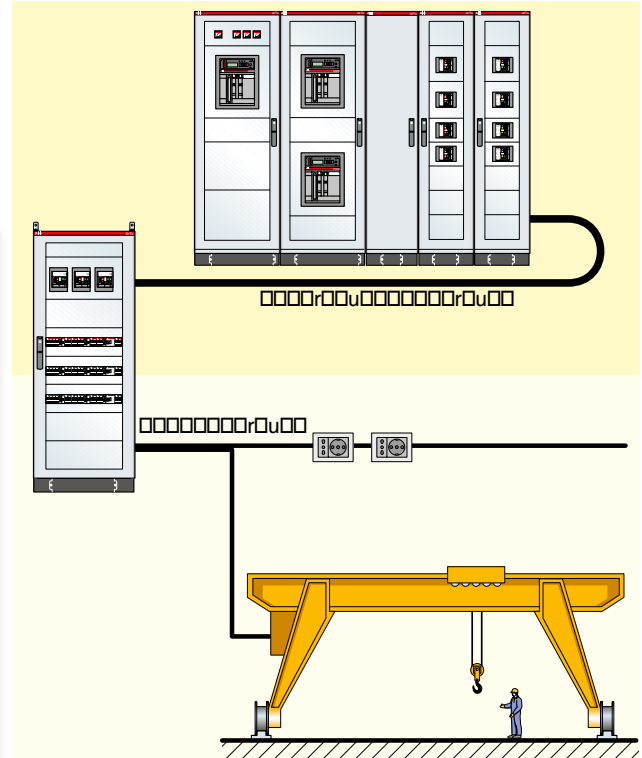
Figure 7



The fault current flows through the secondary winding of the transformer, the line 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.

Before describing such prescriptions, it is useful to know the different circuit types described in the above mentioned Standard; in particular, in a plant, the circuits can be divided into:

- final circuit: it is a circuit which usually supplies equipment (for example an aspirator, a bridge crane, etc.)
- distribution circuit: it is a circuit which supplies a distribution board to which other final circuits are connected.



In a TT system, to achieve a correct protection against indirect contact through the automatic disconnection of the circuit, it is necessary to respect one of the following conditions (in compliance with IEC 60364-4):

#### Protection by means of residual current devices

By assuming 50V as limit voltage (standard environments), to achieve protection against indirect contact by means of residual current devices it is necessary to satisfy the following condition:

$$R_A \cdot I_{\Delta n} \leq 50V \quad \text{then: } R_A \leq \frac{50V}{I_{\Delta n}}$$

where:

$R_A$  is the total resistance (in ohm) of the earth electrode and of the protective conductor of the exposed-conductive-parts<sup>1</sup>;

$I_{\Delta n}$  is the rated residual operating current of the residual current circuit-breaker.

<sup>1</sup> The resistance of the earth electrode 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.



As regards the disconnection times, the Standard distinguishes two possibilities;

- final circuits with rated currents not exceeding 32A: in this case it is necessary that the above mentioned condition with the times shown in Table 3 (values referred to fault currents significantly higher than the rated residual current of the residual current circuit-breakers typically  $5 \cdot I_{\Delta n}$ ) is fulfilled;
- distribution circuit or final circuit with rated currents exceeding 32A: in this case it is necessary that the above mentioned condition is fulfilled with a time not exceeding 1 s (conventional time).

**Table 3: Maximum disconnection times for final circuits not exceeding 32A**

|        | 50V < $U_0 \leq 120V$<br>s |        | 130V < $U_0 \leq 230V$<br>s |      | 230V < $U_0 \leq 400V$<br>s |      | $U_0 > 400V$<br>s |      |
|--------|----------------------------|--------|-----------------------------|------|-----------------------------|------|-------------------|------|
| System | a.c.                       | d.c.   | a.c.                        | d.c. | a.c.                        | d.c. | a.c.              | d.c. |
| TT     | 0.3                        | Note 1 | 0.2                         | 0.4  | 0.07                        | 0.2  | 0.04              | 0.1  |

$U_0$  is the nominal a.c. or d.c. line to earth voltage.

Where in TT systems the disconnection is achieved by an overcurrent protective device and the protective equipotential bonding is connected with all extraneous-conductive-parts within the installation, the maximum disconnection times applicable to TN systems may be used.

NOTE 1 Disconnection may be required for reasons other than protection against electric shock.

NOTE 2 Where compliance with the above mentioned requirement is provided by an RCD, the disconnecting times in accordance with the table above relate to prospective residual currents significantly higher than the rated residual operating current of the RCD (typically  $5 \cdot I_{\Delta n}$ ).

From the above, it is evident that the value of the resistance  $R_A$  of the earthing arrangement results to be different by using residual current circuit-breakers with different sensitivity, since the current quantity at the denominator in the above mentioned relationship is different. In fact, by using a residual current device with 30mA sensitivity, an earthing resistance value lower than

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

shall be obtained, whereas with a less sensitive residual current device (for example with 300mA sensitivity) an earthing resistance value lower than:

$$R_A \leq \frac{50}{0.3} = 166.6\Omega$$

shall be obtained.

As shown in the example, thanks to a more sensitive residual current device, from a practical point of view it will be easier to realize an earthing system coordinated with the characteristics of the device itself.

The Table 4 shows the maximum values of earth resistance which can be obtained with residual current devices and making reference to a common environment (50V):

**Table 4**

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

#### Operating principle of residual current devices

The operating principle of residual current devices consists in 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  $I_{\Delta}$  is equal to zero; in case of an earth fault, if the value of  $I_{\Delta}$  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 operating residual current  $I_{\Delta n}$ , also the total leakage current of the installation under normal operating conditions shall be taken into consideration and, in order to avoid unwanted trips, such current shall not exceed  $0.5 \cdot I_{\Delta n}$ .

#### Protection by means of overcurrent protective devices

The choice of the automatic device for the protection against phase-to-earth faults and indirect contact shall be carried out by coordinating properly the disconnection times with the impedance of the fault loop.

As a consequence, it is necessary to fulfill the following condition:

$$Z_s \cdot I_a \leq U_0$$

where:

- $Z_s$  is the impedance (in ohms) of the fault loop comprising
- the source;
  - the line conductor up to the point of the fault;
  - the protective conductor of the exposed-conductive-parts;
  - the earthing conductor;
  - the earth electrode of the installation;
  - the earth electrode of the source;
- $I_a$  is the disconnection current in the times shown in Table 3 for final circuits with currents not exceeding 32A or within 1 second for distribution circuits and for final circuits with currents exceeding 32A;
- $U_0$  is the nominal a.c. r.m.s. voltage to earth (V).

The choice of the automatic device shall be made by coordinating properly the disconnection times with the impedance of the fault loop.

The relationship  $Z_s \cdot I_a \leq U_0$  may be expressed as :

$$I_a \leq \frac{U_0}{Z_s} = I_{kL\text{-to earth}}$$

where  $I_{kL\text{-to earth}}$  is the phase-to-earth fault current. Therefore, it is possible to state that the protection against indirect contact is verified when the tripping current  $I_a$  of the protective device (within the times shown in Table 3 or within 1s) is lower than the phase-to-earth fault current  $I_{kL\text{-to earth}}$  at the exposed-conductive-part to be protected. It is to underline that in TT distribution systems the use of a residual current device allows to have an earthing arrangement with an earth resistance value which can be easily obtained, whereas the use of automatic circuit-breakers is possible only in case of low earth resistance values  $R_A$  (very difficult to be obtained in practice); besides, in such circumstances, it could be very difficult to calculate the impedance of the fault loop ( $Z_s$ ), because the earthing resistance of the neutral cannot be considered negligible (in fact it could reach values of the same quantity of the earth resistance).

*Protection against indirect contact by means of circuit-*

#### breakers equipped with electronic releases

As previously indicated, the earth fault currents in TT systems have low values and consequently providing this protection by using thermomagnetic/electronic releases with phase protections within the times required by the Standard might be difficult or even impossible; in such cases it is possible to use advanced electronic releases providing protection function G, which improves the protection conditions with earth fault currents not particularly high.

It is important to remember that this protection can evaluate the vectorial sum of the currents flowing through the live conductors (between 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 the ground, without affecting the line conductors.

If this current is higher than the value set for protection G, the circuit-breaker shall trip in the time set on the electronic release.

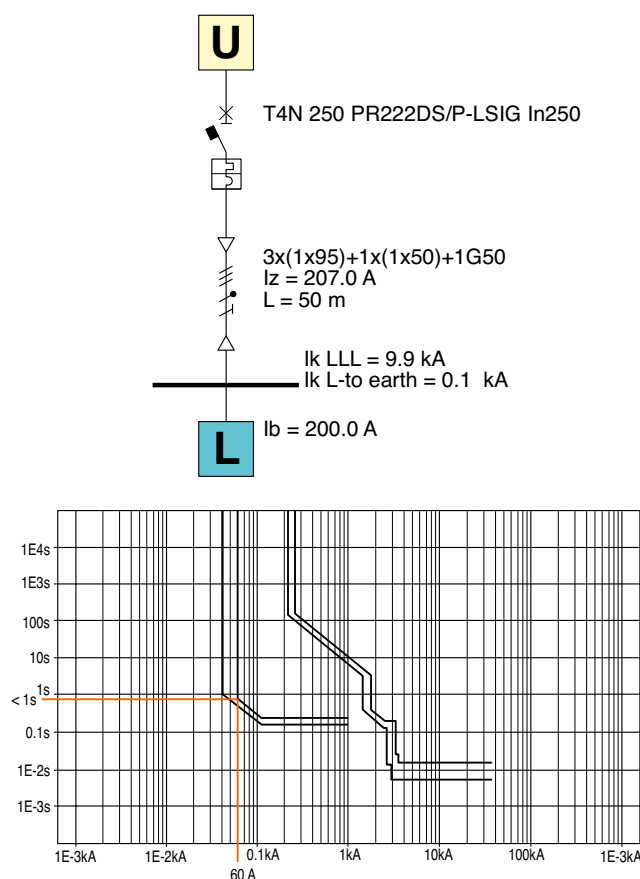
By using function G, the condition to be fulfilled to obtain protection against indirect contact becomes:

$$Z_s \cdot I_4 \leq U_0$$

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 for  $I_n$ , it is easy to realize how, by using function G, it is possible to provide protection against indirect contact for high impedance values of the fault loop and therefore low earth fault currents.

The following example (Figure 8) shows the possible settings of a circuit-breaker Tmax T4N250 In250A equipped with an electronic release type PR222DS/P LSIG.

Figure 8



T4N 250 PR222DS/P-LSIG In 250 A

|                          |                         |               |
|--------------------------|-------------------------|---------------|
| L:                       | $I_1 = 0.80 \times I_n$ | $t_1 = 6s$    |
| S: $I^2t = \text{const}$ | $I_2 = 6.40 \times I_n$ | $t_2 = 0.25s$ |
| I:                       | $I_3 = 12 \times I_n$   |               |
| G: $I^2t = \text{const}$ | $I_4 = 0.20 \times I_n$ | $t_4 = 0.20s$ |

An example: by using protection function G set at  $0.20 \times I_n$  (see Figure 8), the current value over which tripping is obtained within 1s is 60A (value including the upper tolerance).

The value of the phase-to-earth fault current (100A) results to be higher than the trip value within 1 second; therefore protection against indirect current is achieved.

If protection function G were not used, the phase protections would not sense the current of 100A, since the setting of these functions is too high in comparison with the fault currents under consideration.

## Conclusions

To sum up, in TT systems, the Standard IEC 60364 permits the use of:

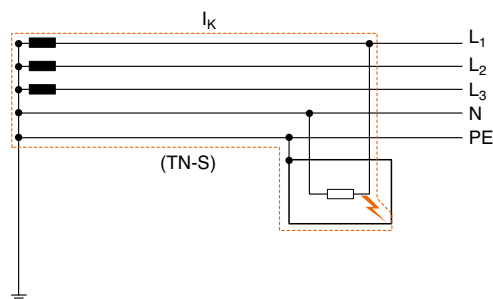
- residual current devices complying with the condition  $R_A \cdot I_{\Delta n} \leq 50V$ , within the disconnection times reported in Table 3 for final circuits with currents lower than 32A, or within 1s for distribution circuits or final circuits with rated currents exceeding 32A;
- automatic protective devices against overcurrents fulfilling the condition  $Z_s \cdot I_a \leq U_0$  within the disconnection times reported in Table 3 for final circuits with currents lower than 32A, or within 1s for distribution circuits or final circuits with rated currents exceeding 32A.

