Earthing Systems

The 3 earthing systems such as defined in IEC 60364 are:

- exposed-conductive parts connected to neutral **-TN-**;
- earthed neutral **-TT-**;
- Unearthed (or impedance-earthed) neutral **-IT-**.

The purpose of these three systems is identical as regards protection of persons and property. They are considered to be equivalent with respect to safety of persons against indirect contacts. However, the same is not necessarily true for dependability of the LV electrical installation with respect to:

- electrical power availability;
- Installation maintenance.

<u>Direct and indirect contacts</u>

Before beginning to study the earthing systems, a review of Electric Shock by direct and indirect contacts will certainly be useful.

- *Direct contact and protection measures:*

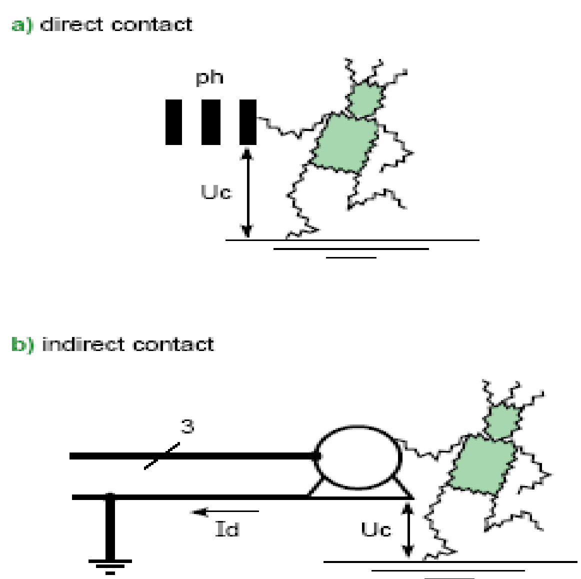
This is accidental contact of persons with a live conductor (phase or neutral) or a normally live conductive element (see figure 2. 3a). In cases where the risk is very great, the common solution consists in distributing electricity using a non-dangerous voltage, i.e. less than or equal to safety voltage. This is safety by extra-low voltage (SELV or PELV). In LV (230/400 V), protection measures consist in placing these live parts out of reach or in insulating them by means of insulators, enclosures or barriers. A complementary measure against direct contacts consists in using instantaneous i= 30 mA High Sensitivity Residual Current Devices known as HS-RCDs.

Treatment of protection against direct contacts is completely independent from the earthing system, but this measure is necessary in all circuit supply cases where implementation of the earthing system downstream is not mastered. Consequently, some countries make this measure a requirement:

- for sockets of rating i 32 A,
- in some types of installations (temporary, worksite, etc.).

- *Indirect contact, protection and prevention measures*

Contact of a person with accidentally energized metal frames is known as indirect contact (see figure 2. 3b). This accidental energizing is the result of an insulation fault. A fault current flows and creates a potential rise between the frame and the earth, thus causing a fault voltage to appear which is dangerous if it exceeds voltage UL. As regards this hazard, the installation standards (IEC 364 at international level) have given official status to three earthing systems and defined the corresponding installation and protection rules.



Earthing systems and protection of persons

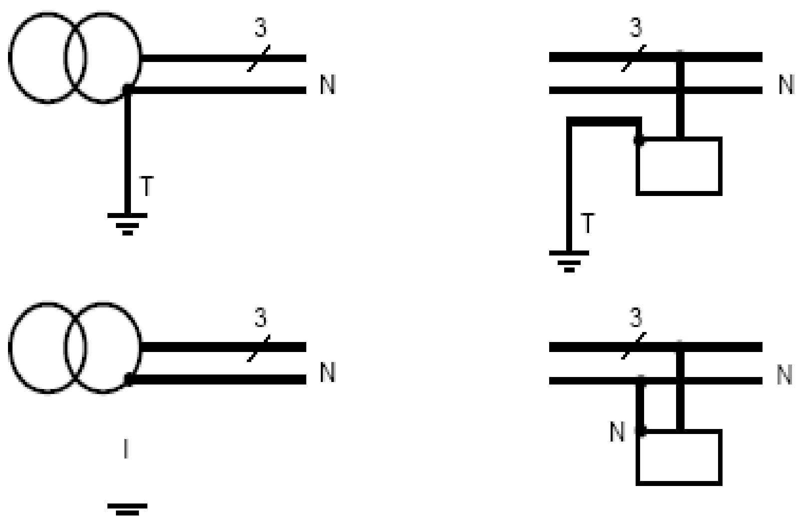
The LV earthing system characterizes the earthing mode of the secondary of the MV/LV transformer and the means of earthing the installation frames. Each earthing system can be applied to an entire LV electrical installation; however several earthing systems may be included in the same installation.

