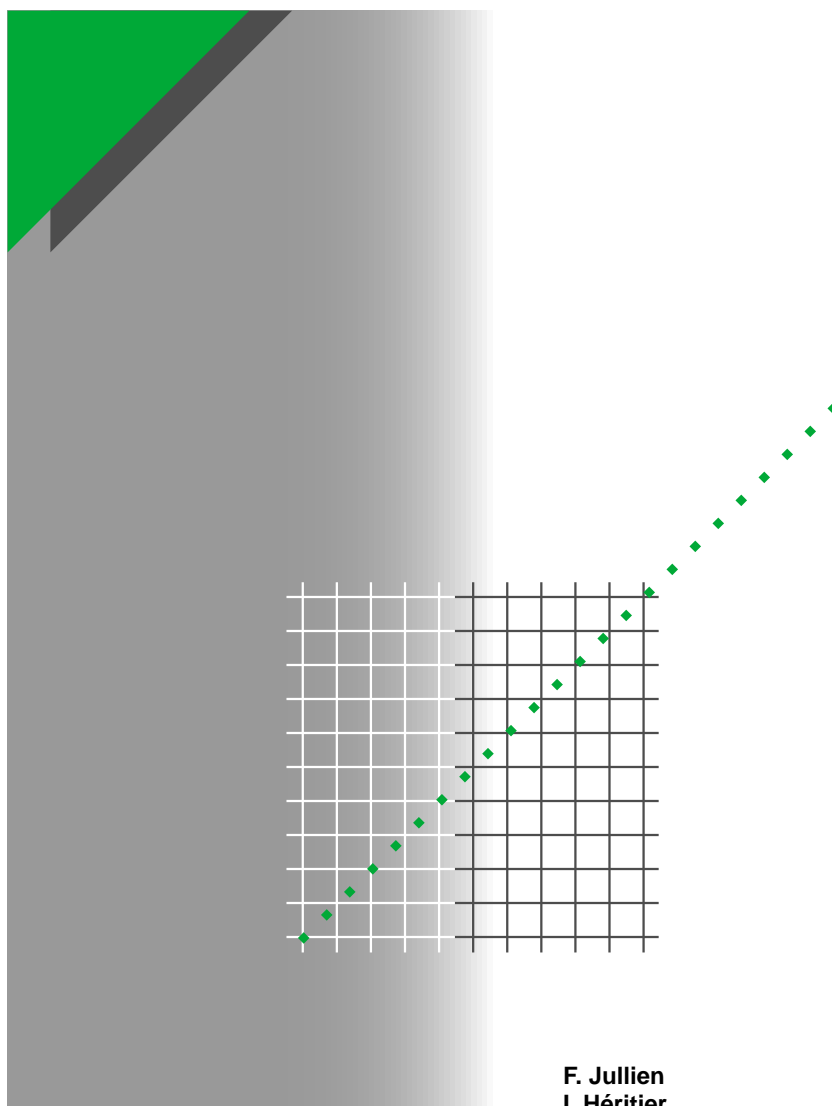


Cahier technique no. 178

## The IT earthing system (unearthed neutral) in LV



Merlin Gerin

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Telemecanique

F. Jullien  
I. Héritier

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### **Foreword**

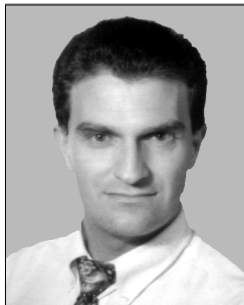
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# no. 178

## The IT earthing system (unearthed neutral) in LV

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## Lexicon

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**BB:** busbar.

**C1** for phase 1, **C2** for phase 2, and **C3** for phase 3: earthing impedance capacitive components for each phase.

**C<sub>R</sub>:** network overall capacity (leakage capacities of cables and filters if any).

**I<sub>C</sub>:** capacitive current.

**I<sub>d</sub>:** fault current flowing in the earth connection resistance  $R_A$  of the application frame.

**I<sub>fu</sub>:** fuse blowing current within a maximum time stipulated by standards.

**I<sub>m</sub>:** short time delay (magnetic or electronic) tripping current (threshold) of a circuit-breaker.

**I<sub>N</sub>:** capacitive current flowing through the earthed neutral connection, in particular through the impedance  $Z_N$ , when present.

**L:** length of faulty circuits.

**m:** ratio of live conductor/protective conductor cross-section ( $S_a / S_{pe}$ ).

$\rho$ : resistivity of copper.

**R<sub>a</sub>:** resistance of the live conductor (phase or neutral) of the circuit where the fault occurred.

**R<sub>A</sub>:** resistance of the earth connection of the application frames.

**R<sub>B</sub>:** resistance of the neutral earth connection.

**RCD:** Residual Current Device.

**R<sub>d</sub>:** fault resistance.

**R<sub>pe</sub>:** resistance of the PE protective conductor.

**R1** for phase 1, **R2** for phase 2, and **R3** for phase 3: earthing impedance resistive components of each phase.

**S<sub>a</sub>:** live conductor cross-section.

**SCPD:** Short-Circuit Protection Device.

**S<sub>pe</sub>:** protective conductor cross-section.

**U<sub>C</sub>:** contact voltage between the frame of a faulty device and another frame or the earth.

**U<sub>0</sub>:** phase to neutral voltage.

**U<sub>L</sub>:** limit safety voltage (24 V) not to be exceeded between the frame of a device and another frame or the earth.

**U<sub>n</sub>:** nominal voltage or phase-to-phase voltage ( $U_1, U_2, U_3$ ), equal to  $\sqrt{3} U_0$  for a three-phase electrical circuit.

**U<sub>r</sub>:** network voltage.

**Z<sub>N</sub>:** additional impedance connected between the neutral point of a network in the IT earthing system and the earth.

**Z<sub>R</sub>:** overall impedance of a network with respect to the earth, made up of the capacitive components **C1**, **C2**, **C3** and the resistive components **R1**, **R2**, **R3**.

# The IT earthing system (unearthed neutral) in LV

Although all Earthing Systems offer users the same degree of safety, they do not all have the same operating characteristics.

This is why, in certain countries, a specific earthing system is stipulated by legislation or standards according to buildings. For example, in France the IT system is compulsory in hospital operating theatres, and the TN-C is forbidden in premises where there is a risk of explosion.

These stipulations apart, dependability objectives (safety, availability, reliability, maintainability and proper operation of low current communication systems) determine which earthing system should be chosen for which installation.

The aim of this “Cahier Technique” is to describe the advantages and areas of application of the IT earthing system.

After a brief introduction of the electrical hazard and the various earthing systems, the first fault situations, followed by the double fault specific to the IT system, are studied, and the advantages and disadvantages of this particular earthing system are developed. This “Cahier Technique” also offers solutions for the surge limiter with the various types of possible overvoltages.

Finally, a choice table is provided for all earthing systems, based on criteria for safety, availability, electromagnetic compatibility and operators’ professional requirements.

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# 1 Introduction

## 1.1 Protection of persons against electric shocks

Use of Safety by Extra Low Voltage (< 25 V) -SELV- is the most drastic solution since it eliminates the electrical hazard. However it is applicable only in low power distribution.

Regarding everyday use of electricity, a number of studies have identified the causes of electric shocks and provided specific solutions for each one.

Electric shocks have two causes, namely:

- direct contact, i.e. a person or an animal touching an exposed live conductor;
- indirect contact, i.e. a person touching the metal frame of an electrical load on which an insulation fault has occurred.

### Protection against direct contact

To provide protection against direct contact, insulation and/or distancing measures are taken.

These measures can be reinforced in final distribution by additional protection in the form of a high sensitivity Residual Current Device (RCD).

### Protection against indirect contact

With respect to protection against indirect contact, between an accidentally energised frame and the earth, the basic solution is to earth all the load frames via the protective conductors. However, this measure does not rule out the existence of a contact voltage hazardous for persons if it exceeds the conventional limit safety voltage  $U_L$  defined by standard IEC 60479. This contact voltage depends on the earthing systems defined in the international standard IEC 60364.

## 1.2 The various standardised earthing systems

The three earthing systems given official status by international standards (IEC 60364) are also stipulated by a large number of national standards: in France by the LV installation standard: NF C 15-100.

A brief reminder of the protection principle of these systems will now be given before describing the IT system in greater detail.

### The TN system

- Its principle:
  - the transformer neutral is earthed;
  - the electrical load frames are connected to neutral.

This type of system has three possibilities:

- the same conductor acts as a neutral and a protective conductor: this is the TN-C system;
- the neutral and the protective conductor are separate: this is the TN-S system;

- and the combination of these two systems, known as TN-C-S when the neutral and the protective conductor are separated downstream of part of the installation in the TN-C system. Note that the TN-S cannot be placed upstream of the TN-C.

- Its operation (see **fig. 1**):

An insulation fault on a phase becomes a short-circuit and the faulty part is disconnected by a Short-Circuit Protection Device (SCPD).

### The TT system

- Its principle:
  - the transformer neutral is earthed;
  - the electrical load frames are also earthed.

- Its operation (see **fig. 2**):

The current of an insulation fault is limited by earth connection impedance.

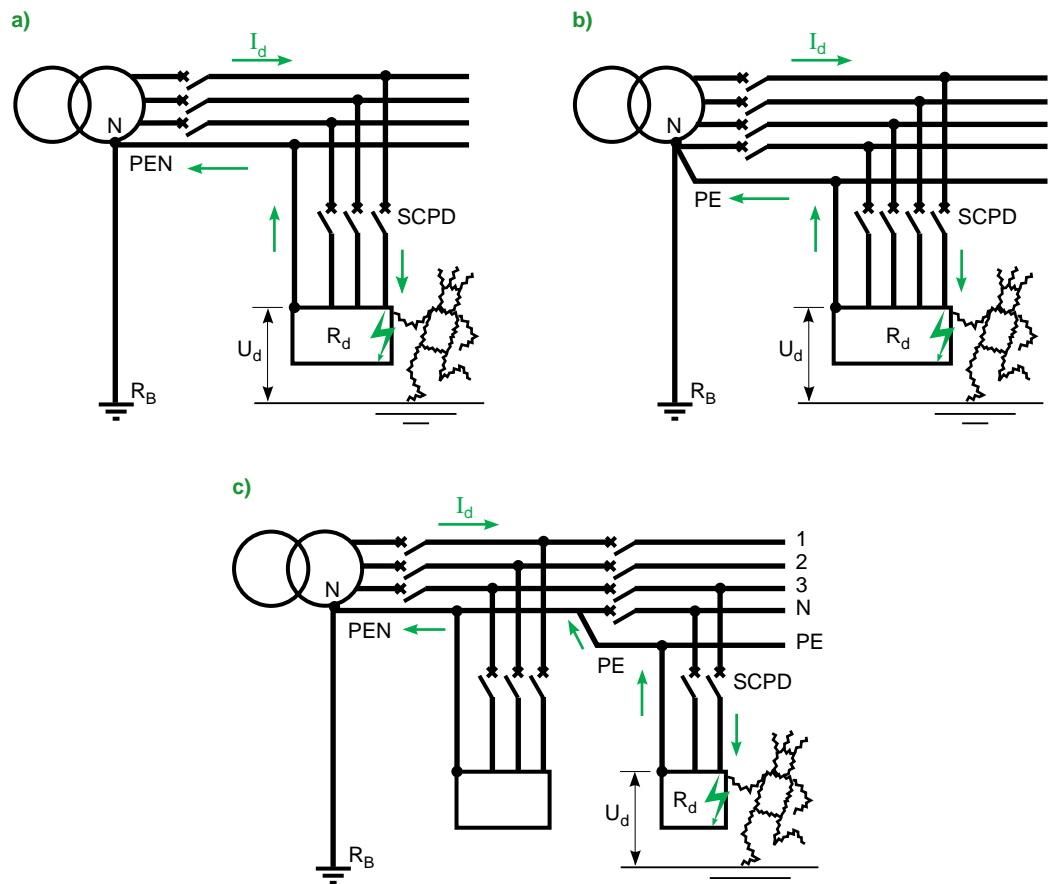


Fig. 1 : insulation fault on a network operated in TN-C [a], TN-S [b] and TN-C-S [c].