If automatic disconnection cannot be obtained in compliance with the disconnection times of the table or within the conventional time, it shall be necessary to provide supplementary equipotential bonding connected to earth; however the use of supplementary protective bonding does not exclude the need to disconnect the supply for other reasons, for example protection against fire, thermal stresses in equipment, etc.

## 5.4 Protection against indirect contact in TN systems

An earth fault in a TN system originates the fault circuit represented in Figure 9.

Figure 9



As shown in the figure, the fault loop does not affect the earthing arrangement and is basically constituted by the protective conductor (PE).

To provide protection against indirect contact in a TN system with automatic disconnection of the circuit, according to Standard IEC 60364-4-41, 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 line conductor up to the point of the fault and the protective conductor between the point of the fault and the source (in ohms);

$I_a$  is the disconnection current in amperes of the protective device within the times defined in Table 5 as a function of the rated voltage  $U_0$  for final circuits with currents not exceeding 32A or within 5 seconds for distribution circuits and for final circuits with current exceeding 32A (for a description of the circuit typologies reference shall be made to the indications given for TT systems).

Table 5: Maximum disconnection times for final circuits not exceeding 32A

|        | 50V<U <sub>0</sub> ≤120V<br>s |        | 120V<U <sub>0</sub> ≤230V<br>s |      | 230V<U <sub>0</sub> ≤400V<br>s |      | U <sub>0</sub> >400V<br>s |      |
|--------|-------------------------------|--------|--------------------------------|------|--------------------------------|------|---------------------------|------|
| System | a.c.                          | d.c.   | a.c.                           | d.c. | a.c.                           | d.c. | a.c.                      | d.c. |
| TN     | 0.8                           | Note 1 | 0.4                            | 5    | 0.2                            | 0.4  | 0.1                       | 0.1  |

NOTE 1 Disconnection may be required for reasons other than protection against electric shock.

NOTE 2 Where compliance with the above mentioned requirement is provided by an RCD, the disconnecting times in accordance with the table above relate to prospective residual currents significantly higher than the rated residual operating current of the RCD (typically 5·I<sub>Δn</sub>).

The choice of the automatic device for the protection against phase-PE faults and against indirect contact shall be carried out by coordinating properly the disconnection times with the impedance of the fault loop.

In TN systems a bolted fault phase-PE on the LV side usually generates a current similar to that of a short-circuit and the earth fault current flowing through the line conductor (or conductors) and the protective conductor does not absolutely affect the earthing arrangement.

The relationship  $Z_s \cdot I_a \leq U_0$  may be expressed as:

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

where  $I_{KLPE}$  is the phase-PE fault current. Therefore, it is possible to state that the protection against indirect contact is verified when the tripping current  $I_a$  of the protective device (within the times shown in Table 5 or within 5s) is lower than the phase-PE fault current  $I_{KLPE}$  at the exposed-conductive-part to be protected.

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

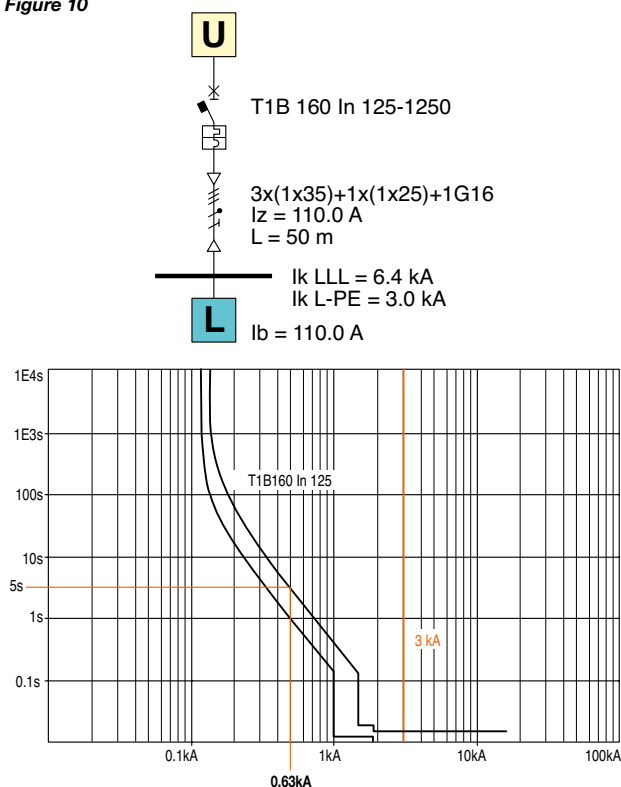
- circuit-breakers with thermomagnetic releases;
- circuit-breakers with electronic releases;
- residual current devices (TN-S only).

### Protection against indirect contact by means of thermomagnetic releases

As previously explained, in TN distribution systems the earth fault currents (to exposed-conductive-parts) 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 thermomagnetic circuit-breakers, provided that the fault current causing disconnection within the specified times is lower than the fault current.

The example (Figure 10) on the following page is aimed at verifying protection against indirect contact in a final circuit which supplies a load with  $I_b > 32A$  in a TN-S system at 400V. To this purpose it shall be sufficient to verify that the phase-PE fault current in correspondence with the considered exposed-conductive-part is greater than the current causing disconnection in 5s.

Figure 10



In this example, the current causing disconnection in less than 5 seconds (considering the upper tolerance) is lower than the phase-PE fault current which results to be 3kA; as a consequence the disconnection times required by the Standard are satisfied.

If the load had been a final circuit (e.g. a small aspirator) with currents lower than 32A, it would have been necessary to verify that the disconnection of the circuit-breaker in case of a phase-PE fault occurred in a time shorter than that given in Table 5.

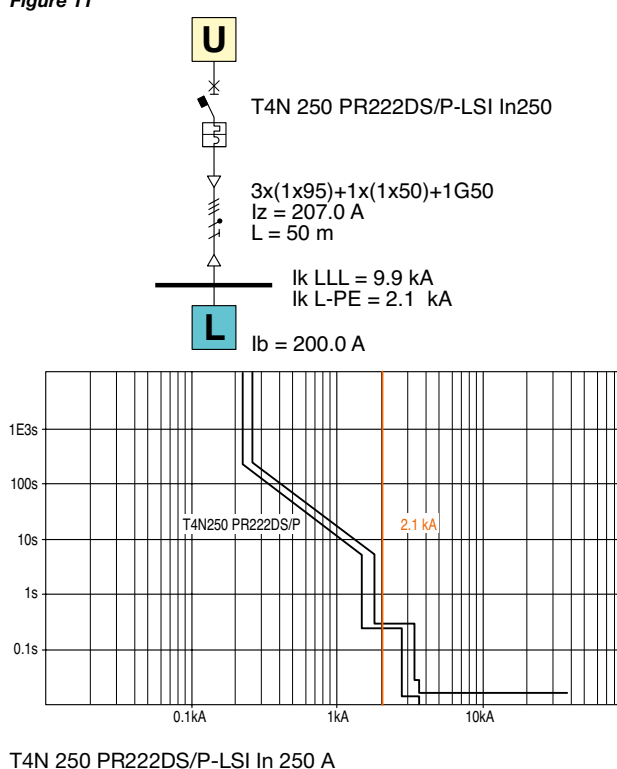
#### Protection against indirect contact by means of electronic releases

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 disconnection times as well as in terms of current thresholds.

The use of these releases finds an application in those plants where the phase-PE fault currents reach a high value and affect the phase protections (L-S-I); however, such use could imply too low settings thus having a negative effect on overcurrent discrimination (overload and short-circuit).

The following example (Figure 11) shows the possible settings of a circuit-breaker T4N 250 In 250A equipped with electronic release type PR222DS/P LSI.

Figure 11



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 protection against indirect contact.

If the circuit to be protected had been a final circuit with rated current lower than 32A, we would have had to verify that the disconnection time of the protection occurred within the times of Table 5.

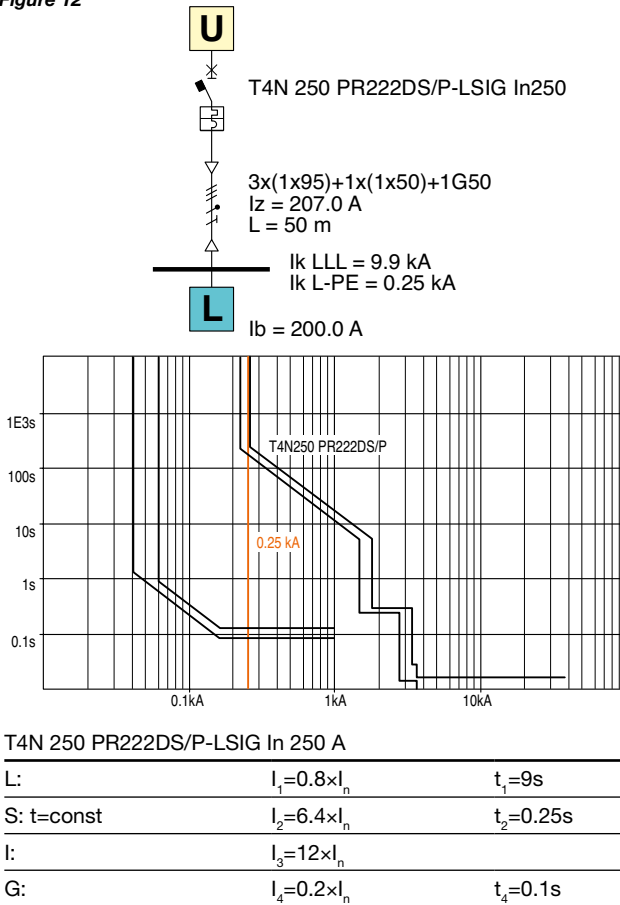
Function G against earth faults improves the protection conditions since it allows to face all the situations in which the impedance of the fault loop takes values so small that the phase protections are not allowed to disconnect within the times prescribed by the Standard, or it is necessary to set the functions S and I at "high" values due to discrimination reasons. 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 of the setting of the protection function against earth faults. Since this value can be set from 0.2 to 1 In (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) in comparison with the phase protection.

The following example (Figure 12) shows the possible settings of a circuit-breaker Tmax T4N250 In 250 A equipped with an electronic release type PR222DS/P LSIG.

Figure 12



In TN-S systems, function G allows the solution of all the situations where the phase protective devices cannot provide adequate protection; in fact, in this case, with a phase-PE fault current of 0.25kA, no phase protection (L-S-I) would have guaranteed disconnection within 5 seconds (since the circuit under consideration is a final circuit with  $I_b > 32A$ ).

If the circuit to be protected had been a final circuit with rated current lower than 32A, we would have had to use an electronic/thermomagnetic release and protect the line against indirect contact by means of the CB phase protections within the times of Table 5.

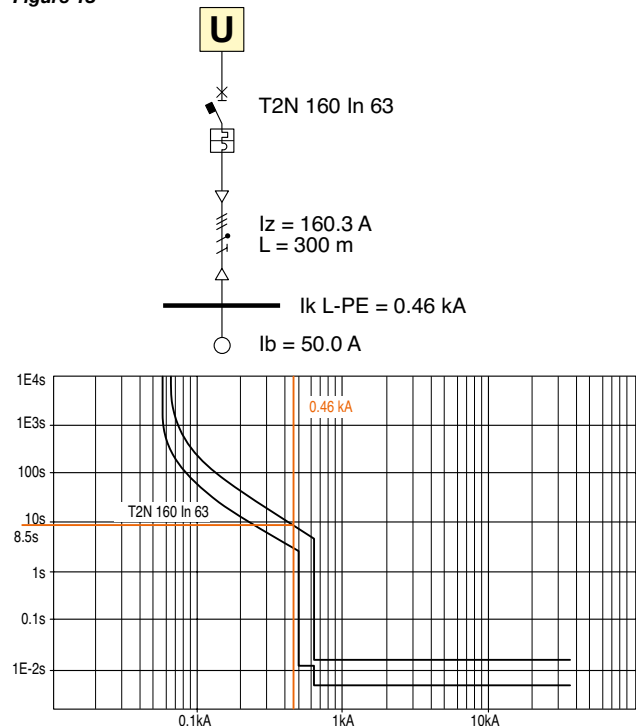
It should be borne in mind that in TN-C systems it is impossible to use function G in a line supplying a three-phase load plus neutral. As a matter of fact, in this case, the microprocessor-based release would not be able to detect the earth fault current, since under such conditions, the sum of the currents in the line 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 next paragraph for a more detailed explanation).