Identification of the system types is thus defined by means of 2 letters:

- the first one for transformer neutral connection:
  - T for "connected" to the earth,
  - I for "isolated" from the earth;
- the second one for the type of application frame connection:
  - T for "directly connected" to the earth,
  - N for "connected to the neutral" at the origin of the installation, which is connected to the earth (see figure 2.5).

Combination of these two letters gives three possible configurations:

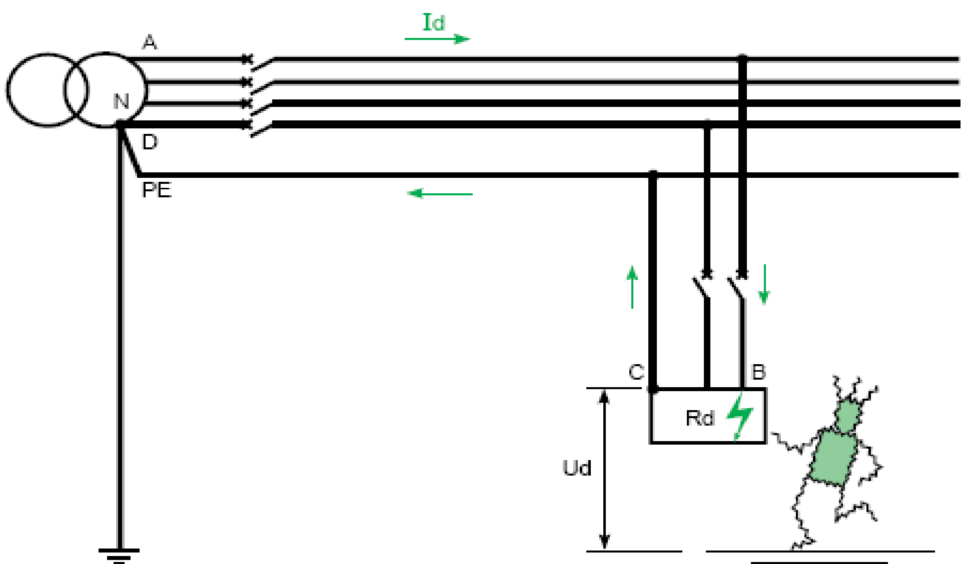
- TT: transformer neutral earthed, and frame earthed,
- TN: transformer neutral earthed, frame connected to neutral,
- IT: unearthed transformer neutral, earthed frame.



1. TN system

When an insulating fault is present, the fault current Id is only limited by the impedance of the fault loop cables:

$Id = Vo / (R_{ph1}+R_d+ R_{PE})$



$$Ud \approx \frac{0.8\,Uo}{2} \text{ if } R_{PE} = Rph \text{ and } Rd = 0$$

$$Id = \frac{Uo}{R_{AB} + Rd + R_{CD}} \Rightarrow \frac{0.8\,Uo}{Rph + R_{PE}}$$

Fault current and voltage in TN system.

As the insulation fault occurs, a phase-neutral short-circuit breaking is achieved by the Short-Circuit Protection Device (SCPD) with a maximum specified breaking time depending on V_L.