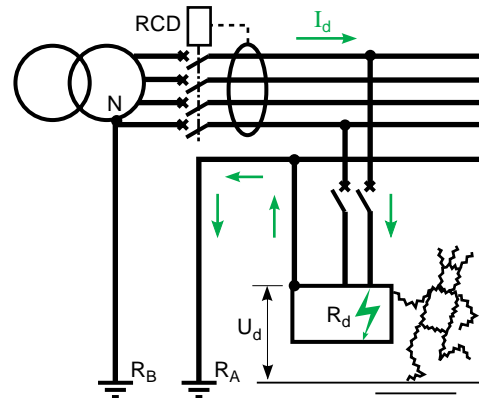


Fig. 2 : insulation fault on a network operated in IT.

Protection is provided by the Residual Current Devices (RCD): the faulty part is disconnected as soon as the threshold  $I\Delta n$ , of the RCD placed upstream, is overshoot by the fault current, so that  $I\Delta n R_B \leq U_L$ .

### The IT system

■ Its principle:

- the transformer neutral is not earthed, but is theoretically unearthed. In actual fact, it is naturally earthed by the stray capacities of the network cables and/or voluntarily by a high impedance of around  $1,500 \Omega$  (impedance-earthed neutral);
- the electrical load frames are earthed.

■ Its operation:

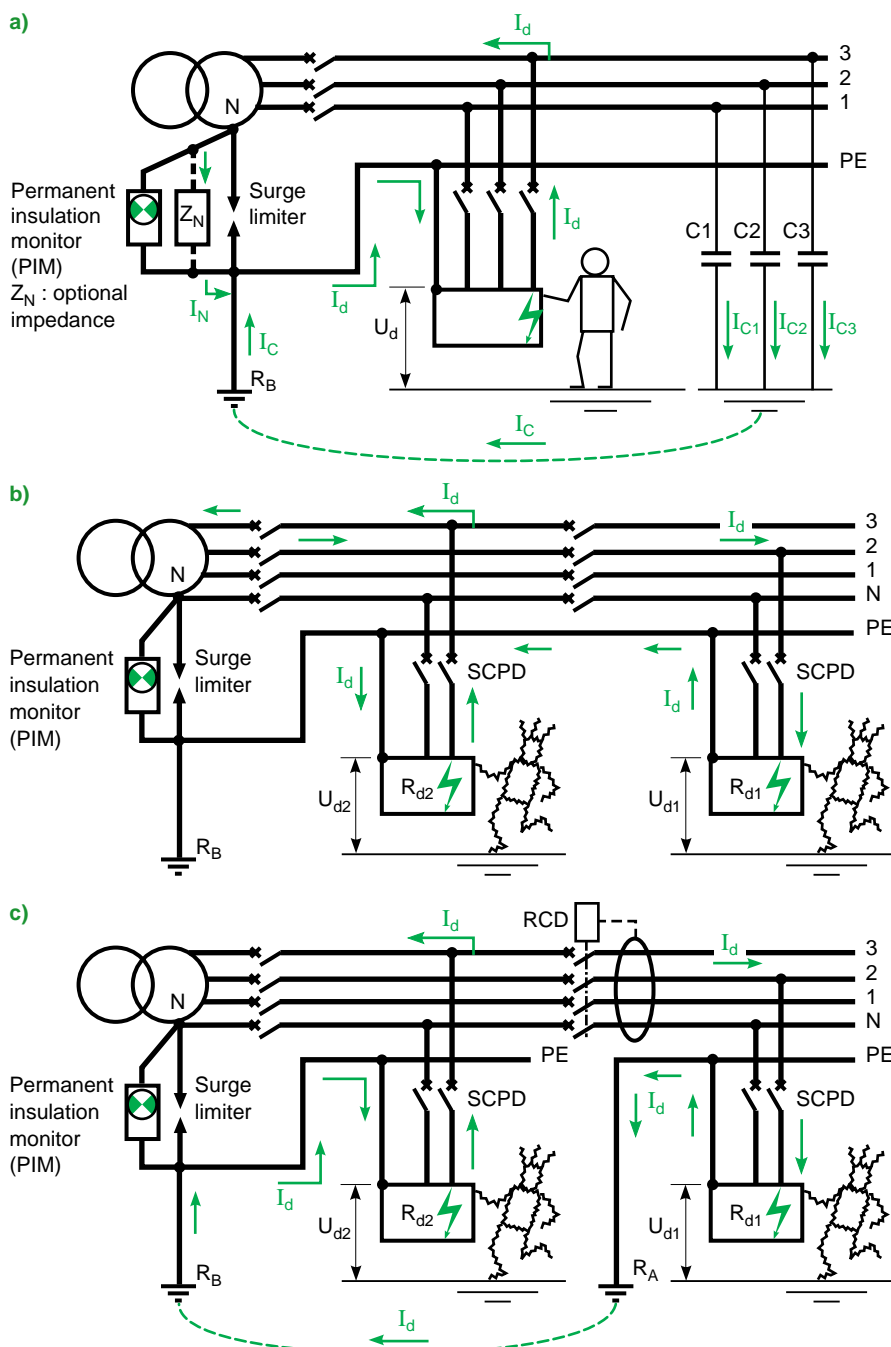
□ should an insulation fault occur, a low current develops as a result of the network's stray capacities (see **fig. 3a**).

The contact voltage developed in the frame earth connection (no more than a few volts) is not dangerous;

□ if a second fault occurs on another phase before the first fault has been eliminated (see **fig. 3b** and **3c**), the frames of the loads in question are brought to the potential developed

by the fault current in the protective conductor (PE) connecting them. The SCPDs (for the frames interconnected by the PE) or the RCDs (for the frames with separate earth connections) provide the necessary protection.

This deliberately brief presentation of the various earthing systems clearly cannot cover all the specific installation possibilities. Readers requiring more details can consult "Cahiers Techniques" no. 114, 172 and 173.



**Fig. 3 :** single [a] and double [b and c] insulation fault on a network operated in IT.



## 1.3 Choosing an earthing system

Although all three earthing systems offer users the same degree of safety against indirect contact, only the IT system guarantees risk-free continuity of supply in the presence of an insulation fault.

This undeniable advantage also has certain drawbacks: for example the need to locate this first fault and the possibility of overvoltages occurring that may affect operation of sensitive loads.

However, choice of earthing system for an installation also depends on parameters other than safety of persons and continuity of supply, namely:

- the environment (e.g. premises with a risk of fire or sites frequently struck by lightning);
- electromagnetic compatibility (EMC) (presence in the installation of harmonics and radiating

fields, and sensitivity of equipment to such phenomena);

- technicality of installation designers and operators;
- maintenance quality and cost;
- network size;
- etc.

Although consideration of the above parameters guarantees choice of the earthing system most suited to the installation, it should be emphasised that the advantage offered by the IT system in terms of availability (2<sup>nd</sup> fault most unlikely) generates installation and operating costs that should be compared with the downtime costs generated by other earthing systems (operating losses and repair costs caused by the first insulation fault).

## 1.4 Type of insulation

### Common mode impedance

All electrical networks have an impedance with respect to earth known as the "common mode impedance", the origin of which is insulation of network cables and loads. This impedance consists of the leakage capacity and resistance between each live conductor and the earth.

In LV, the leakage resistance of a new cable is around 10 M $\Omega$  per kilometer and per phase, whereas its capacity evenly distributed with respect to earth is approximately 0.25  $\mu$ F, i.e. 12.7 k $\Omega$  at 50 Hz.

It should also be noted that in MV and HV this leakage capacity is even greater and MUST be taken into account when drawing up a protection plan (see "Cahier Technique" no. 62).

Loads also have a natural leakage capacity, usually negligible.

### Effect of distributed capacity in the IT system

In electrical installations, other capacities are added to the network cable ones. This is the case of certain electronic loads that are generators of HF harmonic currents, in particular when they use the chopper principle (e.g. pulse

with modulation converters). However, ElectroMagnetic Compatibility (EMC) standards state that these HF currents must be shunted to earth, resulting in the presence of filters and thus capacitors between phases and frame. According to the number of loads, their contribution to the network's "leakage" capacity can be significant or even important. Measurements taken on a variety of electrical power networks show that capacity varies considerably from network to network and covers a range of a few  $\mu$ F to a few dozen  $\mu$ F.

Excessively high capacities may question the advantage of the IT earthing system: if, on the first fault, the value of network impedance with respect to earth means that contact voltage exceeds 50 V, safety of persons is not guaranteed. This is rare, however, as with a 10  $\Omega$  earth connection, the network's earth leakage capacity must exceed 70  $\mu$ F (23  $\mu$ F per phase if the neutral is not distributed).

An IT network must therefore have a limited capacity with respect to earth, and the presence of loads equipped with HF filters must be taken into account in the network design stage.

## 1.5 Equivalent system for a network with unearthed or impedance-earthed neutral

A few definitions and assumptions are given below in order to define the equivalent system for this network (see **fig. 4**):

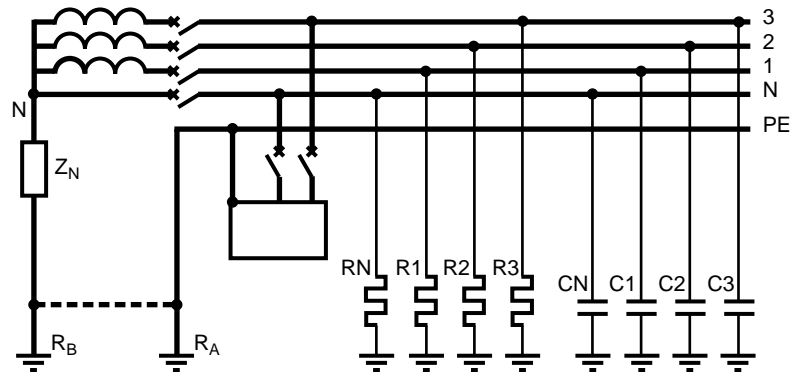
- the neutral point is unearthed or earthed by an impedance ( $Z_N$ ) of high value (normally 1 k $\Omega$  to 2 k $\Omega$ ) whose earth connection is equivalent to a resistance ( $R_B$ );
- the load frames are interconnected either fully or by group. For EMC reasons (see "Cahier Technique" no. 187), it is advisable to

interconnect all the application frames of the same installation and to connect them to the same earth connection (resistance  $R_A$ );

- the earth connections ( $R_A$  and  $R_B$ ) are interconnected (in most cases), or separate.