#### Protection against indirect contact by means of residual current devices

The use of residual current circuit-breakers improve 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 13 shows an example of a final circuit supplied by a cable of 300 m length and protected by a thermal magnetic circuit-breaker type Tmax T2N 160 In 80. Due to the high impedance of the cable, the value of the phase-PE fault current is equal to 0.46 kA. At this value, the circuit-breaker disconnects in a time exceeding 5s (about 8.5s considering the tolerance), which does not comply with the disconnection 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 requirements.

Figure 13



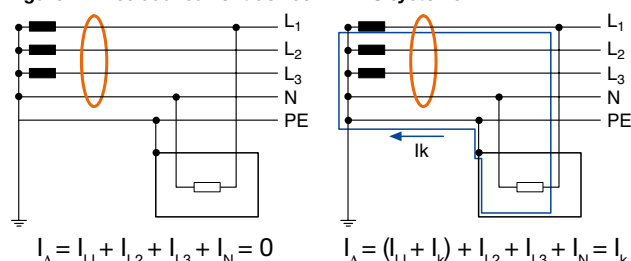
Also residual current circuit-breakers (as function G) cannot be used in TN-C systems since the neutral and protection functions are provided by a single PEN conductor which prevents these devices from operating.

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.



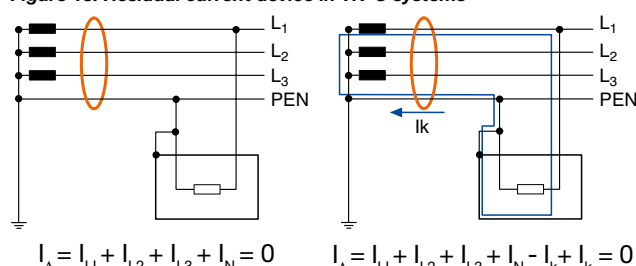
In a TN-S system, the earth fault current returns through the PE protective conductor without affecting the toroid (Figure 14); in this case, the vectorial sum of the currents is different from zero and, if higher than the set threshold, it may cause the operation of the residual current device.

Figure 14: 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 toroid<sup>2</sup> (Figure 15); 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 15: 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 Standard IEC 60364 permits the use of:

- devices (both residual current as well as automatic devices against overcurrents) fulfilling the condition  $Z_s \cdot I_a \leq U_0$  within the times of Table 5 for final circuits with currents lower than 32A, or within 5 seconds for distribution circuits or for circuits with rated currents exceeding 32A.

When automatic disconnection cannot be provided in compliance with the times of the Table 5 or within the conventional time, it is necessary to realize a supplementary protective equipotential bonding connected to earth; however the use of supplementary protective bonding does not exclude the need to disconnect the supply for other reasons, for example protection against fire, thermal stresses in equipment, etc.

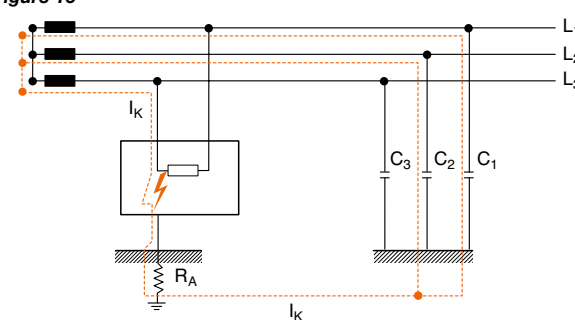
In TN-C systems disconnection of the neutral and use of residual current devices or of devices with similar operating principle (function G against earth faults) are not possible.

<sup>2</sup> 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 16, the earth fault current in IT systems flows through the line conductor capacitances to the power supply source. For this reason, the earth fault shall be characterized by such an extremely low value to prevent the protection from disconnecting; as a consequence, the deriving touch voltages shall be very low.

Figure 16



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

$$R_A \cdot I_d \leq 50 \text{ Va.c.}$$

$$R_A \cdot I_d \leq 120 \text{ Vd.c.}$$

where:

$R_A$  is the sum of the resistance, in ohms, of the earth electrode and protective conductor for exposed-conductive- parts;

$I_d$  is the fault current, in amperes, of the first fault<sup>3</sup> of negligible impedance between a line conductor and an exposed-conductive-part; such value takes account of the leakage currents and of the total earthing impedance of the electrical installation.

If this condition is fulfilled, after the fault, the touch voltage on the exposed-conductive-part will be than 50 V (in alternating current), which is tolerable by the human body for an indefinite time.

In IT system installations, an insulation monitoring device shall be provided to indicate the presence of an anomalous condition after the occurrence of a 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.

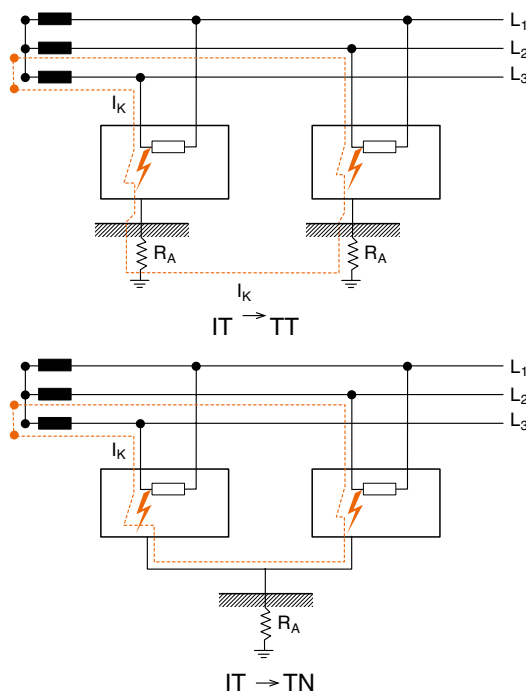
<sup>3</sup> This is referred to by the Standard as first fault to earth; the occurrence of two simultaneous faults on two different phases is called double fault to earth.



The occurrence of an earth fault modifies the distribution system by eliminating the advantages of a network insulated from earth. In particular, two situations may occur in the event of a fault to earth (Figure 17):

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 protective conductor collectively earthed, then the IT system becomes a TN system.

Figure 17



Under these conditions, in case of an earth fault (double fault), the Standard prescribes that the supply shall be disconnected according to the following modalities:

- a) where the exposed-conductive-parts are earthed in groups or individually, the following condition shall be fulfilled:

$$R_A \cdot I_a \leq 50V$$

where:

- $R_A$  is the sum of the resistance of the earth electrode and of the protective conductor for the exposed-conductive-parts;
- $I_a$  is the current causing automatic disconnection of the protective device in a time complying with that for TT systems;

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

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

where the neutral is not distributed

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

where:

- $U_0$  is the nominal voltage between line conductor and neutral conductor;
- $U$  is the nominal voltage between line conductors;
- $Z_s$  is the impedance of the fault loop comprising the line 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 current causing operation of the protective device within the time required for TN systems.

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 disconnection device which must trip to provide 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.

### 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 supply of the circuit if a second fault occurs, when the first is not extinguished, by applying prescriptions analogous to those for 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;
- RCBOs (residual current operated circuit-breakers with integral overcurrent protection) DS200 with rated current from 6A up to 63A;
- RCBOs (residual current operated circuit-breakers with integral overcurrent protection) DS800 with 125A rated current;
- 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 63 A;
- RCD blocks (residual current blocks) DDA 60, DDA 70, DD 90 type to be coupled with the thermal magnetic circuit-breakers type S290 with rated current from 80 A to 100 A with C characteristic curve;
- RCD blocks (residual current blocks) DDA 800 type to be coupled with the thermal magnetic circuit-breakers type S800N and S800S with rated current up to 100 A. These blocks are available in two sizes: 63 A and 100 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 800 |
|-------------|--------|---------|--------|--------|--------|---------|
| <b>S200</b> | 0.5÷63 | •       | -      | -      | -      | -       |
| <b>S290</b> | 80÷100 | -       | •      | •      | •      | -       |
| <b>S800</b> | 10÷100 | -       | -      | -      | -      | •       |

#### - Moulded-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 both with the circuit-breaker Tmax T3 with rated currents up to 225 A (which is the maximum current threshold adjustable on the circuit-breaker) as well as with the circuit-breaker Tmax T4 with rated currents up to 250 A;
- electronic release type PR222DS/P, PR223DS/P, PR223 EF 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 electronic release with residual current integrated protection for the circuit-breaker type Tmax T7 with rated uninterrupted currents from 800 A to 1600 A.

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

|           | In [A]     | RC221 | RC222 | RC223          | PR331      |            |            |             |
|-----------|------------|-------|-------|----------------|------------|------------|------------|-------------|
|           |            |       |       |                | PR222 LSIG | PR223 LSIG | PR332 LSIG | PR332 LSIRc |
| <b>T1</b> | 16 ÷ 160   | •     | •     | -              | -          | -          | -          | -           |
| <b>T2</b> | 10 ÷ 160   | •     | •     | -              | -          | -          | -          | -           |
| <b>T3</b> | 63 ÷ 250   | •     | •     | • <sup>1</sup> | -          | -          | -          | -           |
| <b>T4</b> | 100 ÷ 320  | -     | •     | • <sup>2</sup> | •          | •          | -          | -           |
| <b>T5</b> | 320 ÷ 630  | -     | •     | -              | •          | •          | -          | -           |
| <b>T6</b> | 630 ÷ 1000 | -     | -     | -              | •          | •          | -          | -           |
| <b>T7</b> | 800 ÷ 1600 | -     | -     | -              | -          | -          | •          | •           |

<sup>1</sup> The maximum setting is 225 A

<sup>2</sup> 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 electronic release with residual current integrated protection for circuit-breaker Emax X1 with rated uninterrupted currents from 630 A to 1600 A;

- PR122 electronic release 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<br>PR332<br>PR333<br>LSIG | PR121<br>PR122<br>PR123<br>LSIG | PR332<br>LSIRc | PR122<br>LSIRc |
|-----------|-------------|---------------------------------|---------------------------------|----------------|----------------|
|           |             |                                 |                                 |                |                |
| <b>X1</b> | 630 ÷ 1600  | •                               | -                               | •              | -              |
| <b>E1</b> | 400 ÷ 1600  | -                               | •                               | -              | •              |
| <b>E2</b> | 400 ÷ 2000  | -                               | •                               | -              | •              |
| <b>E3</b> | 400 ÷ 3200  | -                               | •                               | -              | •              |
| <b>E4</b> | 1250 ÷ 4000 | -                               | •                               | -              | -              |
| <b>E6</b> | 3200 ÷ 6300 | -                               | •                               | -              | -              |

- *Residual current releases with external transformer:*
  - RCQ: switchboard electronic residual current release;
  - RD2: residual current monitor for fixing on DIN rail.

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.

In the series DS 951 also the antidisturbance version A AP-R is available.

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 (DS 951 type A AP-R excluded, since it is available with sensitivity  $I_{\Delta n}=30\text{mA}$ ).

The possibility of choosing between type A, AC or A AP-R (with DS 951) allows to obtain a dedicated protection against indirect contact, according to the load connected to the protected line.