To be sure that the protection device really is activated, the current Id must be greater than the operating threshold of the protection device Ia (Id > Ia) irrespective of where the fault occurs. This condition must be verified at the installation design stage by calculating the fault currents for all the distribution circuits.

To guarantee this condition, another approach consists in imposing a maximum impedance value on the fault loops according to the type and rating of the SCPDs chosen. This approach may result in increasing the cross-section of the live and/or protective conductors.

Another means of checking that the device will ensure protection of persons is to calculate the maximum length not to be exceeded by each feeder for a given protection threshold Ia.

$$Id = \frac{0.8\ Uo}{Z} = \frac{0.8\ Uo}{Rph + R_{PE}} = \frac{0.8\ Uo\ Sph}{\rho\ (1+m)\ L}$$

For the protection device to perform its function properly, Ia must be less than Id, hence the expression of Lmax, the maximum length authorised by the protection device with a threshold Ia:

$$Lmax = \frac{0.8\ Uo\ Sph}{\rho\ (1+m)\ Ia}$$

- Lmax: maximum length in m;
- Uo: phase-to-neutral voltage 230 V for a threephase 400 V network;
- ρ: resistivity to normal operating temperature;
- Ia: automatic breaking current:
  - for a circuit-breaker Ia = Im (Im operating current of the magnetic or short time delay trip release),
  - for a fuse, current such that total breaking time of the fuse (prearcing time + arcing time) complies with the standard

$$m = \frac{Sph}{S_{PE}}$$

If the line is longer than Lmax, either conductor cross-section must be increased or it must be protect protected using a Residual Current Device (RCD).

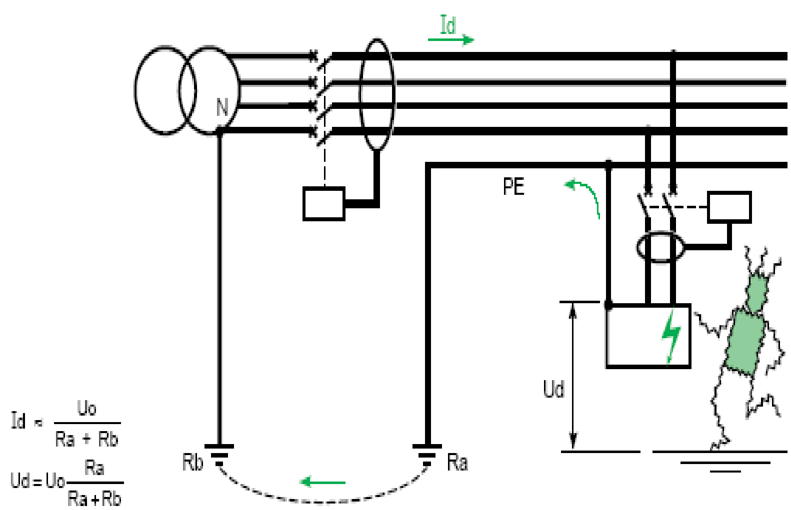
2. TT system

When an insulation fault occurs, the fault current Id (see figure 2.10) is mainly limited by the earth resistances (if the earth connection of the frames and the earth connection of the neutral are not associated). Still assuming that Rd = 0, the fault current is:

Id = 0.8Uo / (Ra + Rb)

This fault current induces a fault voltage in the earth resistance of the applications:

$$U_d = R_a I_d, \text{ or } U_d = \frac{U_o R_a}{R_a + R_b}$$



Fault current and voltage in TT system.

As earth resistances are normally low and of the same magnitude (=10 Ω), this voltage of the order of Uo/2 is dangerous. The part of installation affected by the fault must therefore be automatically disconnected.

As the fault current beyond which a risk is present $\left(I_{d_o} = \frac{U_L}{R_a} \right)$ is far lower than the settings of the overcurrent protection devices, at least one RCD must be fitted at the supply end of the installation. In order to increase availability of electrical power, use of several RCDs ensures time and current discrimination on tripping.

All these RCDs will have a nominal current threshold $I_{\Delta n}$ less than Id0. The standard stipulates that de-energising by the RCDs must occur in less than 1 s.