**NB:** Two earth connections are considered to be separate if they are more than 8 m apart;

- each live conductor has, with respect to earth, an impedance made up of a resistance and a capacity.



**Fig. 4** : equivalent system of a network with unearthed or impedance-earthed neutral.

## 2 The 1<sup>st</sup> insulation fault with the IT earthing system

In normal operating conditions, safety of persons is guaranteed when contact voltage is less than 50 V as per standard IEC 60364 (NF C 15-100). When this contact voltage is exceeded, these

standards require automatic opening of the circuit. The following section shows how use of the IT earthing system for network operation prevents tripping on the first insulation fault.

### 2.1 Calculating fault currents and contact voltage on the first fault

#### General case (resistive fault)

Should a fault with a resistive value  $R_d$  occur between phase 3 and the earth, a fault current  $I_d$  flows in the neutral impedance and in the capacities  $C_1$ ,  $C_2$  and  $C_3$  (see fig. 3a).

Assuming that the phase-to-earth capacities are balanced ( $C_1 = C_2 = C_3 = C$ ), the fault current has the following value:

$$I_d = U_0 \frac{1 + 3j C \omega Z_N}{R_d + Z_N + 3j C \omega Z_N R_d}$$

The capacitive current is written as:

$$I_c = U_0 \frac{3j C \omega Z_N}{R_d + Z_N + 3j C \omega Z_N R_d}$$

and the current in the impedance  $Z_N$ :

$$I_N = \frac{U_0}{R_d + Z_N + 3j C \omega Z_N R_d}$$

The contact voltage  $U_C$  (contact voltage between the frame of a faulty device and another frame or the earth) is calculated from the fault current  $I_d$  flowing in the earth connection resistance  $R_A$  of the application frames if they are not interconnected, else  $R_B$  (only network earth connection):

$$U_C = R_A I_d.$$

#### Case of the full fault

This paragraph calculates the configuration generating the highest contact voltage ( $U_C$ ): thus for a fault occurring on a frame with earth connection separate from that of  $Z_N$ . By application of the above formulae, where  $R_d = 0$ , we obtain:

$$I_d = \frac{U_0}{Z_N + 3j C \omega}$$

$$U_C = R_A \frac{U_0}{Z_N + 3j C \omega}$$

The capacitive current is equal to:

$$I_c = +3j C \omega U_0$$

and the current in impedance  $Z_N$ :

$$I_N = \frac{U_0}{Z_N}$$

In the various examples below, studied for  $Z_N = \infty$  (unearthed neutral) and  $Z_N = 1 \text{ k}\Omega$

(impedance-earthed neutral), the calculations are made for a network in the IT system, 400 VAC ( $U_0 = 230 \text{ V}$ ), where:

$R_A$ , earth connection resistance =  $10 \text{ }\Omega$

$R_d$ , insulation fault value = 0 to  $10 \text{ k}\Omega$ .

#### ■ Case 1:

Low capacity network (e.g. limited to an operating theatre)

$C_1 = C_2 = C_3 = C = 0.3 \text{ }\mu\text{F}$  per phase.

#### ■ Case 2:

Power network, where

$C_1 = C_2 = C_3 = C = 1.6 \text{ }\mu\text{F}$  per phase.

#### ■ Case 3:

Very long power network, where

$C_1 = C_2 = C_3 = C = 10 \text{ }\mu\text{F}$  per phase, i.e. roughly 40 km of cables!

The results of all these calculations, grouped in the table in **figure 5**, confirm the low fault voltage ( $\approx 20 \text{ V}$  in the most unfavourable cases), ensuring continuity of operation, without risk for persons, of a network designed using the IT system. They prove that addition of an impedance between the neutral and the earth has very little effect on contact voltage.

$R_d \text{ (k}\Omega\text{)}$			0	0.5	1	10
<b>Case 1</b>	$Z_N = \infty$	$U_C \text{ (V)}$	0.72	0.71	0.69	0.22
		$I_d \text{ (A)}$	0.07	0.07	0.07	0.02
	$Z_N = 1 \text{ k}\Omega$	$U_C \text{ (V)}$	2.41	1.6	1.19	0.21
		$I_d \text{ (A)}$	0.24	0.16	0.12	0.02
<b>Case 2</b>	$Z_N = \infty$	$U_C \text{ (V)}$	3.61	2.84	1.94	0.23
		$I_d \text{ (A)}$	0.36	0.28	0.19	0.02
	$Z_N = 1 \text{ k}\Omega$	$U_C \text{ (V)}$	4.28	2.53	1.68	0.22
		$I_d \text{ (A)}$	0.43	0.25	0.17	0.02
<b>Case 3</b>	$Z_N = \infty$	$U_C \text{ (V)}$	21.7	4.5	2.29	0.23
		$I_d \text{ (A)}$	2.17	0.45	0.23	0.02
	$Z_N = 1 \text{ k}\Omega$	$U_C \text{ (V)}$	21.8	4.41	2.26	0.23
		$I_d \text{ (A)}$	2.18	0.44	0.23	0.02

**Fig. 5** : comparison of fault currents and contact voltages on a first fault.

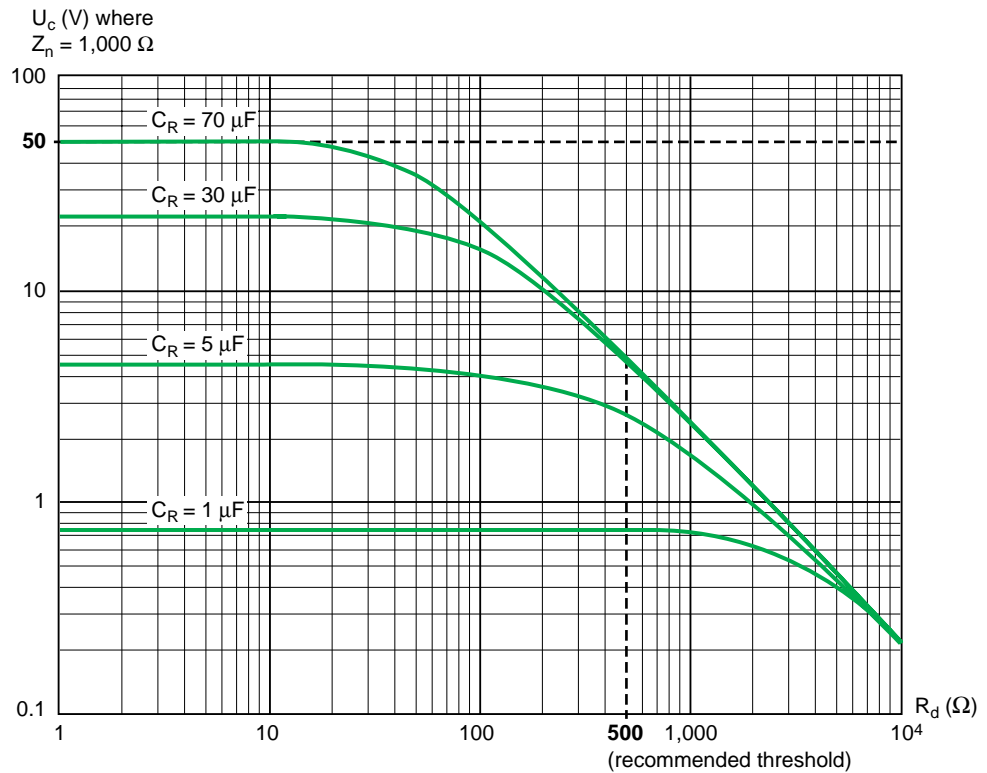
The curves in **figure 6** representing these results show the considerable effect of network capacity on the value of  $U_C$ .

In point of fact, regardless of the distributed capacity of the sound network or network on which a first fault has occurred, users can be certain that this voltage will always be less than the conventional safety voltage and thus without risk for persons. Also, the currents of a first full fault are low and thus have minimum destructive or disturbing (EMC) effect.

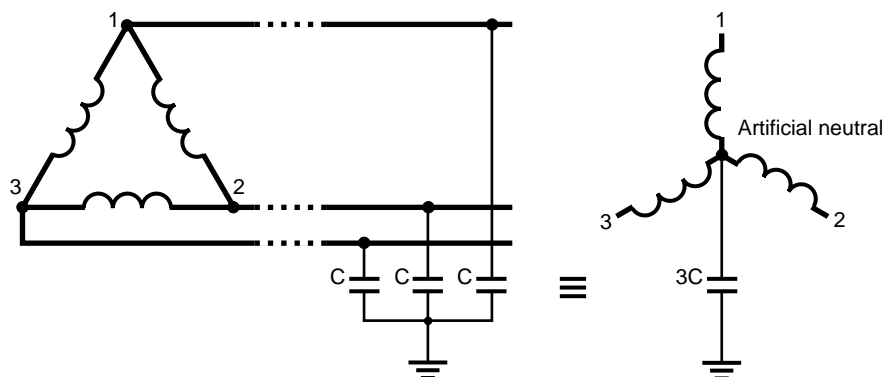
### Effect of distributed capacities, vector chart and neutral potential

#### ■ Effect of distributed capacities on a sound network

The capacities of all 3 phases create an artificial neutral point. In the absence of an insulation fault, if network capacities are balanced, this neutral point is then at earth potential (see **fig. 7**). In the absence of a fault, the phase-to-earth potential is thus equal to phase to neutral voltage for each phase.



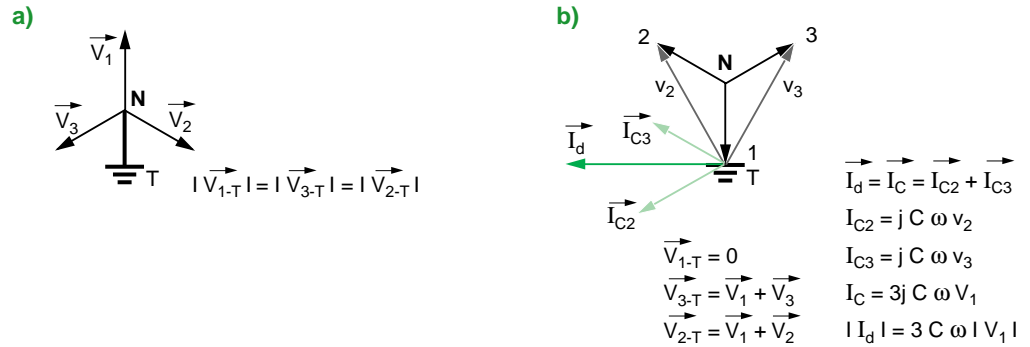
**Fig. 6 :** contact voltage on a first insulation fault is always less than safety voltage.