## 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

### 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                        | AC, A               | A AP-R      | AC, A               |
| Tripping characteristics                      |                      | instantaneous                |                     |             |                     |
| Rated current                                 | In [A]               | 6 ≤ In ≤ 40                  | 6 ≤ In ≤ 40         | 6 ≤ In ≤ 32 | 6 ≤ In ≤ 32         |
| Poles                                         |                      | 1P+N                         |                     |             |                     |
| Rated voltage                                 | Ue [V]               | 230                          |                     |             |                     |
| Insulation voltage                            | Ui [V]               | 500                          |                     |             |                     |
| Rated frequency                               | [Hz]                 | 50...60                      |                     |             |                     |
| Rated breaking capacity IEC/EN 61009          | Icn [A]              | 4500                         | 6000                | 6000        | 10000               |
| Rated breaking capacity                       | Icu [kA]             | 6                            | 10                  | 10          | 10                  |
| IEC/EN 60947-2 two poles - 230 V              | Ics [kA]             | 4.5                          | 6                   | 6           | 10                  |
| Thermomagnetic release characteristics        | B: 3 In ≤ Im ≤ 5 In  | •                            | •                   |             | •                   |
|                                               | C: 5 In ≤ Im ≤ 10 In | •                            | •                   | •           | •                   |
| Rated sensitivity IΔn [A]                     |                      | 0.01-0.03-0.1-0.3-0.5-1*     | 0.03-0.1-0.3-0.5-1* | 0.03        | 0.03-0.1-0.3-0.5-1* |

\* Type AC only

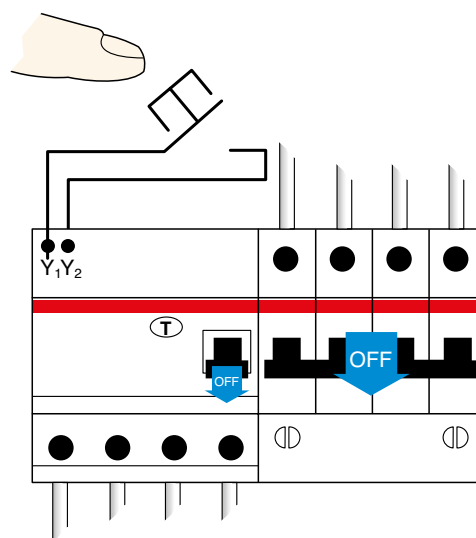
### Thermal-magnetic residual current circuit-breakers (RCCBs) DS200 series

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 thermal-magnetic 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]                        |                                          |                                      |         |       |
| Rated frequency                               |                      | [Hz]                          |                                          |                                      |         |       |
| Rated breaking capacity IEC/EN 61009          |                      | Icn [A]                       | 4500                                     | 6000                                 | 10000   | 25000 |
| Rated breaking capacity * IEC/EN 60947-2      |                      | Icu [kA]                      | 6                                        | 10                                   | 15      | 25    |
|                                               |                      | Ics [kA]                      | 4.5                                      | 7.5                                  | 11.2    | 12.5  |
| 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

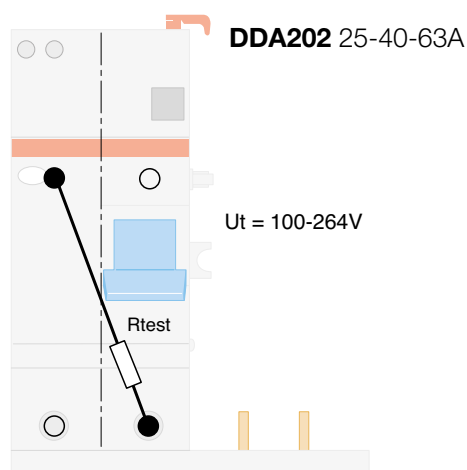
*Residual current blocks DDA 200 series to be coupled with the thermal magnetic circuit-breakers (MCBs) type S200*

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, AP-R (antidisturbance versions), S (selective version), AE (with emergency stop function) and B (also sensitive to residual continuous currents or with minimum residual ripple); 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.

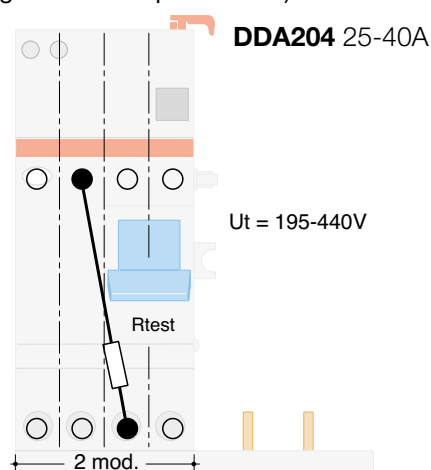
The DDA 200 blocks, 25-40 A standard version, thanks to their design and to the choice of the operating range for the test pushbutton are suitable to be used in electrical and naval installations (where the voltage phase-neutral is 115-125V).

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

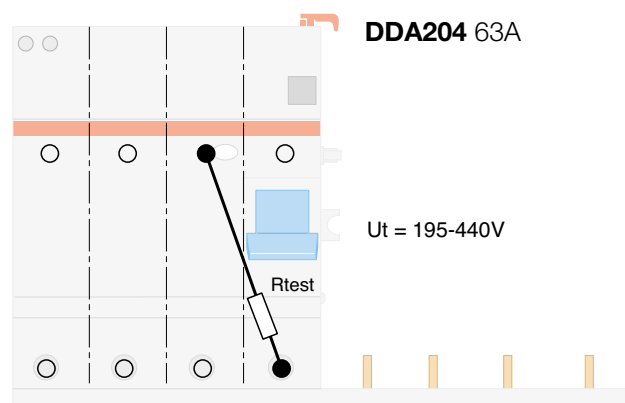


In the compact four-pole blocks with two modules (available size 25-40A), the test pushbutton is connected at a point between the two central phases, with operating range from 195 to 440V; for this configuration in particular, it results to be suitable both for systems with 400V between the phases (as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

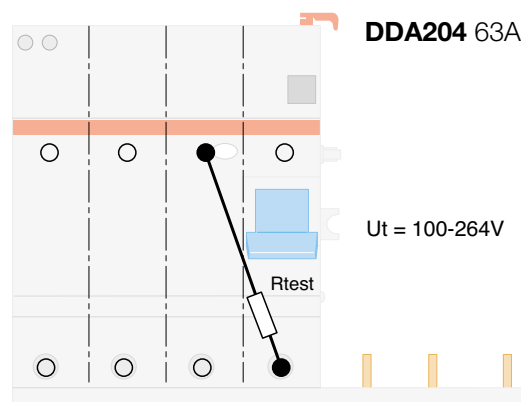
voltage between phases would be  $115-125V \times 1.73 = 200/215V$  which are voltage values included in the operating range of the test pushbutton).



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<br>AC                          | DDA200<br>A | DDA200<br>A AE | DDA200<br>AC AP-R | DDA200<br>A AP-R | DDA200<br>AC-S | DDA200<br>A S | DDA200<br>B/B-S |
|-----------------------------------------------|--------------------------------|---------------------------------------|-------------|----------------|-------------------|------------------|----------------|---------------|-----------------|
| Reference Standard                            |                                | IEC/EN 61009 Annex G                  |             |                |                   |                  |                |               |                 |
| Type (waveform of the leakage current sensed) |                                | AC                                    | A           | A              | AC                | A                | AC             | A             | B               |
| Tripping characteristic                       |                                | instantaneous                         |             |                |                   |                  | selective      |               | inst.-selective |
| Rated current $I_n$ [A]                       |                                | 25, 40, 63                            | 25, 40, 63  | 63             | 25, 40, 63        | 25, 40, 63       | 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]<br>$I_{cs}$ [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       | 0.03-0.3        |

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]<br>$I_{cs}$ [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 800 series to be coupled with the thermal magnetic circuit-breaker type S800N and S800S  
For assembly with MCBs S 800N and S800S the RCD blocks type DDA 800 are available in the followings type: AC, A, A selective and A AP-R (antidisturbance version).

## RCD blocks DDA 800 series

|                                               |                                | DDA800 AC                             | DDA800 A       | DDA800 A S    | DDA800 A AP-R       |
|-----------------------------------------------|--------------------------------|---------------------------------------|----------------|---------------|---------------------|
| Reference Standard                            |                                | IEC/EN 60947-2 Annex B                |                |               |                     |
| Type (waveform of the leakage current sensed) |                                | AC                                    | A              | A (selective) | A (antidisturbance) |
| Tripping characteristic                       |                                | instantaneous                         |                | selective     | instantaneous       |
| Rated current                                 | $I_n$ [A]                      | 63-100                                |                |               |                     |
| Poles                                         |                                | 2P, 3P, 4P                            |                |               |                     |
| Rated voltage                                 | $U_e$ [V]                      | 230/400; 240/415; 400/690             |                |               |                     |
| Insulation voltage                            | $U_i$ [V]                      | 690                                   |                |               |                     |
| Rated frequency                               | [Hz]                           | 50...60                               |                |               |                     |
| Rated breaking capacity<br>IEC/EN 61009       | $I_{cu}$ [kA]<br>$I_{cs}$ [kA] | $I_{cu}/I_{cs}$ of the associated MCB |                |               |                     |
| Rated sensitivity                             | $I\Delta n$ [A]                | 0.03 - 0.3                            | 0.03 - 0.3-0.5 | 0.3 - 1       | 0.3                 |

## 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  | F200 B/B-S      |
|-----------------------------------------------|-------------------|--------|--------------|-------------|-----------|-----------------|
| Reference Standard                            | IEC/EN 61008      |        |              |             |           |                 |
| Type (waveform of the leakage current sensed) | AC                | A      | AC           | A           | A         | B               |
| Tripping characteristic                       | instantaneous     |        |              |             | selective | inst.-selective |
| Rated current           In [A]                | 16, 25, 40, 63    |        | 25, 40, 63   |             | 40, 63    | 40, 63          |
| Poles                                         | 2P, 4P            |        |              |             |           | 4P              |
| Rated voltage           Ue [V]                | 230/400 - 240/415 |        |              |             |           |                 |
| Insulation voltage       Ui [V]               | 500               |        |              |             |           |                 |
| Rated frequency        [Hz]                   | 50...60           |        |              |             |           |                 |
| Rated sensitivity IΔn [A]                     | 0.01...0.5        |        | 0.03         |             | 0.1...1   | 0.03-0.3        |

## 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 for T3-T4 circuit-breakers 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 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) for T3 and T4*

Together with the family of residual current releases previously described, ABB SACE has developed 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 and with Tmax T3 four-pole in fixed 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 re-

sidual 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 moulded-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 with “measurement module”
- PR122/P LSIg and PR332/P LSIg with “measurement module” and Rc rating plug
- PR123/P LSIg and PR333/P LSIg with Rc rating plug.

The releases PR332 and PR333, which provide residual current protection, can be supplied with the circuit-breakers type Tmax T7 (only with PR332), 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 E1 and E2, in three-pole and four-pole version and Emax E3 (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.