Note that protection by RCD:

- does not depend on cable length;
- authorises several separate Ra earth connections (an unsuitable measure since the PE is no longer a unique potential reference for the entire installation).

3. IT system

The neutral is unearthed, i.e. not connected to the earth. The earth connections of the frames are normally interconnected (just like the TN and TT earthing systems).

In normal operation (without insulation fault), the network is earthed by the network leakage impedance. In order to properly set the potential of a network in IT with respect to the earth, we advise that you place an impedance (Zn=1,500Ω) between transformer neutral and the earth.... this is the IT impedance-earthed system.

<u>Behavior on the first fault</u>

- **Unearthed neutral:**

The fault current is formed as follows (maximum value in the case of a full fault and neutral not distributed).

If = $I_{c1} + I_{c2}$, where:

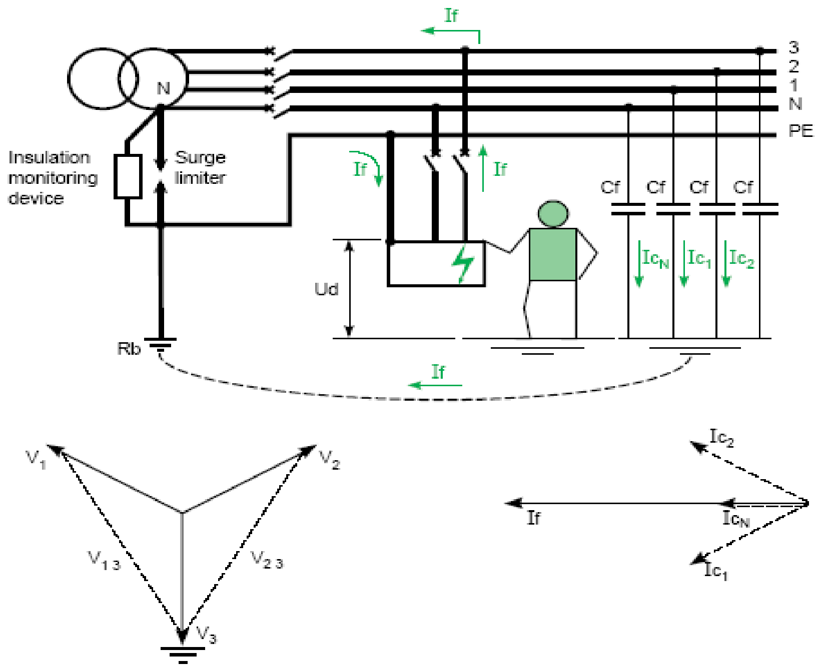
$I_{c1} = j\, C_f\, \omega\, V_{13}$, $I_{c2} = j\, C_f\, \omega\, V_{23}$, $Id = Uo_3\, C_f\, \omega$.

For 1 km of 230/400V network, the fault voltage will be equal to:

Uc = Rb Id, i.e. 0.7 V if Rb = 10 Ω.

This voltage is not dangerous and the installation can thus be kept in operation.

If the neutral is distributed, the shift of neutral potential with respect to the earth adds a current $I_{cn} = Uo\, C_f\, \omega$ and $Id = Uo_4\, C_f\, \omega$.



First insulation fault current in IT system.

- **Impedance earthed neutral:**

First fault current:

$$Id = \frac{U}{Zeq} \text{ where}$$

$$\frac{1}{Zeq} = \frac{1}{Zn} + 3j\ Cf\ \omega$$

The corresponding fault voltage is still low and not dangerous; the installation can be kept in operation. Although risk-free continuity of service is a great advantage, it is necessary:

- to know that there is a fault,

- to track it and eliminate it promptly, before a second fault occurs.