**Fig. 7 :** the network's distributed capacities create a connection between neutral and earth.

■ Vector chart in presence of a full fault  
 In event of a full fault on phase 1, the potential of phase 1 is at earth potential (see **fig. 8**). The neutral-to-earth potential is thus equal to phase to neutral voltage  $V_1$ , and that of phases 2 and 3 with respect to earth is equal to phase-to-phase voltage. If the neutral is

distributed, the fault current is arithmetically increased:  
 $I_C = 4j C \omega V_1$ .  
 However, detection, location and correction of this fault must be immediate in order to reduce the risk of a second simultaneous fault occurring which would result in opening of the faulty circuits.



**Fig. 8 :** vector charts of a network in the IT system, without fault [a] and with an earth fault on phase 1 [b].

## 2.2 Permanent insulation monitors, history and principles

The first LV electrical distribution networks were operated using the IT earthing system. Operators rapidly sought to detect the presence of the first insulation fault in order to prevent the hazards linked to a short-circuit current of varying impedance and the de-energisation of a faulty feeder (with the lowest rating protection) or of the two faulty feeders.

### The first PIMs

These devices used 3 lamps connected between the phases and the earth (see **fig. 9**).

On a sound network, the three lamps form a balanced three-phase load, all lit and with the same brilliance. When an insulation fault occurs, one of the three lamps is short-circuited by the fault impedance. Voltage is reduced at the

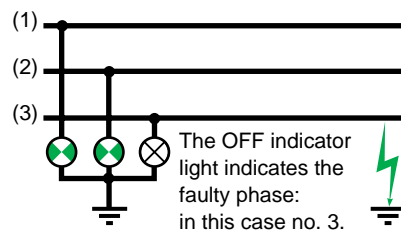
terminals of this lamp, and lamp brilliance decreases. However, voltage at the terminals of the other two lamps increases until phase-to-phase voltage is reached. Their luminosity also increases.

This system is easy to install and use. However, given that its practical operating threshold is low, attempts were quickly made to try to detect impedant faults in order to anticipate the full fault.

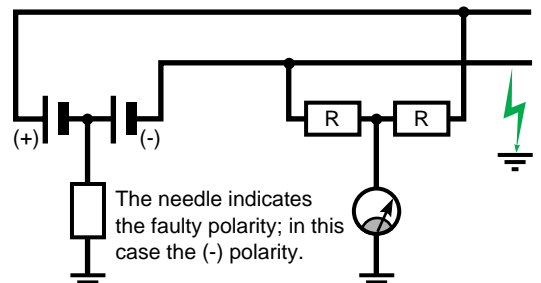
### For a DC network

(supplied by batteries or by DC generator).

The technique of the voltmeter balance (see **fig. 10**) was the first to be used, and indeed is still used today.



**Fig. 9 :** principle of the first PIM.



**Fig. 10 :** principle of the PIM with voltmeter balance.

The principle consists of measuring and comparing voltages between the (+) polarity and the earth, on the one hand, and the (-) polarity and the earth on the other. This principle makes auxiliary power sources unnecessary, since the network supplies the PIM directly via measurement sensors (resistances).

This technique applies to two-phase AC and DC networks and does not allow live fault tracking.

#### For AC networks

The most commonly used PIM are those with insulation measurement by DC current injection. Permanent measurement of insulation resistance required use of active systems in place of the previously used passive systems. This resistance can be measured accurately in DC (see **fig. 11**), which is why the first PIMs, placed between the network and the earth, injected a low DC current which flowed through the fault. This simple, reliable technique is still extensively used today, but does not allow live fault tracking.

Note that when these PIMs are used on mixed networks (containing rectifiers without galvanic insulation), they may be disturbed or even

“blinded” if a fault is present on the DC part of the network.

These were followed by PIMs with AC current injection at low frequency (< 10 Hz), operating on the same principle. Although these PIMs allow live fault tracking, they can be “misled” by cable capacities that are seen as insulation faults and disturbed by frequency converters (variable speed controllers).

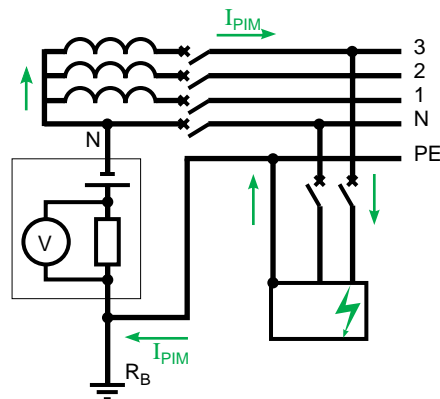
#### For all AC and DC networks

Finally, nowadays, given that networks are frequently of the mixed AC/DC kind as well as variable frequency, the new PIMs are able to monitor insulation on all types of networks.

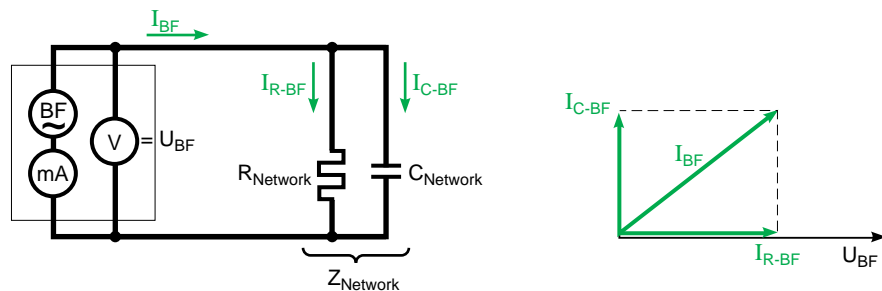
- Some use squared wave pulses at very low frequency ( $\approx 1\text{Hz}$ ). They allow PIM not to be disturbed by earth leakage capacities, as they are then immediately loaded then unloaded by the next strobe pulse of opposite sign. They are universal in use and easily adapted to modern networks, in particular to those supplying power electronic devices which often deform the AC pulse. However, their response time, depending on the network’s earth leakage capacity, may be as much as a few minutes and does not allow the detection of intermittent faults.

- In order to compensate the usage restrictions of these PIMs for very long networks and networks with a large number of capacitive filters, the low frequency AC current injection technique has been improved by means of “synchronous demodulation” (see **fig. 12**): this type of PIM applies a low frequency AC voltage between the network and the earth, measures the current flowing back via network insulation impedance and calculates the voltage-current shift.

It is then possible to determine the resistive and capacitive components of this current and thus relate the threshold to the resistive component only. This upgrade, the result of digital technology, combines the advantages of DC current and low frequency AC current injection without their disadvantages.



**Fig. 11** : principle of PIM with current injection.



**Fig. 12** : the low frequency AC current injection technique has been improved by means of “synchronous demodulation”, which enables the insulation drop (resistive leakage) to be distinguished from capacitive leakage.

### PIM standards

#### ■ The manufacturing standards

Standard IEC 61557-8 is in existence since February 1997. It defines the special specifications governing insulation monitors designed for permanent monitoring, irrespective of the measurement principle, of insulation resistance with respect to earth of unearthed AC and DC IT system networks, and of AC IT system networks containing rectifiers supplied without galvanic separation (transformer with separate windings).

It places particular emphasis on three points.

□ Properly inform specifiers and contractors. The manufacturer must provide the characteristics of the devices he produces and in particular those that are dependent on network capacity (response time and threshold values).

□ Ensure that these devices are properly integrated in their electrical environment. This requires compliance with the specifications of standards IEC 61326-1 and 61326-10 concerning ElectroMagnetic Compatibility (EMC).

□ Guarantee operating safety for users. The main stipulations are: device operating testing must be possible without inserting an additional impedance between the monitored network and the earth, settings must be protected to prevent modification by error or by unauthorised users, and impossibility of device disconnection (the need to use a tool for disassembly).

#### ■ The operating standards

As concerns PIM setting, standard IEC 60364 provides an initial answer: "A PIM designed according to... is set at a value less than the minimum value of the insulation resistance defined for the installation in question", i.e. greater than or equal to  $0.5 \text{ M}\Omega$  for a circuit with a nominal voltage greater than or equal to 500 V. Guide NF C 15-100 states: "...set at a value roughly less than 20% of the resistance of the installation as a whole..."

However, a clear distinction must be made between the insulation resistance of the installation, which only takes electrical distribution into account, and the insulation level which is set for overall network monitoring, including the various machines and switchgear connected to it.

In the previous chapter we saw that for faults greater than  $500 \Omega$ , contact voltage does not exceed 5 V with an earth connection of  $10 \Omega$  (see fig. 5). In practice, for a normal industrial installation, it is thus reasonable, without taking risks, to set the lower alarm threshold at a value of between  $500 \Omega$  and  $1,000 \Omega$ , ensuring effective fault tracking (and thus location of the reported insulation fault). To organise preventive tracking, it is useful to have a first level threshold around  $10 \text{ k}\Omega$  for example. This threshold must be adapted according to installation characteristics and operating requirements. Note that short networks allow a higher prevention threshold.

## 2.3 Tracking the 1<sup>st</sup> insulation fault

When tracking a fault, although certain operators merely identify the faulty feeder, accurate determination of the location of this fault is recommended (e.g. damaged cable or insulation fault in a device) in order to put it right as quickly as possible.

### Tracking by successive de-energisation of feeders

This means of fault tracking is quoted for memory only. It consists of opening the feeders one by one, beginning with the main feeders. When the faulty feeder is opened, the current injected by the PIM decreases markedly and drops below the detection threshold. The audible alarm normally controlled by the PIM then stops, enabling remote identification of the faulty feeder.

This procedure, which requires interruption of operation on each feeder, is contrary to the operating philosophy of the IT earthing system, which stipulates continuity of supply. Although frequently used in the past, it is gradually disappearing with the development of the new

fault tracking systems which allow live tracking (without power breaking).

### Live tracking

#### ■ Detecting the fault current

As seen above (see fig. 3a), a current  $I_d$  flows through the first insulation fault at the same frequency as that of the network (50 Hz or 60 Hz), returning to the source via the capacities of the other sound phases and via the neutral impedance if any.

An initial live tracking method (without interrupting distribution) consisted of using a clamp-on probe to measure the earth "leakage" current on each feeder. The faulty feeder was the one on which the highest value was measured.

This method has two drawbacks, namely:

□ It is not reliable for networks with a large number of feeders some of which are highly capacitive (how can the earth current of a short faulty feeder be distinguished from that of a long capacitive feeder?).

□ It is not applicable on networks with few capacitive leakages (the fault current is virtually undetectable).

In order to improve detection of the fault current path (at power frequency) using a clamp-on probe, two “tricks” were used.

The first consisted of increasing this fault current by temporarily placing a low impedance in parallel on the PIM.

The second consisted of distinguishing the capacitive leakage currents from the fault current by the periodic use of the above-quoted impedance by means of a beating relay (approx. 2 Hz).

■ Detecting an injected current

This method uses a low frequency sinusoidal pulse ( $\leq 10$  Hz) injected by a generator or a PIM. Choice of low frequency for fault tracking ensures no disturbance by network leakage capacities, but this frequency cannot be less than 2.5 Hz, as detection with a magnetic sensor becomes difficult. This method uses devices sensitive to the injected pulse only, that can either be fixed with detection toroids placed on all feeders, or portable with a clamp-on probe tuned to signal frequency in order to locate the exact position of the fault (see **fig. 13**).