These electronic releases for residual current protection

Table 4

|                                                                                                        | RC221                | RC222                           |                                                      | RC223                                                    |
|--------------------------------------------------------------------------------------------------------|----------------------|---------------------------------|------------------------------------------------------|----------------------------------------------------------|
| Circuit-breaker size                                                                                   | T1-T2-T3             | T1-T2-T3                        | T4 and T5 4p                                         | T3-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 <sup>(1)</sup>                                                                 | [V]                  | 85...500                        | 85...500                                             | 110...440                                                |
| Operating frequency                                                                                    | [Hz]                 | 45...66                         | 45...66                                              | 0-1000                                                   |
| Self-supply                                                                                            | ■                    | ■                               | ■                                                    | ■                                                        |
| Test operation range <sup>(1)</sup>                                                                    | 85...500             | 85...500                        | 85...500                                             | 110...500                                                |
| Rated service current                                                                                  | [A]                  | up to 250 A                     | up to 500 A                                          | up to 250 A <sup>(2)</sup>                               |
| Rated residual current trip                                                                            | [A]                  | 0.03 - 0.1 - 0.3<br>0.5 - 1 - 3 | 0.03 - 0.05 - 0.1 - 0.3<br>0.5 - 1 - 3 - 5 - 10      | 0.03 - 0.05 - 0.1<br>0.3 - 0.5 - 1                       |
| Time limit for non-trip                                                                                | [s]                  | instantaneous                   | instantaneous - 0.1 - 0.2<br>- 0.3 - 0.5 - 1 - 2 - 3 | instantaneous - 0 - 0.1 -<br>0.2 - 0.3 - 0.5 - 1 - 2 - 3 |
| 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 <sub>Δn</sub> (tolerance ± 3%)                                      | ■                    | ■                               | ■                                                    | ■                                                        |
| Indication of alarm timing at 75% I <sub>Δn</sub> (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/withdrawable |                      |                                 | ■                                                    | ■ <sup>(3)</sup>                                         |

<sup>(1)</sup> Operation up to 50 V phase-neutral (55 V for RC223)

<sup>(2)</sup> Up to 225 A for T3

<sup>(3)</sup> For T4 only

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] | 3 - 5 - 7 - 10 - 20 - 30                 |
| Tripping times             | [s] | 0.06 - 0.1 - 0.2 - 0.3 - 0.4 - 0.5 - 0.8 |
| 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<br>6 A - 250V AC 50/60 Hz            |
| Residual current relay trip signalling          |                                       | Yellow magnetic flag change-over contacts (NO, NC; NO)<br>6 A - 250 V AC 50/60 Hz |
| Remote opening control                          |                                       | NO contact<br>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 M compact 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)<br>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 (PR222DS/PD), PR223DS and PR223EF 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**

|               |               | $I_4$                                                                                                                                      | $t_4$                                                                               |
|---------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| PR222         | $I^t=k$       | 0.2 – 0.25 – 0.45 – 0.55 – 0.75 – 0.8 – $1 \times I_n$ manual setting<br>0.2... $1 \times I_n$ (step $0.1 \times I_n$ ) electronic setting | 0.1s, 0.2s, 0.4s, 0.8s manual setting<br>0.1...0.8s (step 0.01s) electronic setting |
| PR223         | $I^t=k$       | 0.2... $1 \times I_n$ (step $0.1 \times I_n$ )                                                                                             | 0.1...0.8s (step 0.01s) electronic setting                                          |
| PR331         | $I^t=k - t=k$ | 0.2 – 0.3 – 0.4 – 0.6 – 0.8 – 0.9 – $1 \times I_n$                                                                                         | 0.1s, 0.2s, 0.4s, 0.8s                                                              |
| PR332 – PR333 | $I^t=k - t=k$ | 0.2... $1 \times I_n$ (step $0.02 \times I_n$ )                                                                                            | 0.1...1s (step 0.05s)                                                               |
| PR121         | $I^t=k - t=k$ | 0.2 – 0.3 – 0.4 – 0.6 – 0.8 – 0.9 – $1 \times I_n$                                                                                         | 0.1s, 0.2s, 0.4s, 0.8s                                                              |
| PR122 – PR123 | $I^t=k - t=k$ | 0.2... $1 \times I_n$ (step $0.02 \times I_n$ )                                                                                            | 0.1...1s (step 0.05s)                                                               |

**Figure 1**

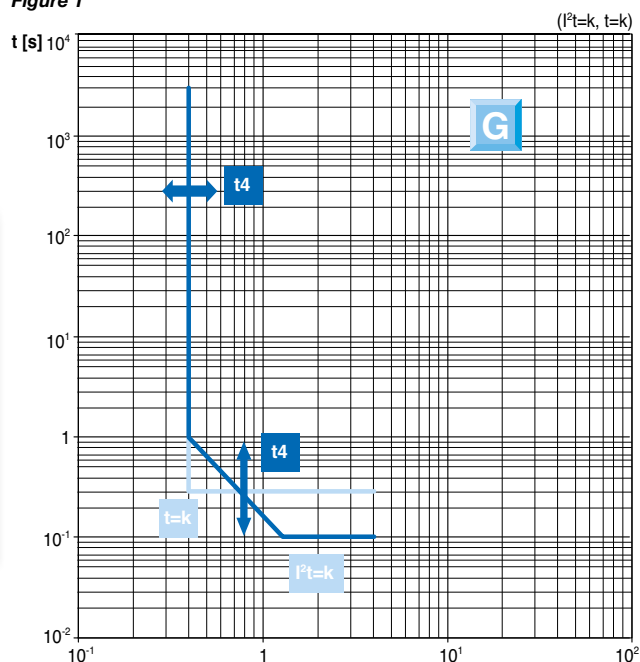


ABB SACE electronic releases have been designed by using microprocessor-based technology. This allows the realization of protection functions guaranteeing high reliability, accuracy of tripping and insensitivity to external environment.

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 contact<sup>1</sup> 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

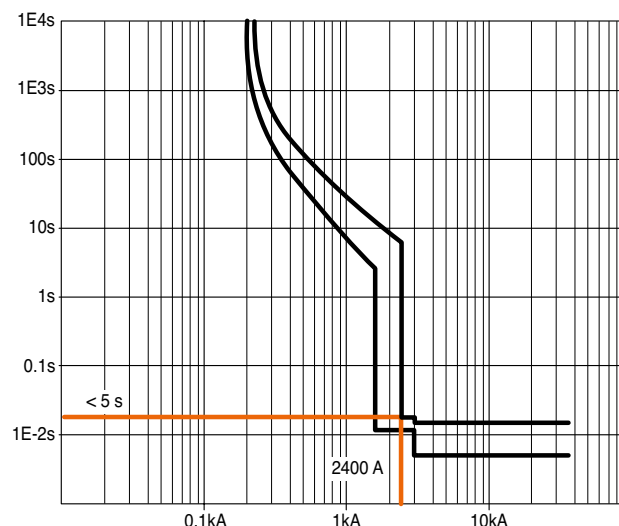
- $U_0$  is the phase to earth supply voltage in volt (230 V);
- 0.8 is a coefficient keeping into account a 80% reduction in the supply voltage due to the effect of the short-circuit current;
- 1.5 is a coefficient keeping into account the increase

- of the resistance value during the short-circuit;
- $\rho$  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 within 5s  $I_a = 2400 \text{ A}$
- tolerance on the tripping current  $\pm 20\%$

Figure 2



From the formula it results:

$$L_{\max} = (0.8 \cdot 230 \cdot 95) / [1.5 \cdot 0.018 \cdot (1 + 95/50) \cdot 2400] = 93 \text{ m}$$

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

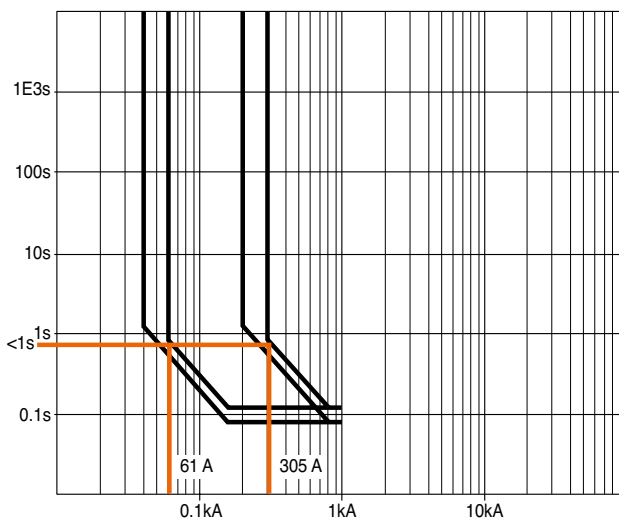
<sup>1</sup> The verification of the maximum protected length results from the relationship for protection against indirect contact in TN systems  $Z_e I_{\Delta} \leq U_0$ , expressed as a function of the cable length. By introducing in the formula the minimum value of current which causes the instantaneous 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 LSiG*

|                                               |                                                |
|-----------------------------------------------|------------------------------------------------|
| rated current                                 | $I_n = 250 \text{ A}$                          |
| setting range of function G                   | $I_a = 50 - 250 \text{ A}$                     |
| tripping current within 5s at minimum setting | $I_a = 61 \text{ A per } I_n = 50 \text{ A}$   |
| tripping current within 5s at maximum setting | $I_a = 305 \text{ A per } I_n = 250 \text{ A}$ |
| tolerance on the tripping current             | $\pm 10\%$                                     |

Figure 3



From the formula it results:

$$L_{\max} = (0.8 \cdot 230 \cdot 95) / [1.5 \cdot 0.018 \cdot (1 + 95/50) \cdot 61] = 3659 \text{ m}$$

with  $I_a = 50 \text{ A}$

and

$$L_{\max} = (0.8 \cdot 230 \cdot 95) / [1.5 \cdot 0.018 \cdot (1 + 95/50) \cdot 305] = 731 \text{ m}$$

with  $I_a = 250 \text{ A}$

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.

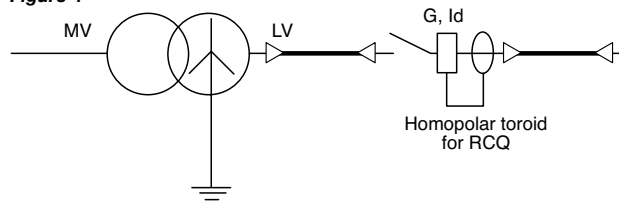
## 6.5 Advanced protection systems against earth fault

### 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:

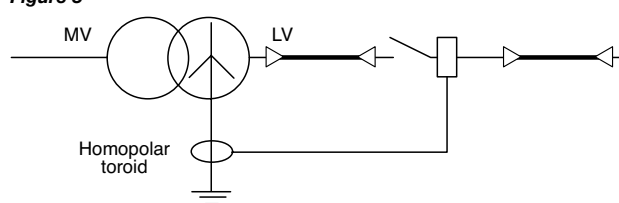
1. The Unrestricted Earth Fault Protection (UEFP) is the protection against the earth faults occurring on the load side of the circuit-breaker terminals at the secondary winding of the transformer. This type of protection (Figure 4), a subject already dealt with in the previous chapters, is obtained 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:

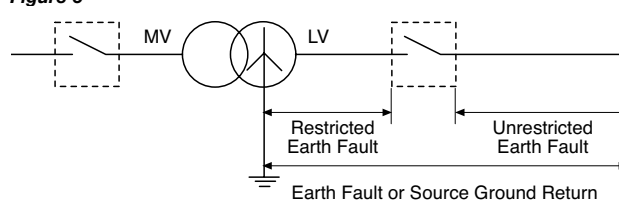
Figure 5



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.

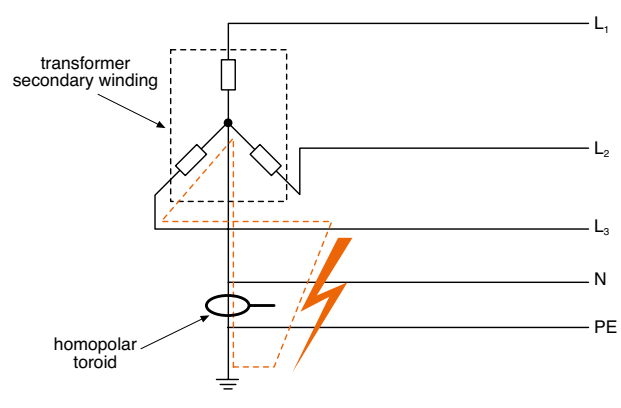
Figure 6



### 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 terminals<sup>1</sup>.

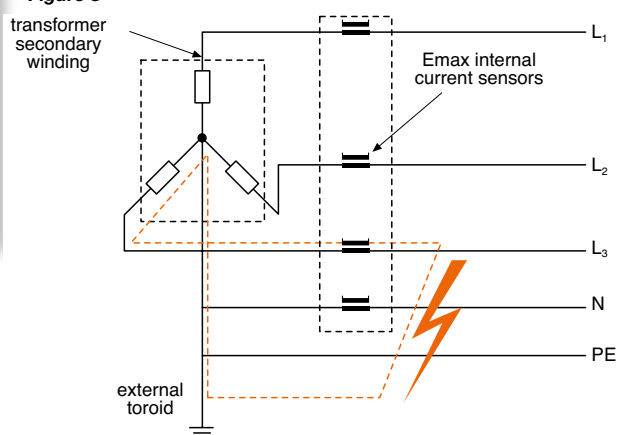
Emax series circuit-breakers equipped with the electronic releases type PR123 and PR333 (Emax X1) allow two independent curves for protection G: one for the internal protection (function G without external toroid) and one

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).