To meet this need:

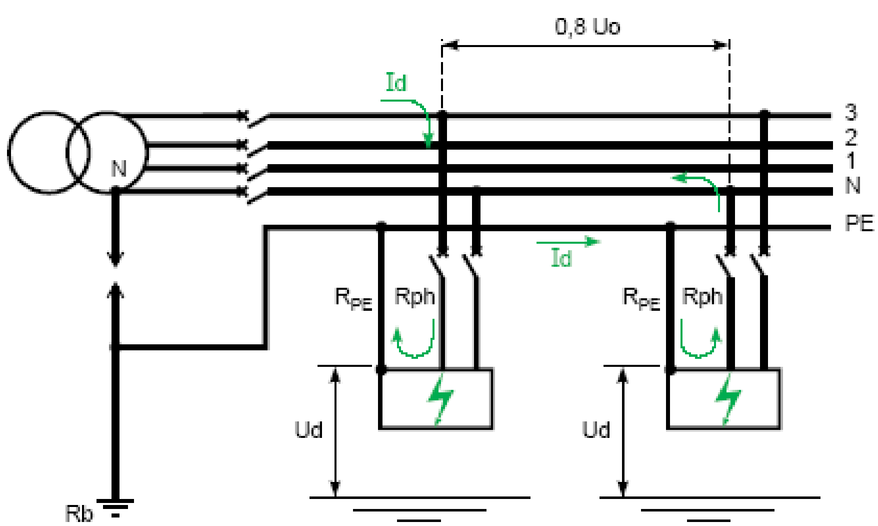
- the fault information is provided by an Insulation Monitoring Device (IMD) monitoring all live conductors, including the neutral,

- locating is performed by means of fault trackers.

Behavior on the second fault

When a second fault occurs and the first fault has not yet been eliminated, there are three possibilities:

- the fault concerns the same live conductor: nothing happens and operation can continue,
- the fault concerns two different live conductors: if all the frames are inter-connected, the double fault is a short-circuit (via the PE). The Electric Shock hazard is similar to that encountered with the TN system. The most unfavorable conditions for the SCPDs (smallest Id) are obtained when both faults occur on feeders with the same characteristics (cross-sections and lengths).



$$Id \approx \frac{0.8\ Uo}{2\ (R_{PE} + Rph)} \qquad Ud \approx \frac{0.8\ Uo}{2}$$

2nd insulation fault current in IT system (distributed neutral).

The SCPDs have to comply with the following relationships:

- If the neutral is distributed and one of the two faulty conductors is the neutral:

$$Ia \leqslant \frac{0.8\ Uo}{2\ Z}$$

- or if the neutral is not distributed:

$$Ia \leqslant \frac{0.8\ Uo\ \sqrt{3}}{2Z}$$

Note that if one of the two faults is on the neutral, the fault current and fault voltage are twice as low as in the TN system. This has resulted in standard makers authorizing longer SCPD operating times. Just as in the TN earthing system, protection by SCPD only applies to maximum cable lengths:

- Distributed neutral:

$$Lmax = \frac{1}{2} \frac{0.8\, Uo\, Sph}{\rho\, (1+m)\, Ia}$$

- Non-distributed neutral:

$$Lmax = \frac{\sqrt{3}}{2} \frac{0.8\, Uo\, Sph}{\rho\, (1+m)\, Ia}$$

This is provided that the neutral is protected and its cross-section equal to phase cross section...This is the main reason why certain country standards advise against distributing the neutral.

- Case where all frames are not interconnected.

For frames earthed individually or in groups, each circuit or group of circuits must be protected by a RCD. In point of fact, should an insulation fault occur in groups connected to two different earth connections, the earthing system's reaction to the insulation fault (Id, Ud) is similar to that of a TT system (the fault current flows through the earth). Protection of persons against indirect contacts is thus ensured in the same manner Note that in view of the times specified by the standard, horizontal time discrimination can be achieved to give priority to continuity of service on certain feeders.

In order to protect LV unearthed networks (IT) against voltage rises (arcing in the MV/LV transformer, accidental contact with a network of higher voltage, lightning on the MV network), standard stipulates that a surge limiter must be installed between the neutral point of the MV/LV transformer and the earth (Rb).