When the devices (generator, sensors and load) are fixed, live fault tracking can be automatic on detection of a fault, with transmission of an order by the PIM.

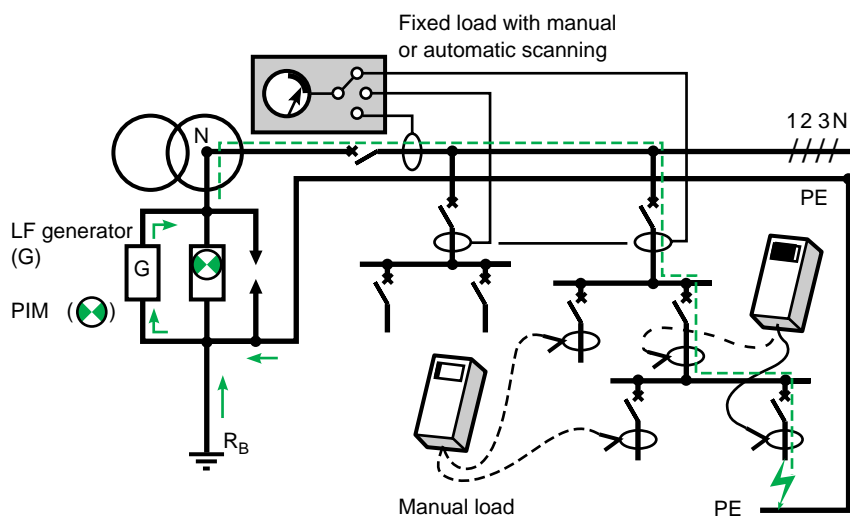
■ Measuring insulation of each feeder

Operators, with their ever-increasing need for continuity of supply, are no longer prepared even to wait for the first fault, but want to be able to programme maintenance work and thus anticipate the next feeder likely to be affected by an insulation fault.

It is thus necessary to “monitor” the changes in insulation of each feeder and to carefully identify the resistive and capacitive insulation components.

The synchronous demodulation principle can also be used by measuring, first, the injection current flowing in the feeders (by the toroid sensors) and, second, the injection voltage.

Development of this tracking method is encouraged by application of digital techniques to the management of electrical power distribution (see “Cahier Technique” no. 186): the user can now remotely and continually monitor insulation changes of the various feeders. Use of digital buses enables data to be centralised on a supervisor, displayed and logged, thus allowing intelligent, predictive maintenance.



**Fig. 13** : tracking can take place with fixed or portable devices sensitive to the injected pulse.



## 3 The 2<sup>nd</sup> insulation fault with the IT earthing system

As we have already seen in the previous chapter, the advantage of using the IT system in network operation lies in the possibility of continuity of supply even though an insulation fault has occurred on a circuit.

This message has been received loud and clear by standard drafters who, in order to maintain a high level of availability, stipulate in installation standards indication and tracking of this first fault so as not to fear a second fault. Protection devices are also provided for this second fault in order to guarantee the same level of safety of persons as for the TN and TT earthing systems.

### 3.1 Analysis of the double insulation fault

In this section, fault currents and contact voltage are calculated by considering two full insulation faults on two different live conductors (on one phase and the neutral if the neutral is distributed, or on two different phase conductors if the neutral is not distributed) of two circuits of identical cross-section and length.

This assumption, which results in a minimum fault current, is the one normally chosen to calculate the maximum lengths protected by the short-circuit protection devices.

#### Contact voltage and double fault current when the frames are interconnected

When a fault current occurs between two faulty frames, a current flows in the phase conductors and the PE protective conductor ensuring interconnection of frames (see fig. 3b).

This current is only limited by the impedance of the fault loop equal to the sum of the impedances of the live conductors concerned and the circuit of the equipotential links (PE).

There are a number of methods for calculating fault currents for an electrical installation (see "Cahier Technique" no. 158).

In this case, the conventional method has been chosen, as it enables calculation of fault current and contact voltage values without making too many assumptions on installation characteristics. It will thus be used from now on in this "Cahier Technique" to give an idea of the value of the currents and voltages involved on a double fault in the IT system.

It is based on the simplified assumption that considers that, during the duration of the fault, the voltage at the origin of the feeder considered is equal to 80% of installation nominal voltage.

The two sections below study the fault currents and contact voltage which depend on how the frames are earthed. There are two possibilities, namely:

■ The load frames are all interconnected by a PE protective conductor: this is the general case.

■ The frames are not interconnected and are connected to separate earth connections (configuration to be avoided due to EMC: see "Cahier Technique" no. 187).

This assumes that the impedance of the feeder in question accounts for 80% of total impedance of the faulty loop, and that upstream impedance accounts for 20%.

For the following calculations:

$U'$  = phase to neutral voltage, ( $= U_0$  if one of the two faults is on the distributed neutral),

or

$U'$  = phase-to-phase voltage, ( $= \sqrt{3} U_0$  if the neutral is not distributed).

$R_a = \rho \frac{L}{S_a}$  = resistance of the live conductor

(phase or neutral) of the circuit on which the fault occurred.

$R_{pe} = \rho \frac{L}{S_{pe}}$  = resistance of the circuit protective

conductor.

$S_a$  = cross-section of the live conductor.

$S_{pe}$  = cross-section of the protective conductor.

$L$  = length of the faulty circuits.

$m = \frac{S_a}{S_{pe}}$  = ratio of live conductor cross-section

over protective conductor cross-section (normally  $\leq 1$ ).

■ If we consider that the live and PE conductors of the two faulty feeders have the same cross-section and length and if we ignore their reactance:

□ if one of the faults is on the neutral

$$I_d = \frac{0,8 U_0}{2(R_a + R_{pe})}, \text{ i.e. } I_d = 0,8 U_0 \frac{S_a}{2\rho(1+m)L},$$

□ if the double fault concerns two phase

$$\text{conductors } I_d = 0,8 \sqrt{3} U_0 \frac{S_a}{2\rho(1+m)L}.$$

■ The corresponding contact voltage is  $U_c = R_{pe} I_d$ , i.e.:

□ if one of the faults is on the neutral

$$U_c = 0,8 U_0 \frac{m}{2(1+m)}, \text{ or}$$

□ if the double fault concerns two phase

$$\text{conductors } U_c = 0,8 \sqrt{3} U_0 \frac{m}{2(1+m)}.$$

**NB:** this method is not applicable for installations supplied by generator set, as, due to high generator impedance compared with the impedance of the supplied network, voltage at the origin of the network in question is low when a fault occurs ( $\ll 0.8 U_n$ ). In this case, irrespective of the earthing system, only complete electro-technical methods, of the impedance method type, can be used.

	Faults on 2 identical feeders (where $m = 1$ )	Faults on a BB and a feeder (where $m = 4$ )
Double fault		
■ phase - neutral	$U_c = 46 \text{ V}$	$U_c = 73.6 \text{ V}$
■ phase - phase	$U_c = 79.7 \text{ V}$	$U_c = 127.5 \text{ V}$

**Fig. 14 :** contact voltages on a double fault for a 230/400 V network in the IT earthing system.

■ Digital example

The results presented in the table in **figure 14** confirm that a double insulation fault is a risk for safety of persons since contact voltage is greater than limit safety voltage  $U_L$ . The automatic protection devices must then de-energise the installation.

### Contact voltage and double fault current when the frames are not interconnected

If the two faults occur on two loads connected to two separate earth connections (see fig. 3c), the fault current  $I_d$  is then closed by the earth and is limited by the earth connection resistances  $R_A$  and  $R_B$ .

A simple calculation shows that this second insulation fault is just as dangerous (see **fig. 15**), and must therefore be automatically eliminated, and that the threshold of the short-circuit protection devices cannot be reached.

	$U_c$	$I_d$
Double fault		
■ phase - neutral	115 V	11 A
■ phase - phase	200 V	20 A

**Fig. 15 :** fault currents and contact voltages on a double fault on two frames with separate earth connections, where  $R_A = R_B = 10 \Omega$ .

## 3.2 Elimination of the double insulation fault

### Case of interconnected application frames

In view of the importance of the fault current, comparable with a short-circuit current, automatic short-circuit protection devices (SCPD) can be used for tripping if cable lengths are compatible with their operating thresholds. Otherwise residual current devices (RCD) are used.

Elimination of the double fault must also satisfy other requirements which apply regardless of the type of SCPD installed (fuse or circuit-breaker):

■ The contact voltages calculated in the previous chapter, for all SCPD types, leave little time for fault elimination. In order to simplify the network designer's task, standard IEC 60364 specifies maximum breaking times as a function of operating voltage (see **fig. 16**).

■ Multi-pole breaking, including the neutral conductor when distributed.

The reasons for this are:

□ breaking only of the faulty phase conductor of a feeder means that three-phase machines are supplied by the two other phases,

□ breaking of the neutral exposes to phase-to-phase voltage, single-phase loads normally supplied by phase to neutral voltage.


Network $U_0$ (V)	Maximum breaking time (s)	
	Non-distributed neutral	Distributed neutral (*)
127	0.4	1
230	0.2	0.5
400	0.06	0.2
>> 400	0.02	0.08

**Fig. 16 :** maximum breaking time specified for the IT earthing system by installation standards (\* for single-phase networks).

■ Protection of the neutral conductor when it is distributed.

Figure 3b shows that when a double fault occurs, the two SCPDs detect the fault current but each one on a single phase or on the neutral.

This situation calls for particular monitoring of SCPD characteristics: this is because if the cables of the two feeders have similar cross-sections, the two SCPDs play an equal role in breaking, but if the cross-sections are different, there is a risk of only one SCPD, the one with

the lowest rating, performing breaking. It is thus necessary to verify that its breaking capacity on one phase, thus under  $\sqrt{3} U_0$ , is greater than  $I_d$ . For this reason, circuit-breaker manufacturers specify the single-phase breaking capacities of their devices according to each nominal voltage, and standard IEC 60947-2 specifies a test sequence for circuit-breakers designed for protection of IT networks. Devices failing to satisfy the requirements of these tests must be marked: 

Protection must also be confirmed for the neutral conductor when its cross-section is less than that of the phase conductors. Note that four-pole circuit-breakers (the fourth pole has a half rating) can be used to protect cables with neutral cross-section half of phase cross-section.

It should be stressed that four-pole SCPDs are becoming increasingly necessary, irrespective of the installation earthing system used (TN, TT or IT), due to the proliferation of harmonics in networks, and thus that the neutral can be overloaded by harmonic currents of rank 3 and multiples.

#### ■ Fuse protection

The fuse blowing zone is located between two envelope curves.

Using the expression of current  $I_d$ , defined in the previous chapter, and the condition  $I_{fu} < I_d$ , it is possible to determine the maximum length of the protected circuit.

□ If the neutral conductor is distributed:

$$L_{\max} = \frac{0,8 U_0 S_1}{2p (1+m) I_{fu}}$$

□ If the neutral conductor is not distributed:

$$L_{\max} = \frac{0,8 \sqrt{3} U_0 S_{ph}}{2p (1+m) I_{fu}}$$

$I_{fu}$  corresponds to the fuse blowing current within a maximum time stipulated by the standards. It should be checked that this time is compatible with protection of persons in event of a double fault.