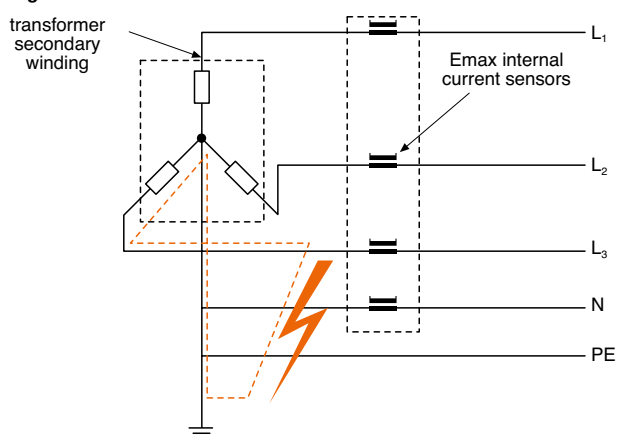
The following figure shows an earth fault on the load side of an Emax circuit-breaker: the fault current flows through one phase only and, if the vectorial sum of the currents detected by the four current transformers (CTs) results to be higher than the set threshold, the electronic release activates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

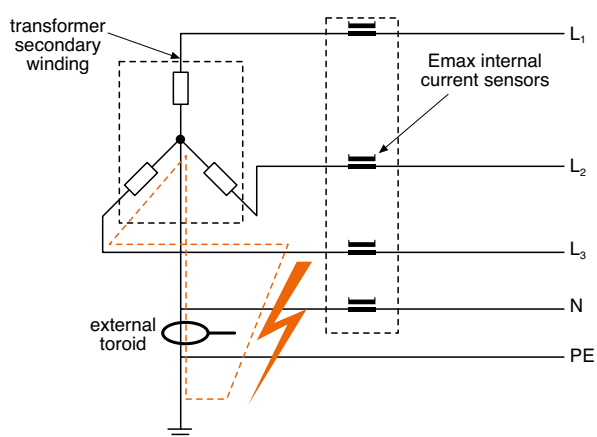
Figure 9



<sup>1</sup> 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.

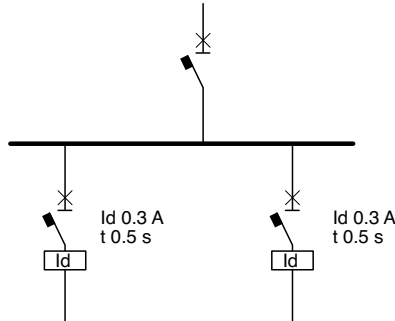
## 7 Discrimination of the protections against earth fault

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:

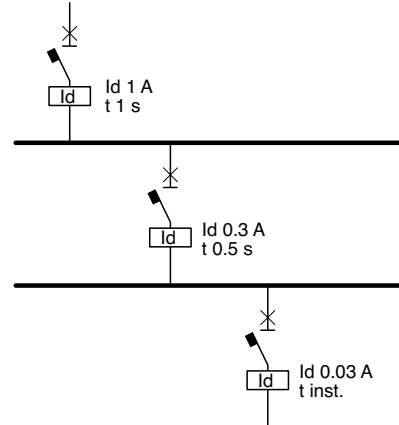
1. horizontal residual current discrimination (Figure 1): it consists in protecting each single line with a residual current circuit-breaker; in this way, in the event of an earth fault, only the outgoing affected by the fault shall be disconnected, since the residual current circuit-breakers are not 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-breakers 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 be-

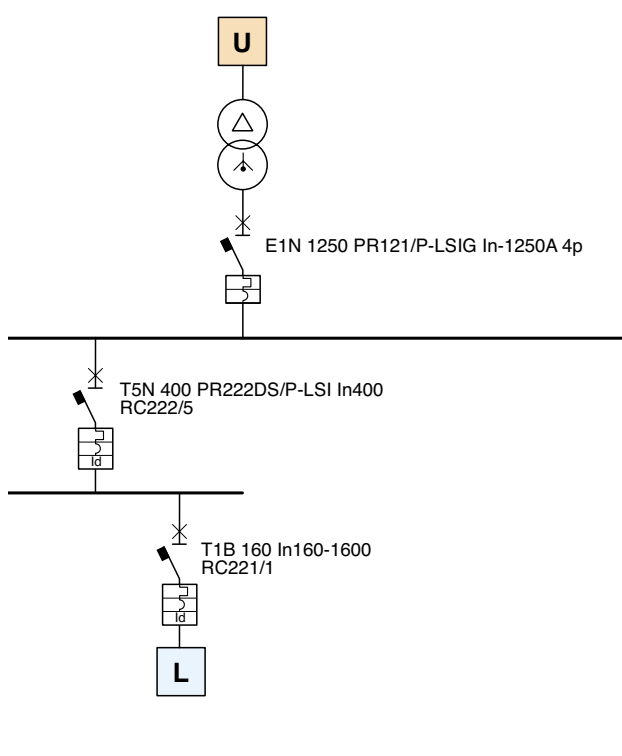
tween two residual current devices in series, the following conditions shall be satisfied:

- 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.

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.

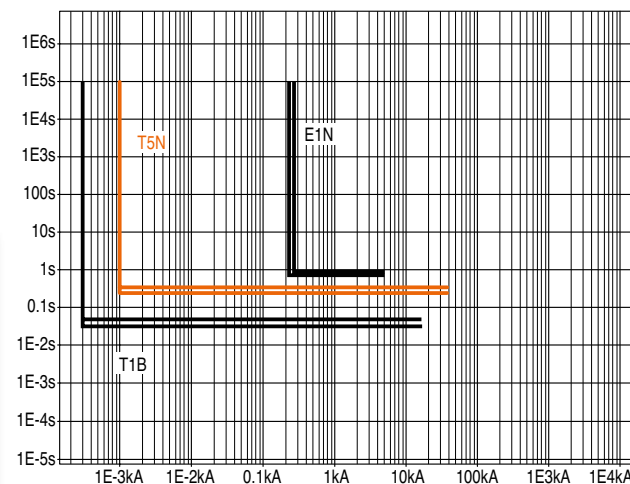
Obviously, the requirement of the Standards shall be verified for each circuit-breaker, as regards protection against indirect contact.

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





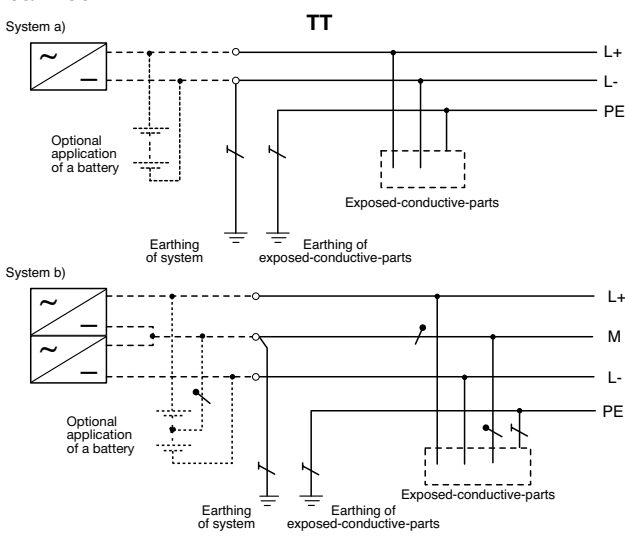
# Annex A

## 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 independent<sup>1</sup> earthing arrangements.

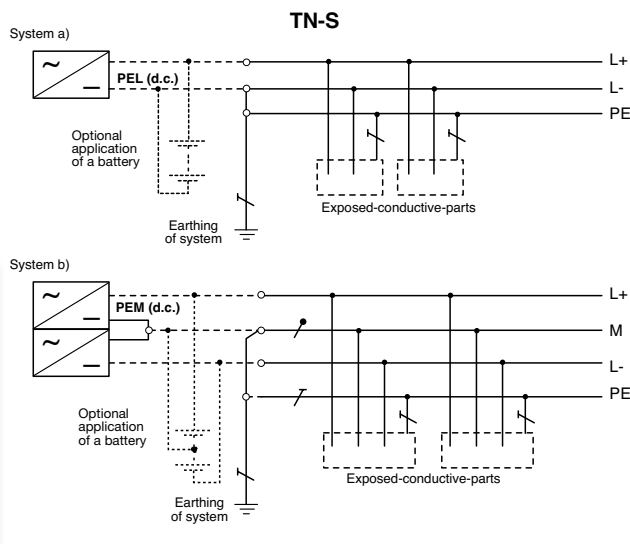
If necessary, the middle point of the supply can be earthed.



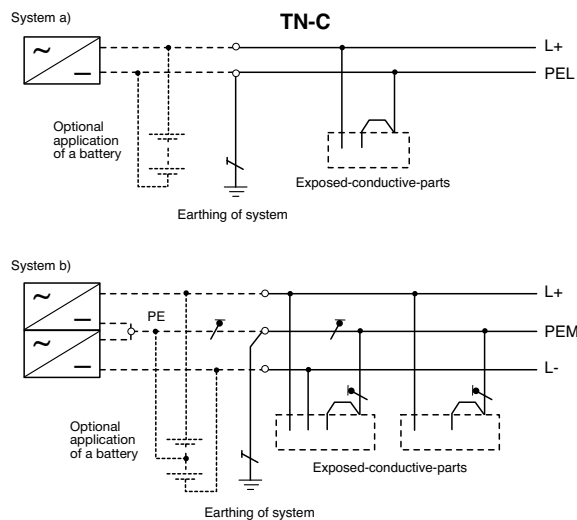
**TN System:** a polarity, or the middle point of the supply, is directly earthed; the exposed-conductive-parts are connected to the same earthed point.

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-S** – the conductor of the polarity connected to earth and the protective conductor PE are separated;

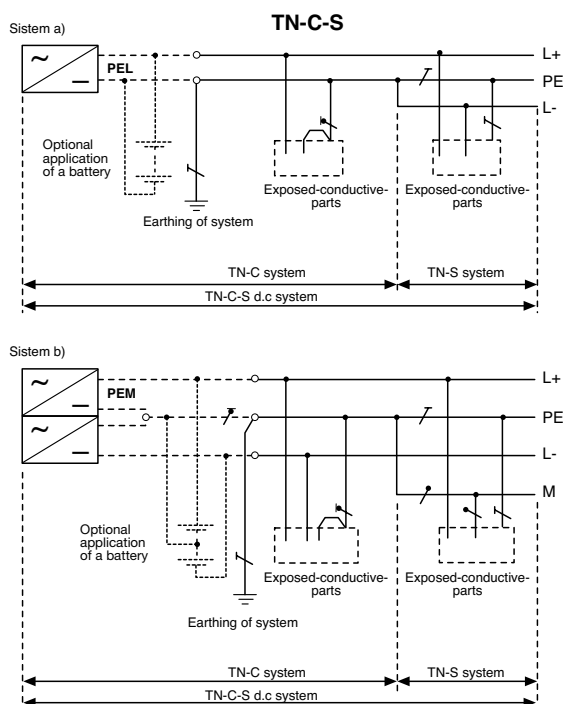


1. **TN-C** – the functions of earthed polarity and protective conductor are combined in a single conductor called PEN



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

### 3. TN-C-S – the functions of earthed polarity and protective conductor are partially combined in a single conductor PEN and partially separated.



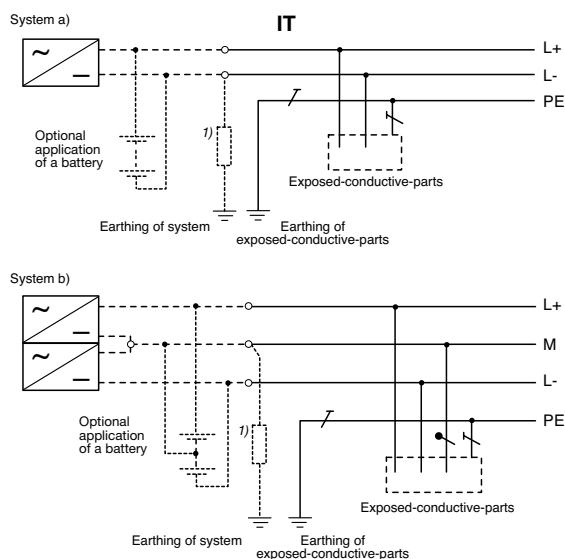
To the purpose of protection against indirect contact, the Standard IEC 60364-4 prescribes that a protective device automatically disconnects the supply to the circuit so that, in the event of a fault between a live part and an exposed-conductive-part or a protective conductor, a prospective touch voltage 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 person<sup>2</sup>.

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.

**IT System:** the supply network is not earthed, whereas the exposed-conductive-parts are earthed



1) The system may be connected to earth via sufficiently high impedance

<sup>2</sup> 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);

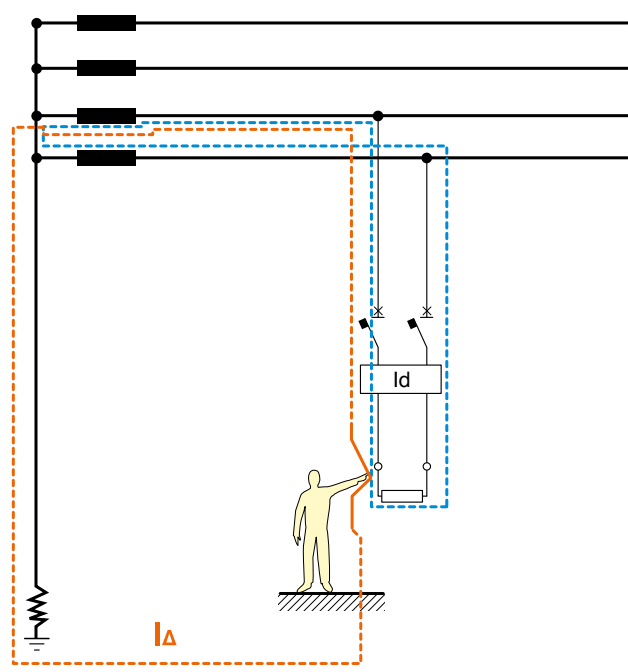
- the use of obstacles intended to prevent unintentional contact with live parts (the protection prevents from unintentionally touching only, but not from intentional one and therefore it is only a partial protection);
- placing live parts out of reach to prevent unintentional contact with these parts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

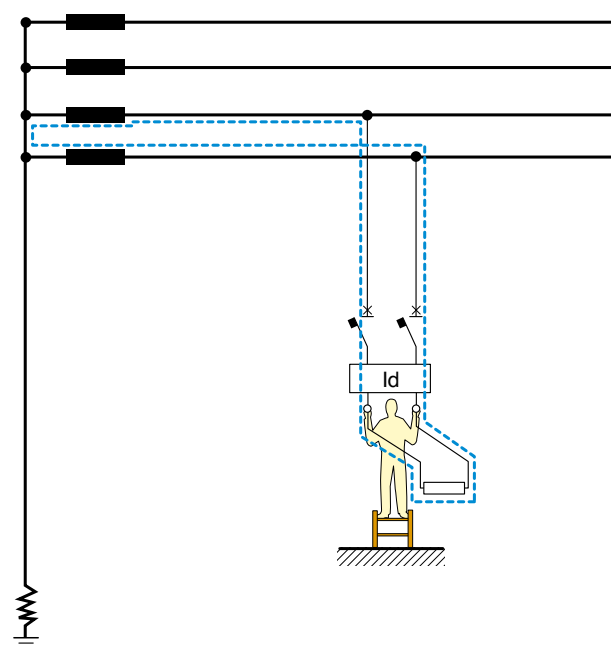


As known, the residual current device operates certainly with  $I_{\Delta} \geq I_{\Delta n}$  (where  $I_{\Delta n}$  is the sensitivity of the residual current device).

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  $I_{\Delta}$  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 double or reinforced insulation;
- protection by provision of a non-conducting location\*;
- protection by earth-free local equipotential bonding\*;
- protection by electrical separation for the supply of only one item of current-using equipment.
- protection by electrical separation for the supply of more than one item of current-using equipment\*.

*Protection by double or reinforced insulation*

\*These are protective measures for application only when the installation is controlled under the supervision of skilled or instructed persons.

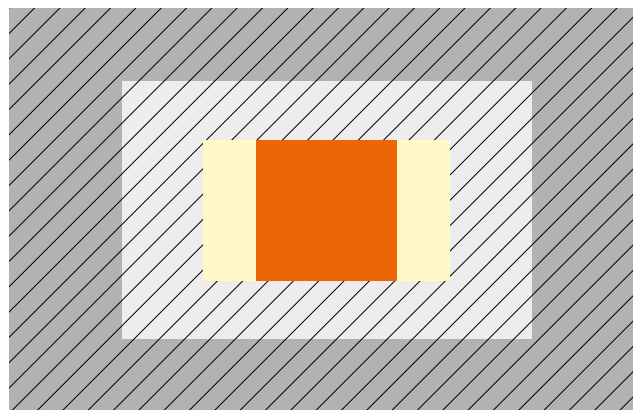
This protection is ensured by using electrical equipment which prevents a dangerous voltage from occurring due to a fault in the basic insulation.

To provide this protective measure it is necessary to use electrical equipment having defined particular features:

- double insulation or reinforced insulation (class II equipment);
- components having an insulation equivalent to Class II equipment (e.g. boards with complete insulation)
- 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.

In addition to the above mentioned equipment, the Standard prescribes the use of enclosures and conductors having particular characteristics; as regards the prescriptions relevant to the above mentioned components reference should be made to the Standard itself.

Figure 1



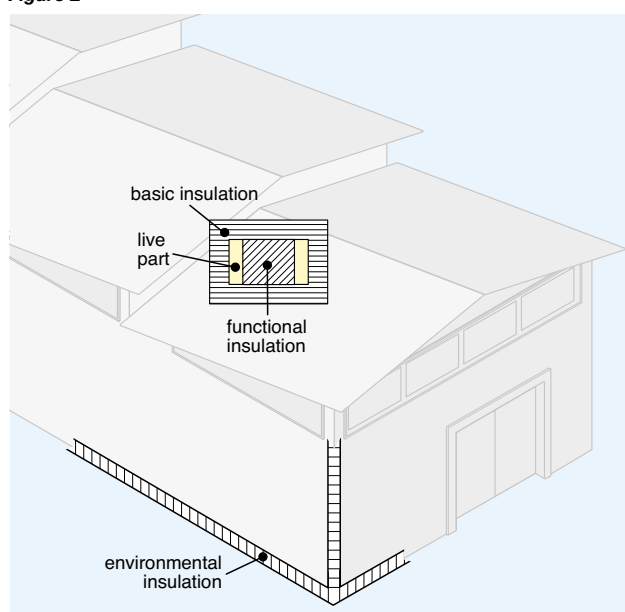
-  = live part
-  = functional isolation: in an electrical device it insulates the parts at different potentials thus enabling operations
-  = basic insulation is the insulation of the normally live parts
-  = supplementary insulation is applied in addition to basic insulation and guarantees insulation in case of a failure of the latter
-  = 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.

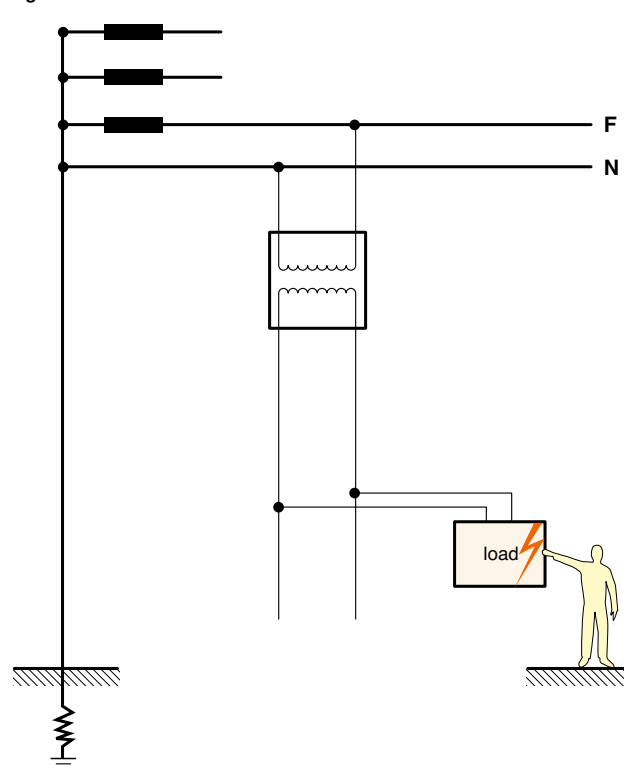
### Protection by electrical separation

Protection by electrical separation, which represents a protective measure against indirect contact, allows limiting the voltage on the human body thanks to the insulation impedance of the earthing system; to make this protective measure effective it is necessary that the separated circuits are properly insulated.

The supply source used to comply with the Standard requirements shall have at least a simple separation with a maximum voltage delivered to the separated circuit not higher than 500V.

It is necessary to pay particular attention to the number of items of current-using equipment supplied by the circuit; in fact, this protective measure is applicable for the supply of more items only when the plant is controlled by or under the supervision of skilled or instructed persons, which is not required for the supply of only one item of current-using equipment.

Figure 3



<sup>1</sup> 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 the protection systems SELV or PELV, there is no hazard of indirect contact since the supply voltage has such a reduced value that it cannot be dangerous for human beings.

As regards direct contact for nominal voltages not exceeding 25V a.c. and 60V d.c., protection is already guaranteed for both types of system and therefore it is not required (however, as regards PELV systems it is necessary that the exposed-conductive-parts and/or the live parts are connected by a protective conductor to the main earthing terminal).

For higher voltages (but however lower than 50V a.c. or 120V d.c.), the protection against direct contact shall be guaranteed by one of the following possibilities:

- using barriers or enclosures with degree of protection not lower than IPXXB or IP2X (for horizontal surface a degree not lower than IPXXN or IP4X);
- covering completely the exposed-conductive-parts with insulation removable only by destruction.

#### *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  $I_{\Delta} \geq I_{\Delta n}$

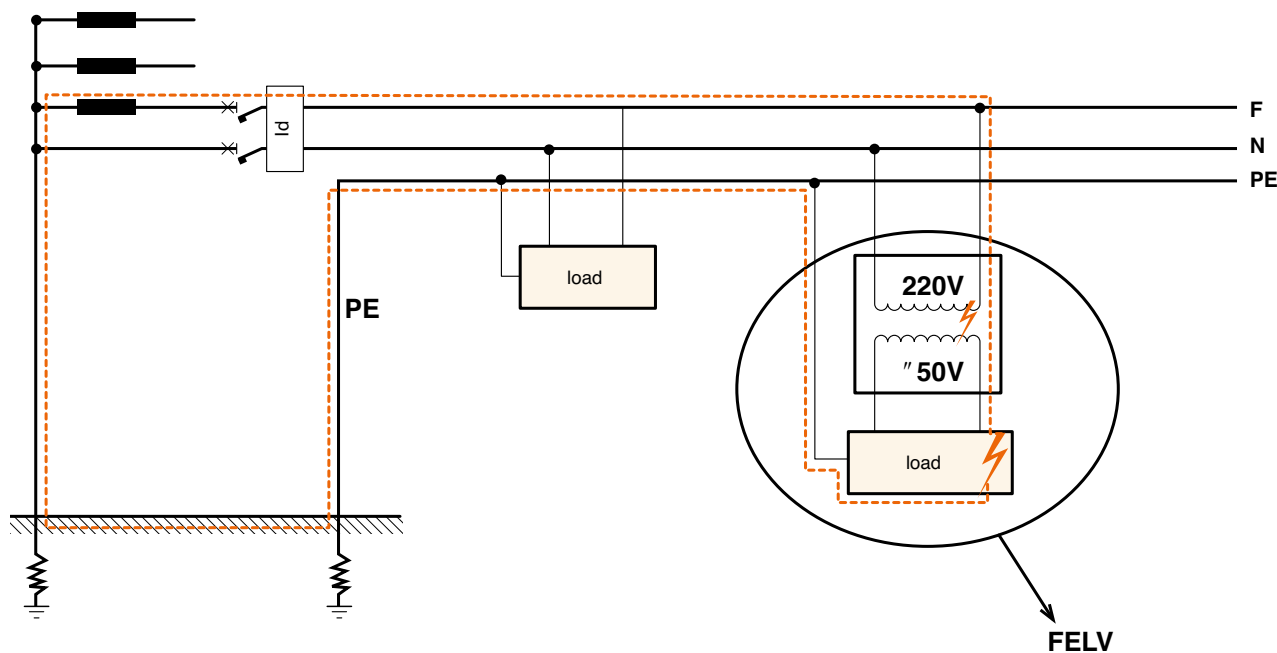
- the exposed-conductive-parts of the FELV circuit are connected to the earth-free equipotential bonding insulated conductor (in a system where protection by electrical separation is provided).