Note that use of fuses in the IT earthing system often clashes with the need for multi-pole breaking, including that of the neutral conductor when distributed.

#### ■ Circuit-breaker protection

Protection of persons is guaranteed when the fault current is greater than the circuit-breaker's short time delay protection setting.

Just as with fuses, the maximum length of the protected circuit can be determined according to the expression of current  $I_d$ , defined in the previous chapter and the condition  $I_m < I_d$ . The maximum length of the circuit protected by a circuit-breaker is:

□ with the distributed neutral conductor:

$$L_{\max} = 0,8 U_0 \frac{S_a}{2p (1+m) I_m}$$

□ with the non-distributed neutral conductor:

$$L_{\max} = 0,8 \sqrt{3} U_0 \frac{S_a}{2p (1+m) I_m}$$

Note that whether protection is provided by fuse or circuit-breaker, the fact of distributing the neutral in IT divides by  $\sqrt{3}$  the maximum length protected.

#### ■ Improvement of tripping conditions.

When tripping conditions are not satisfied (lengths greater than maximum lengths protected), the following measures can be taken:

□ reduce the value of  $I_m$  of the circuit-breakers: however current discrimination between circuit-breakers may be reduced as a result;

□ increase PE conductor cross-section. The impedance of the return circuit of the double fault current is thus reduced and enables an increase in maximum length for protection of persons. However, although contact voltage will be reduced, the electrodynamic stresses on the cables will increase.

□ Increase live conductor cross-section. This is the most expensive solution and also results in an increase in three-phase short-circuit currents.

□ Finally, there is a simple solution that requires no calculation: use of low sensitivity RCDs on very long feeders. This solution is also possible in IT, as the PE conductor is separate from the neutral conductor which is not the case in TN-C.

#### Case of application frames with separate earth connections

When an installation supplies a number of separate buildings at a distance from one another, their application frames are often connected to separate earth connections. The impedance of the path of fault current  $I_d$  is then increased by the resistance of the two earth connections in question, and the condition necessary for protection of persons (respect of maximum breaking times) can no longer be guaranteed by the short-circuit protection devices. The simplest study and installation solution is to use RCDs. Their settings follow the same rules as in TT.

To derive maximum benefit from the continuity of supply offered by the IT system, the RCDs must be prevented from tripping on the first fault by not setting their threshold  $I\Delta n$  at too low a level, particularly for circuits with a high leakage capacity, while at the same time respecting the

$$\text{inequation: } I\Delta n < \frac{U_L}{R_A}$$

The thresholds  $I\Delta n$  of the RCDs normally used for this purpose are between 3 and 30 A.

# 4 Special features of the IT earthing system

## 4.1 Overvoltages in the IT system

Electrical networks can be subject to overvoltages of varying origins. Some overvoltages, such as differential mode ones (between live conductors) affect all the earthing systems. Readers requiring more information on this subject should consult "Cahier Technique" no. 179.

This section is particularly concerned with common mode overvoltages, which mainly affect the IT system as the network is then "unearthed":

- overvoltages due to insulation faults,
- overvoltages due to internal disruptive breakdown in the MV/LV transformer,
- overvoltages due to lightning striking the upstream LV network,
- overvoltages due to lightning striking the building in which the installation is housed.

These overvoltages are particularly taken into account by standard NF C 15-100 which stipulates installation of a surge limiter downstream of an MV/LV transformer and when there is a risk of lightning (overhead lines).

### Overvoltages due to insulation faults

- When the first insulation fault occurs, the phase-to-earth voltage of the sound phases is permanently brought to the phase-to-phase voltage of the network.

LV equipment must thus be designed to withstand a phase-to-earth voltage of  $U_0 \sqrt{3}$  and not the phase to neutral voltage  $U_0$  for the time required to track and eliminate the fault. This particularly applies to:

- "Y" capacitive filters fitted on many electronic devices;
- installation PIM when installed between phase and earth because the neutral is not accessible. When choosing a PIM, it is thus important to verify the voltage of the network to be monitored declared by its manufacturer.

These recommendations are specified in particular in standard IEC 60950.

- On occurrence of the first fault, a transient overvoltage appears with a possible peak of  $2.7 \times \sqrt{2} U_0$  ( $U_0$  = phase to neutral voltage of the LV network). On a 230 V/400 V network, this value is 880 V, an overvoltage level that is not dangerous for equipment with an insulation of 1,800 V (voltage constraint at power frequency on the LV side as per IEC 60364-4-442).

Note that these overvoltages do not cause permanent short-circuiting of the surge limiter.

### Overvoltages due to intermittent insulation faults

Intermittent faults (according to international electrotechnical vocabulary, or "restricting" or "arcing" faults in Anglo-saxon literature) behave like a series of transient faults.

Experience and theoretical studies show that intermittent faults can generate overvoltages and thus result in equipment destruction. Such overvoltages are particularly observed on MV networks operated with an earthed connection by a tuned limiting reactance (Petersen coil). These overvoltages are caused by incomplete discharging of zero sequence capacity on re-arcing. The zero sequence voltage therefore increases each time the arc is ignited. Assuming that the arc is ignited at the highest value of the phase-to-earth voltage of the faulty phase, and zero sequence voltage increases each time, overvoltages of 5 to 6 times phase to neutral voltage may be generated.

Yet again, in the IT system, protection is provided by the surge limiter, and presence of an impedance between neutral and earth encourages rapid discharging of the zero sequence capacity.

### Overvoltages due to internal disruptive breakdown of the MV/LV transformer

Voltage withstand at power frequency of LV equipment is defined in standard IEC 60364-4-442 which specifies their values and durations (see **fig. 17**).

- Internal disruptive breakdown between the MV/LV windings. This kind of overvoltage is at network frequency.

Acceptable AC voltages on LV equipment	Breaking time (s)
$U_0 + 250$ V (i.e. 650 V in IT)	> 5
$U_0 + 1,200$ V (i.e. 1600 V in IT) *	≤ 5

(\* ) For an IT network, the voltage  $U_0$  must be replaced by the voltage  $\sqrt{3} U_0$ .

**Fig. 17** : acceptable AC voltage constraints on LV installation equipment in the IT system for a 230/400 V network.

These overvoltages are rare and their “sudden” appearance means that the surge limiter, whose certain arcing voltage is set at least at 2.5 times type voltage (NF C 63-150), i.e. for example 750 V for a limiter placed on the neutral of a 230/400 V network, immediately earths the LV network, preventing it from rising to MV potential.

■ MV/frame internal disruptive breakdown also known as “return disruptive breakdown”  
When the transformer frame and the LV network are connected to the same earth connection (see **fig. 18**) there is a risk of LV equipment disruptive breakdown if the voltage  $R_p I_{h_{MT}}$  exceeds equipment dielectric withstand, with  $R_p$  (earth connection resistance) and  $I_{h_{MT}}$  (zero sequence current due to MV disruptive breakdown).

One solution is to connect the LV installation frames to an earth connection that is electrically separate from that of the substation frames.

However, in practice, this separation is difficult due to frame meshing in MV/LV substations.

Consequently standard IEC 60364-4-442 states that the LV installation frames can be connected to the earth connection of the transformer substation frames if the voltage  $R_p I_{h_{MT}}$  is eliminated within the stipulated times.

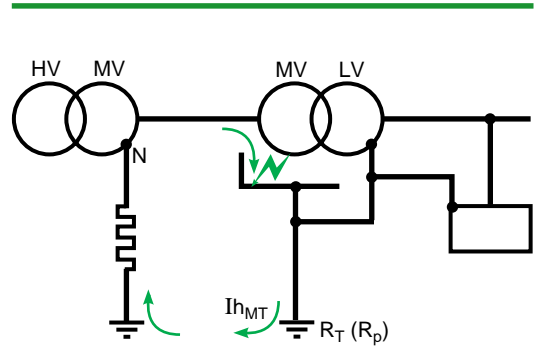
### Overvoltages due to lightning striking the upstream MV network

When lightning strikes the MV network, a wave is transmitted to the live conductors on the LV side as a result of capacitive coupling between the transformer windings.

If the installation is in IT, the surge limiter absorbs the overvoltage occurring on the live conductor to which it is connected (neutral or phase) and is short-circuited if this overvoltage is very high: the network can then be compared to a network in TN-S. Experience and measurements have resulted in the following observations:

- Overvoltages of around 2 kV occur at the end of short cables (10 m) irrespective of load and earthing system.
- Higher overvoltages occur at the end of cables with open end or which supply loads likely to generate resonance. Even with a resistive load, overvoltages exist (see **fig. 19**), caused by wave propagation and reflection phenomena and by capacitive coupling between conductors.

In view of the waveform of these overvoltages, the surge limiter is effective on the conductor to which it is connected. Consequently, regardless of the earthing system, we strongly recommend that surge arresters be installed at the origin of the LV network, between all live conductors and



**Fig. 18** : when the substation frames (MV) and the PE earth connection (LV) are connected to the same earth connection, the LV load frames are brought to the potential  $I_{h_{MT}} R_p$ .

$\hat{u}$ (kV)	Ph/Ph	Ph/PE	Ph/N	N/PE	PE/deep earth
System :					
■ IT	0.38	4.35	0.20	4.30	1.62
■ TN-S	0.36	4.82	0.20	4.72	1.62

**Fig. 19** : overvoltages, caused by a lightning shock wave, measured at the end of a 50m cable supplying a resistive load.

the earth, if there is a risk of the upstream MV network being directly struck by lightning (case of overhead lines) and especially if the LV network is also at risk. The surge limiter continues to perform its function for MV/LV disruptive breakdown.

### Overvoltages due to lightning striking the building housing the installation

These overvoltages are caused by lightning current flowing through the building's earth connection, particularly when lightning strikes a building equipped with a lightning rod.

The entire earth network then markedly rises in potential with respect to the deep earth. The LV network, immediately earthed by the surge limiter, changes from the IT to the TN-S system if all the application frames are interconnected. The lightning energy thus flown off can be considerable and require replacement of the limiter.

In order to minimise these overvoltages on electrical installations, the building's horizontal and vertical equipotentiality must be the best possible in low and high frequency. A single earth circuit (PE network) is naturally recommended, and use of metal cable trays with proper electrical connections (braids) is highly advisable for distribution.

## 4.2 Surge limiters

Nominal voltage of a limiter -Un- (V) (NF C 63-150)	Arcing U (V) at power frequency	on 1.2/50 impulse wave	Example : limiter to be chosen for a 230/400 V network...
250	$400 < U < 750$	< 1,750	... if connected between the earth and the <b>neutral</b> .
440	$700 < U < 1,100$	< 2,500	... if connected between the earth and the <b>phase</b> .
660	$1100 < U < 1,600$	< 3,500	

**Fig. 20** : the nominal voltage of a surge limiter must be adapted to network voltage.

The previous section clearly explains why the surge limiter is an “essential accessory” of the IT earthing system and thus stipulated by standards. It also protects the PIM against overvoltages.

Its clipping thresholds for overvoltages at power frequencies and for common mode impulse overvoltages are defined by standard NF C 63-150 (see **fig. 20**). These thresholds are lower than the specified withstand of equipment used on LV networks (230/400 V).

It must be connected as close as possible to the MV/LV transformer between neutral and earth, or between a phase and earth if the transformer’s secondary connection is of the delta or non-distributed neutral kind.

### NB:

- limiters are not necessary on networks downstream of a LV/LV transformer,
- standard IEC 60364 does not specify use of surge limiters, as it considers that occurrence of an MV/LV fault is rare. However, when this fault does occur, its consequences are frequently serious.

### Operation

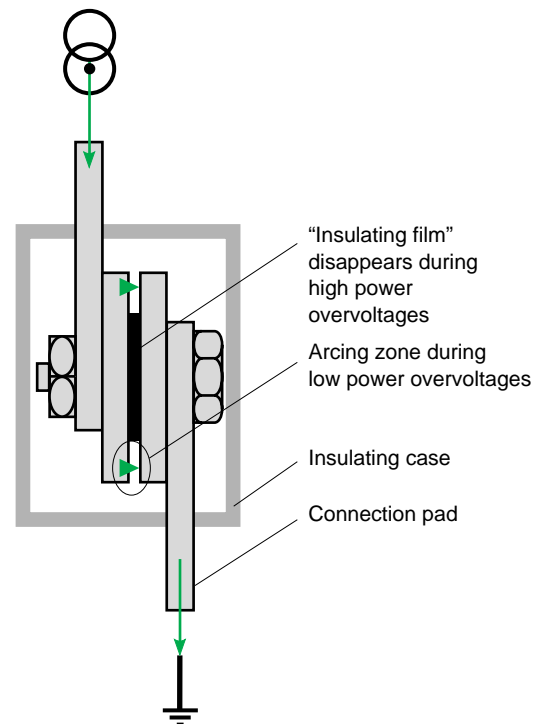
A surge limiter consists of two conductive components separated by an insulating film (see **fig. 21**).

Impulse overvoltages generate arcing between the two conductive components, but do not short-circuit the limiter.

Energetic overvoltages melt the insulating film, thus allowing the run-off of a high current to earth. The cartridge must then be replaced: its short-circuiting is reported by the PIM just as an insulation fault. Moreover, it is useful, for live fault tracking, to consider its earth connection in the same way as a feeder, particularly if this connection is normally inaccessible (such as when, for example, the limiter is placed in the transformer cubicle).

### Important characteristic

When all the application frames are properly interconnected, the double fault concerning both the arced surge limiter and an insulation fault on



**Fig. 21** : surge limiter principle (Merlin Gerin Cardew type).

a phase, becomes a short-circuit. Limiter withstand must then be sufficient for the time required to eliminate the fault current (For example, 40 kA must be withstood for 0.2 sec for Merlin Gerin Cardew limiters).

In the rare case of the second insulation fault occurring upstream of the incoming circuit-breaker, the double fault is eliminated by the MV protection devices (just as for an upstream short-circuit on the main LV switchboard). For this reason, the time delay setting of the transformer’s MV protection must take the thermal withstand [ $I^2t$ ] of the surge limiter into account. The cross-section of the connection conductor upstream and downstream of the surge limiter must also have the same thermal withstand. Its cross-section is calculated in standard NF C 15-100.

### 4.3 Why use an impedance?

An impedance can be connected between the network and the earth, normally between the transformer neutral and the earth. Its value is approximately 1,700  $\Omega$  at 50 Hz.

Its purpose is to reduce variations in potential between network and earth, caused by MV disturbances or fluctuations in potential of the local earth. It is therefore particularly recommended for short networks supplying measurement instruments sensitive to this potential and for networks placed next to communication networks (Bus).

A reading of the table in figure 5 shows that when the network is very slightly capacitive (case 1), the neutral impedance  $Z_N$  causes the fault current to increase, which nevertheless remains very low ( $\approx$  250 mA in figure 5). This effect is even slighter when the network is highly capacitive (cases 2 and 3). In practice, this impedance effects only very slightly the contact voltage  $U_C$  which remains less than  $U_L$  in sound networks.

Finally, presence of a resistance in the impedance enables a reduction of the ferromagnetic resonance hazard.

## 5 Advantages and disadvantages of the IT earthing system in LV

The main advantage of using the IT earthing system for network operation is without doubt the continuity of supply it offers, as there is no need to trip on the first fault (as described in the section below). Another of this system's strong points is guaranteed safety against the fire

hazard and for control and monitoring circuits of machine tools. However, to benefit fully from such advantages, the restrictions of this system must also be considered.

### 5.1 Increased availability

This advantage can be confirmed by a simple probability calculation.

Let us assume that the occurrence of an insulation fault in an electrical installation is one fault every three months (90 days),

$$\text{i.e. } \lambda = \frac{1}{90} \text{ j}$$

and the time needed to track and put right the faulty part is one day,

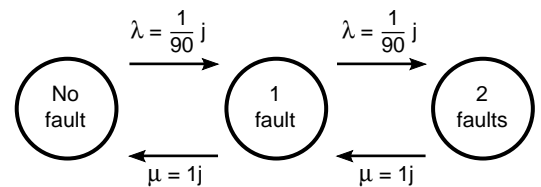
$$\text{i.e. } \mu = 1 \text{ j.}$$

The Markof graph technique gives the representation shown in **figure 22** and enables us to calculate that the average time between two double faults is 8,190 days!

This corresponds to an average electrical power availability that is 91 times better in IT than in TN or TT.

Consequently, preference is frequently given to the IT earthing system for use in:

- hospitals,
- airport take-off runways,



**Fig. 22** : a Markof graph shows that average electrical power availability is 91 times better in IT than in TN or TT.

- vessels,
- plants with continuous manufacturing processes,
- laboratories,
- cold storage units,
- electrical power plants.

### 5.2 Increased safety against the fire hazard

Electricity is often the cause of fire. Standards set the threshold for this risk at 500mA on an insulation fault (NF C 15-100, part 482.2.10). This value can be considerably exceeded, particularly with stray currents that flow through building structures when faults occur in the TN system.

Also worthy of note is that the IT is the only earthing system that monitors insulation of the neutral conductor, compared with the TNS which can insidiously turn into a TNC on a neutral-PE fault with an increase in the fire hazard.

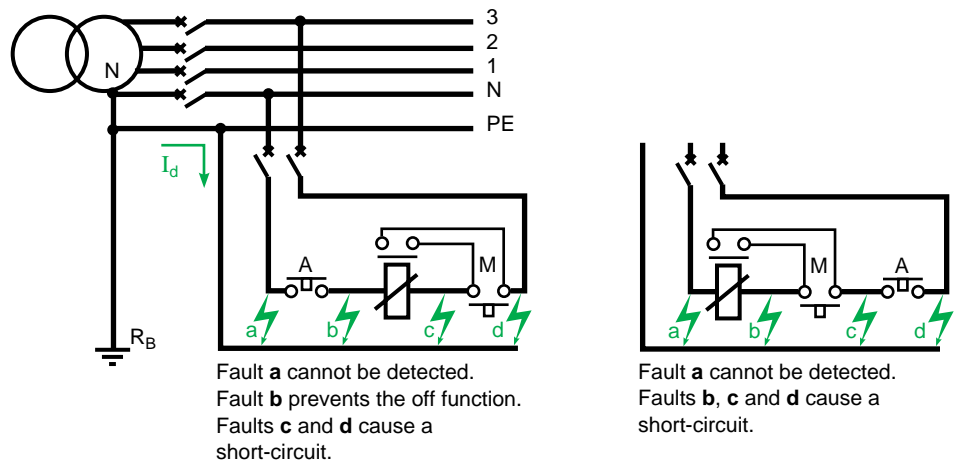
It is because the current of the first fault is particularly low that the IT earthing system has been chosen for use in certain establishments at risk from fire and explosion (see chapter 1). Furthermore the first PIMs were used in firedamp mines.



### 5.3 Less downtime on control and monitoring circuits

The relay diagram illustrated in **figure 23** with the TN earthing system shows three possible insulation faults which, when full, result in immediate downtime, whose material and economic consequences are rarely negligible. These faults have the same consequences with the TT system. In particular, faults **c** and **d** cause tripping of the master protection device, and prevent all subsequent operations, such as for example the order to change direction on a transporter bridge! These same first faults which can cause operating malfunctions or even accidents with the TN and TT systems, have no effect with the IT system, except if they occur as the second fault (extremely unlikely, see section 5.1). These examples show that even if safety of persons with respect to the electrical hazard is guaranteed by the various earthing systems, or

by use of Safety by Extra Low Voltage (SELV), safety of persons with respect to mechanical hazards may not be guaranteed in certain cases. More care must therefore be taken when wiring such circuits in the TT and TN than in the IT system, as the latter warns the operator of the incident (first insulation fault), thereby guarding against electrical and mechanical hazards. PIMs are increasingly used for just this purpose, to monitor automation networks. An additional solution is often advisable, particularly with relays using electronic devices sensitive to electromagnetic disturbances. The aim is to supply all the control and monitoring circuits separately by means of a LV/LV transformer with separate windings. Despite this, as stated in chapter 2, use of the IT earthing system has its limits which are described in the section below.



**Fig. 23** : monitoring circuit may be concerned by several types of insulation faults always resulting in downtime with TT and TN system.

### 5.4 Restrictions and precautions for using the IT earthing system

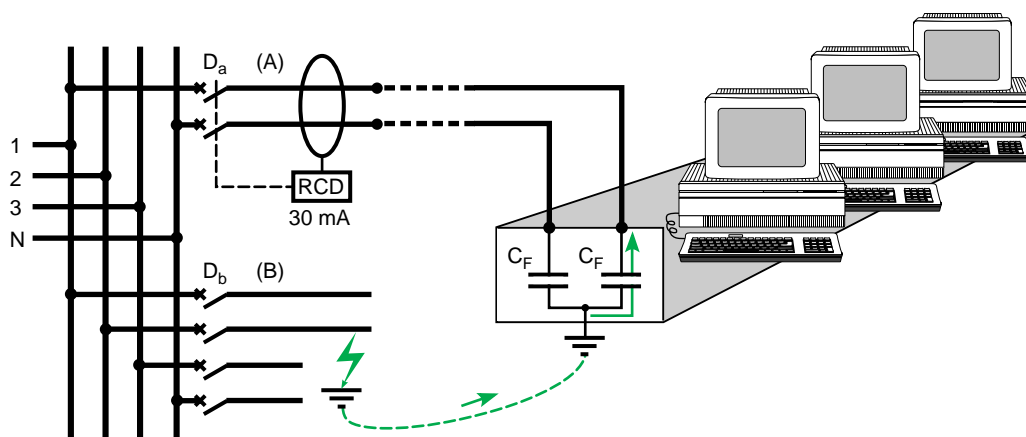
The restrictions for using the IT system are linked to loads and networks.