#### 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 system<sup>1</sup> 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

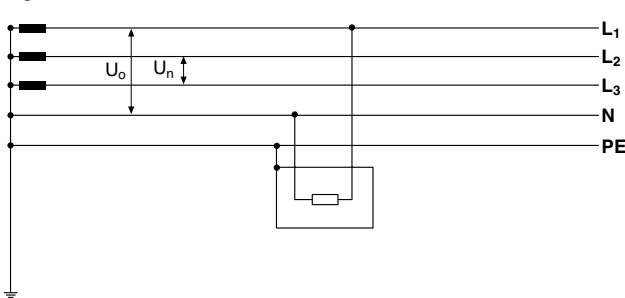
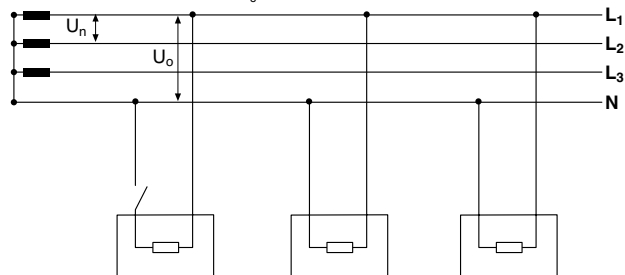


Figure 2

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  $U_n/2$ .

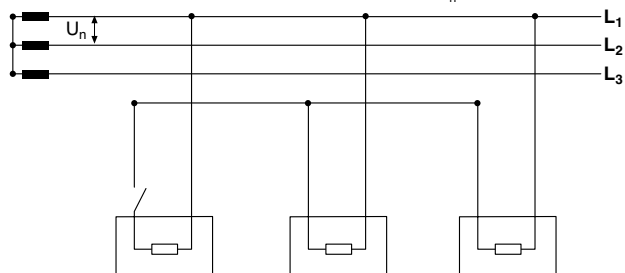
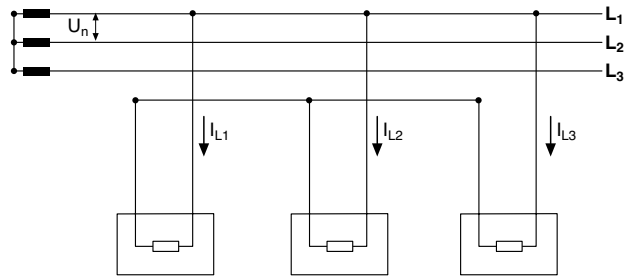


Figure 3

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.

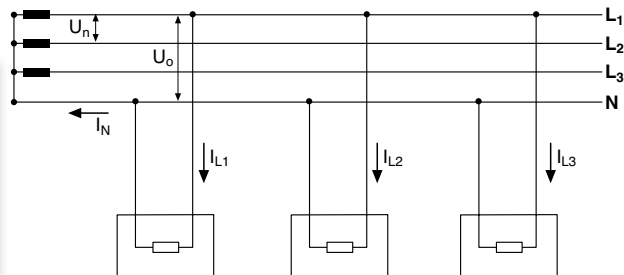
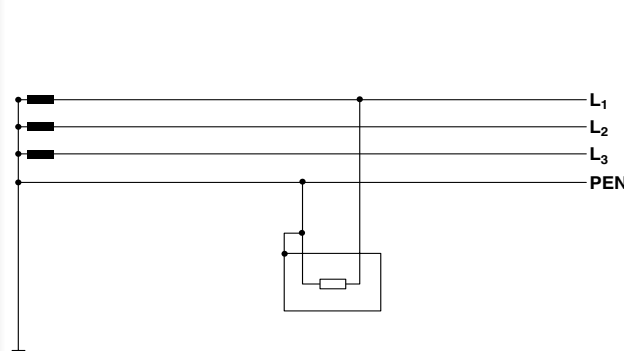


Figure 4

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



<sup>1</sup> 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)<sup>1</sup>;
- 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 conductors 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 distributed<sup>2</sup>, 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:

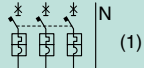
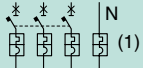
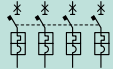
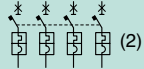
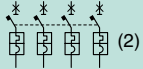
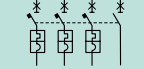
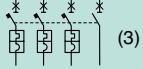
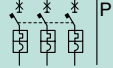
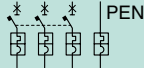
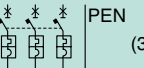
- the neutral conductor is effectively protected against the short-circuits by a protective device placed on the supply side (i.e. located at the origin of the installation);
- the circuit is protected by a residual current device with a rated residual current not exceeding 0.15 times the current-carrying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

<sup>1</sup> TT systems always require that the neutral conductor is disconnected, TN-S systems don't require the neutral conductor is disconnected for three-phase circuit plus neutral.

<sup>2</sup>The Standard advises against the distribution of the neutral in IT systems, see Chapter 5.

Table 1 summarizes the items above.

Table 1

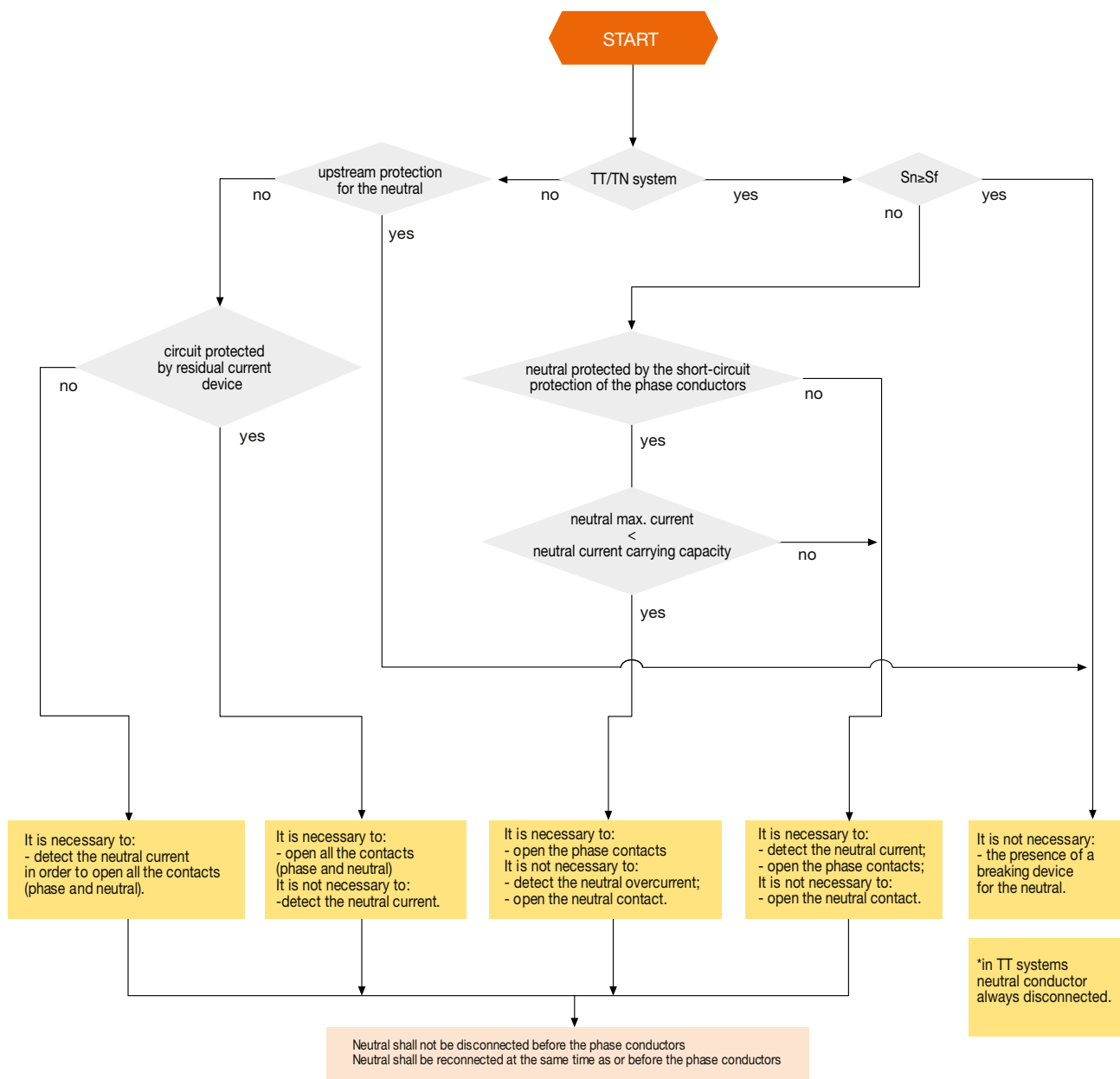
|                       | TT or TN-S systems                                                                      |                                                                                       | TN-C system                                                                         |                                                                                           | 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      | -                                                                                       | -                                                                                     |  |      | -                                                                                    |
|                       | -                                                                                       | -                                                                                     |                                                                                     |  (3) |                                                                                      |
| Phase + PEN           | -                                                                                       | -                                                                                     |  | -                                                                                         |                                                                                      |

(1) minimum requirement prescribed by the installation standards for TN-S systems only, whereas TT systems require the neutral conductor always disconnect

(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 mm<sup>2</sup> in copper or 25 mm<sup>2</sup> 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 16mm<sup>2</sup> with copper cable or 25 mm<sup>2</sup> with aluminum cable, if both the following conditions are met:

- the cross section of the neutral conductor is at least 16 mm<sup>2</sup> for copper conductors and 25 mm<sup>2</sup> 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<br>$S$ [mm <sup>2</sup> ] | Min. neutral cross-section<br>$S_N$ [mm <sup>2</sup> ] |
|---------------------------------------|-----------------------------------------------|--------------------------------------------------------|
| 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                                                     |

<sup>1</sup>in TN-C distribution systems, the Standards prescribe for the PEN conductors the minimum cross section of 10 mm<sup>2</sup> if made by copper and 16 mm<sup>2</sup> 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<br>$S$ [mm <sup>2</sup> ] | Cross-sectional area of the protective conductor<br>$S_{PE}$ [mm <sup>2</sup> ] |
|----------------------------------------------------------------|---------------------------------------------------------------------------------|
| $S \leq 16$                                                    | $S$                                                                             |
| $16 < S \leq 25$                                               | 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 [mm<sup>2</sup>];
- $I$  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·mm<sup>3</sup>];
- $B$  is the inverse of the temperature coefficient of the resistivity at 0° C for the conductor;
- $\rho_{20}$  is the resistivity of the conductor material at 20°C in [Ω·mm];
- $\theta_i$  is the initial temperature of the conductor in [°C];
- $\theta_f$  is the final temperature of the conductor in [°C];
- $\theta_i$  and  $\theta_f$  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:

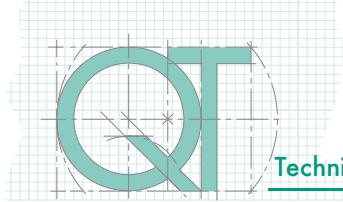
Table 4

| Material | $B$<br>[°C] | $Q_C$<br>[J/°C·mm <sup>3</sup> ] | $\rho_{20}$<br>[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 mm<sup>2</sup> if a mechanical protection is provided
- 4 mm<sup>2</sup> if no mechanical protection is provided.



## Glossary

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



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