#### Limits linked to loads

- With a high earth capacitive coupling (presence of filters). A number of devices fitted with capacitive filters (see **fig. 24**) offer the same disadvantage, due to their number, as very long networks when the IT system is used. These capacitive leakages have a particularity, with respect to distributed capacity mainly due to network cables, i.e. they can be unbalanced.

Device	Network/earth capacity
Micro-computer	20 nF to 40 nF
UPS	40 nF
Variable speed controllers	70 nF
Fluorescent tubes (in ramps of 10)	20 nF

**Fig. 24** : guideline capacitive values for HF filters built into various devices.



**Fig. 25 :** in the IT system, capacitive current flow can cause nuisance tripping of the RCDs "by sympathy". In this case, in presence of a fault on feeder B, circuit-breaker  $D_a$  placed on a highly capacitive feeder (presence of several filters) may open instead of  $D_b$ .

Office computer equipment: micro-computers, monitors and printers, concentrated on the same single-phase feeder, is an example of this. It should be borne in mind that interference suppression filters (compulsory according to the European Directive for EMC) placed on these devices, generate in single-phase permanent leakage currents at 50 Hz that can reach 3.5 mA per device (see IEC 95); these leakage currents add up if the devices are connected on the same phase.

To prevent nuisance tripping (see **fig. 25**), especially when the RCDs installed have low thresholds, the permanent leakage current must not exceed  $0.17 I_{\Delta n}$  in IT. In practice, the supply by a 30 mA RCD of three micro-computer stations is the maximum recommended. This problem also exists with the TT and TN systems.

For memory:

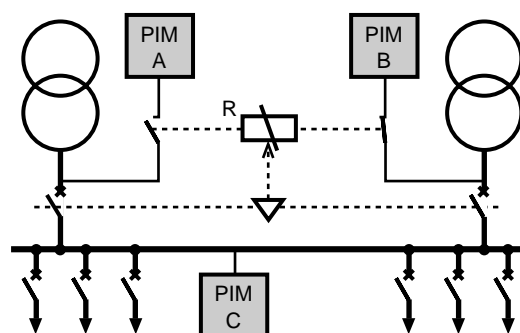
- to guarantee safety of persons ( $U_C \leq U_L$ ), the limit not to be exceeded is  $3C \leq 70 \mu F$ .
- for insulation monitoring, PIMs with DC current injection are not affected by these capacities.

Note that if the devices are connected on all three phases, these capacitive currents cancel each other out when they are balanced (vector sum).

■ With a low insulation resistance

This particularly applies to induction furnaces and arc welding machines, as well as very old cables.

A low insulation resistance is equivalent to a permanent insulation fault: the IT system is "transformed" into a TN or TT system, with a PIM on permanent alert.



**Fig. 26 :** insulation monitoring of the various parts of a network with a replacement source.

**Limits due to the physical characteristics of networks**

High "capacitive leakages" disturb insulation monitoring using PIMs with AC current injection and tracking of the first fault using a very LF generator (see chapter 2).

When an insulation fault occurs, they can also cause flow of residual currents likely to generate nuisance tripping "by sympathy" of the RCDs placed on very long or highly capacitive feeders (see "Cahier Technique" no. 114).

Use of the IT system is thus advised against for very long networks, containing long feeders, for example for electrical power distribution in a number of buildings at a distance from one another.

**Case of networks with replacement power supply**

The fact that a network can be supplied by several sources makes it necessary to detect the first fault and to trip on the second fault, irrespective of the voltage source in operation.

■ Permanent monitoring of network insulation, regardless of the supply source, makes it necessary to choose PIM position carefully. In some positions insulation monitoring may be partial (see **fig. 26**).

Permanent connection of two PIMs at positions A and B is not acceptable as they would each obstruct the other on coupling.

On the other hand, position C could be acceptable, as access to supply sources is reserved for authorised users, but there is the risk on source switching of finding that a fault already exists on the new source.

It is thus preferable to provide a PIM on each source [A and B] with a relay [R] preventing simultaneous operation of both devices on the same circuit.

There are also new insulation monitoring systems which exchange digital data via bus and automatically adapt to network configuration.

These PIMs make use of special, often complicated, relays unnecessary (see **fig. 27**).

■ Tripping on a double fault, whatever the voltage source, calls for (just like the TN system) verification of SCPD compatibility with the presumed fault currents, particularly when the replacement source is a generator set. This is because the short-circuit current it delivers is far lower than that supplied by an MV/LV transformer supplied by the public distribution networks: the SCPD threshold must be set accordingly.

The first solution is to lower the threshold of these protection devices, but the problem is that this also reduces current discrimination ability. A second, simpler, solution, is to provide low sensitivity RCDs.

■ With an Uninterruptible Power Supply (UPS) The problems experienced are the same as with

a generator set. Only insulation monitoring is more complex as it is linked to the various operating configurations that a UPS can assume.

#### In practice

In all these restriction cases, the most appropriate solution is to reserve use of IT for the network only supplying the devices requiring a high degree of electrical power availability.

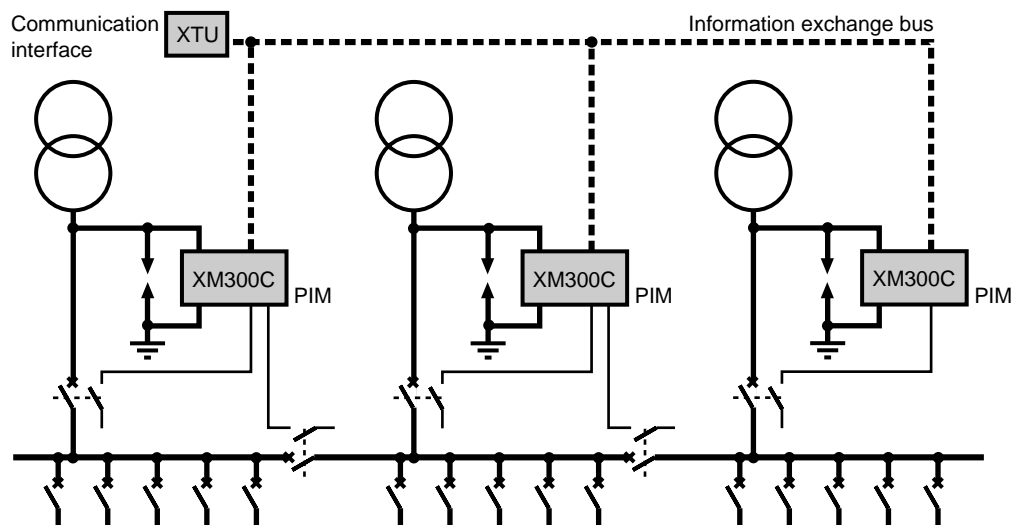
■ For existing installations, in order to restore continuity of supply, it is necessary to identify low insulation feeders and supply them separately with, for example, a TN system, and save the network in IT for the more demanding applications. This solution requires use of a new transformer, either LV/LV, or directly MV/LV, according to power requirements. A similar approach can be applied in order to supply machines experiencing operating problems in IT.

■ For new installations, electrical power distribution in IT must be provided as soon as the need for continuity of supply is apparent. It is preferable, in order to reduce the incidence of network capacity with respect to earth, to limit the size of this network to a building, for example.

Finally, if phase to neutral voltage is required, distribution of the neutral conductor should not be a cause for concern as:

- neutral insulation is monitored,
- use of circuit-breakers with B or G curve and of low sensitivity RCDs simplifies the protection study,

...and avoids the installation (and thus the additional cost) of a specific transformer or a special line.



**Fig. 27** : insulation monitoring system of the various parts of a network with several sources (Merlin Gerin's VigiloHM System).

## 6 Conclusion

Evolution of the various earthing systems should mirror the changing needs of electrical power users.

### 6.1 Availability: an increasing need to be satisfied

The increasing number of computer, automation and control/monitoring equipment has resulted in all major economic entities (industrial, commercial, etc.) calling for greater availability of electrical power.

Today, electrical power is considered to be a simple product with which a number of quality criteria, particularly availability, are associated. To ensure that users benefit from this increased availability, this demand, already acknowledged by electricity utilities, must also be incorporated

in the design of the new internal and private distribution installations... precisely there where the IT earthing system assumes its full importance by indicating the very first fault (not dangerous) and preventing tripping.

However, for the network to benefit from all the advantages of the IT system, designers must carefully consider the future operation of the network and have excellent knowledge of the devices to be supplied.

### 6.2 The IT earthing system finds its true place

#### Usable in a very large number of electrical installations

The IT earthing system can be used in a very large number of electrical installations in industrialised countries, with the exception of applications (e.g. arc furnace, old lighting circuit) and situations (e.g. damp environment, very long network) normally or frequently exhibiting a low insulation level. These countries possess skilled electricians, sufficiently reactive to offer rapid installation servicing (the same day). Moreover, their infrastructures allow use of remote supervision.

#### For adapted distribution circuits

Changes in continuity of service requirements and implementation of new machines with specific characteristics, particularly in the field of electromagnetic compatibility (EMC) mean that the electrical power supply sometimes requires specially adapted distribution circuits. This accounts for the emergence of private distribution networks comprising a variety of sub-networks with an appropriate earthing system. In these conditions, the IT system easily guarantees the necessary continuity of supply.

### 6.3 The added advantage of safety

Installation designers must also identify fire and explosion hazards and satisfy EMC requirements (disturbance of measurements and communications).

The IT earthing system offers the most advantages and best meets operators' requirements with such specific features as:

- better EMC (interconnection of frames and in theory a single earth connection),
- minimum fire and explosion hazards (low first fault currents).

Moreover, its use is encouraged by the upgrading of equipment (PIM, tracking device, supervisor, etc.) allowing:

- anticipation of maintenance (prediction),
- quicker tracking of the first insulation faults (automation), or even remote tracking (remote supervision via digital connections),
- preparation of troubleshooting (remote diagnosis).

## 6.4 In short

Our readers now understand the importance of properly listing the requirements relating to equipment used, the environment and the study conditions of the installation and subsequent modifications, before choosing the earthing system for an electrical distribution network. A brief reminder of the advantages and disadvantages inherent in each earthing system

is essential at this point: this is the purpose of **figure 28**.

**NB:** The installation cost is not included in this table as the possible additional cost of an IT system (PIM, fault tracking system) must be compared with the financial loss generated by unexpected downtime on the first fault... this must be evaluated for each activity.

	TT	TN-C	TN-S	IT
Safety of persons (perfect installation)	■ ■ ■	■ ■ ■	■ ■ ■	■ ■ ■
Safety of equipment				
■ against the fire hazard	■ ■ ■	□	□ □	■ ■ ■
■ for machine protection on an insulation fault	■ ■ ■	□	□	■ ■ ■
Availability of electrical power	□ □	□ □	□ □	■ ■ ■ ■
Electromagnetic compatibility	□ □	□	□ □	□ □
For installation and maintenance				
■ skill	■ ■	■ ■ ■ ■	■ ■ ■ ■	■ ■ ■
■ availability	□	□ □	□ □	■ ■ ■
■ ■ ■ ■ excellent				
■ ■ ■ good				
□ □ average				
□ poor				

**Fig. 28** : summary of the advantages and disadvantages of the various earthing systems.

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- IEC 61000: Electromagnetic compatibility.
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