# Chapter E
# LV Distribution

## Contents

# 1 Earthing schemes

*In a building, the connection of all metal parts of the building and all exposed conductive parts of electrical equipment to an earth electrode prevents the appearance of dangerously high voltages between any two simultaneously accessible metal parts*

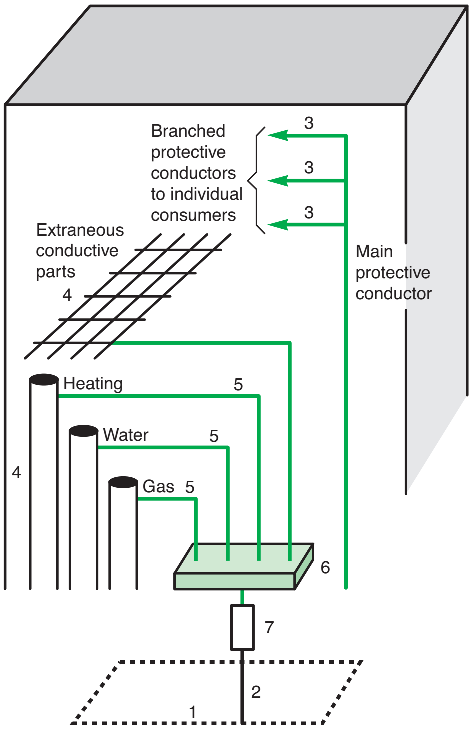


**Fig. E1** : *An example of a block of flats in which the main earthing terminal (6) provides the main equipotential connection; the removable link (7) allows an earth-electrode-resistance check*

## 1.1 Earthing connections

### Definitions

National and international standards (IEC 60364) clearly define the various elements of earthing connections. The following terms are commonly used in industry and in the literature. Bracketed numbers refer to **Figure E1** :

- Earth electrode (1): A conductor or group of conductors in intimate contact with, and providing an electrical connection with Earth (cf details in section 1.6 of Chapter E.)
- Earth: The conductive mass of the Earth, whose electric potential at any point is conventionally taken as zero
- Electrically independent earth electrodes: Earth electrodes located at such a distance from one another that the maximum current likely to flow through one of them does not significantly affect the potential of the other(s)
- Earth electrode resistance: The contact resistance of an earth electrode with the Earth
- Earthing conductor (2): A protective conductor connecting the main earthing terminal (6) of an installation to an earth electrode (1) or to other means of earthing (e.g. TN systems);
- Exposed-conductive-part: A conductive part of equipment which can be touched and which is not a live part, but which may become live under fault conditions
- Protective conductor (3): A conductor used for some measures of protection against electric shock and intended for connecting together any of the following parts:
  - ☐ Exposed-conductive-parts
  - ☐ Extraneous-conductive-parts
  - ☐ The main earthing terminal
  - ☐ Earth electrode(s)
  - ☐ The earthed point of the source or an artificial neutral
- Extraneous-conductive-part: A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation (4). For example:
  - ☐ Non-insulated floors or walls, metal framework of buildings
  - ☐ Metal conduits and pipework (not part of the electrical installation) for water, gas, heating, compressed-air, etc. and metal materials associated with them
- Bonding conductor (5): A protective conductor providing equipotential bonding
- Main earthing terminal (6): The terminal or bar provided for the connection of protective conductors, including equipotential bonding conductors, and conductors for functional earthing, if any, to the means of earthing.

### Connections

**The main equipotential bonding system**

The bonding is carried out by protective conductors and the aim is to ensure that, in the event of an incoming extraneous conductor (such as a gas pipe, etc.) being raised to some potential due to a fault external to the building, no difference of potential can occur between extraneous-conductive-parts within the installation.

The bonding must be effected as close as possible to the point(s) of entry into the building, and be connected to the main earthing terminal (6).

However, connections to earth of metallic sheaths of communications cables require the authorisation of the owners of the cables.

**Supplementary equipotential connections**

These connections are intended to connect all exposed-conductive-parts and all extraneous-conductive-parts simultaneously accessible, when correct conditions for protection have not been met, i.e. the original bonding conductors present an unacceptably high resistance.

**Connection of exposed-conductive-parts to the earth electrode(s)**

The connection is made by protective conductors with the object of providing a low-resistance path for fault currents flowing to earth.

### Components (see **Fig. E2**)

Effective connection of all accessible metal fixtures and all exposed-conductive-parts of electrical appliances and equipment, is essential for effective protection against electric shocks.

| **Component parts to consider:** | |
|---|---|
| **as exposed-conductive-parts** | **as extraneous-conductive-parts** |
| Cableways<br>■ Conduits<br>■ Impregnated-paper-insulated lead-covered cable, armoured or unarmoured<br>■ Mineral insulated metal-sheathed cable (pyrotenax, etc.) | Elements used in building construction<br>■ Metal or reinforced concrete (RC):<br>□ Steel-framed structure<br>□ Reinforcement rods<br>□ Prefabricated RC panels<br>■ Surface finishes:<br>□ Floors and walls in reinforced concrete without further surface treatment<br>□ Tiled surface<br>■ Metallic covering:<br>□ Metallic wall covering |
| Switchgear<br>■ cradle of withdrawable switchgear | |
| Appliances<br>■ Exposed metal parts of class 1 insulated appliances | |
| Non-electrical elements<br>■ metallic fittings associated with cableways (cable trays, cable ladders, etc.)<br>■ Metal objects:<br>□ Close to aerial conductors or to busbars<br>□ In contact with electrical equipment. | Building services elements other than electrical<br>■ Metal pipes, conduits, trunking, etc. for gas, water and heating systems, etc.<br>■ Related metal components (furnaces, tanks, reservoirs, radiators)<br>■ Metallic fittings in wash rooms, bathrooms, toilets, etc.<br>■ Metallised papers |

| **Component parts not to be considered:** | |
|---|---|
| **as exposed-conductive-parts** | **as extraneous-conductive-parts** |
| Diverse service channels, ducts, etc.<br>■ Conduits made of insulating material<br>■ Mouldings in wood or other insulating material<br>■ Conductors and cables without metallic sheaths | ■ Wooden-block floors<br>■ Rubber-covered or linoleum-covered floors<br>■ Dry plaster-block partition<br>■ Brick walls<br>■ Carpets and wall-to-wall carpeting |
| Switchgear<br>■ Enclosures made of insulating material | |
| Appliances<br>■ All appliances having class II insulation regardless of the type of exterior envelope | |

*Fig. E2 : List of exposed-conductive-parts and extraneous-conductive-parts*

## 1.2 Definition of standardised earthing schemes

*The different earthing schemes (often referred to as the type of power system or system earthing arrangements) described characterise the method of earthing the installation downstream of the secondary winding of a MV/LV transformer and the means used for earthing the exposed conductive-parts of the LV installation supplied from it*

The choice of these methods governs the measures necessary for protection against indirect-contact hazards.

The earthing system qualifies three originally independent choices made by the designer of an electrical distribution system or installation:

- The type of connection of the electrical system (that is generally of the neutral conductor) and of the exposed parts to earth electrode(s)
- A separate protective conductor or protective conductor and neutral conductor being a single conductor
- The use of earth fault protection of overcurrent protective switchgear which clear only relatively high fault currents or the use of additional relays able to detect and clear small insulation fault currents to earth

In practice, these choices have been grouped and standardised as explained below.

Each of these choices provides standardised earthing systems with three advantages and drawbacks:

- Connection of the exposed conductive parts of the equipment and of the neutral conductor to the PE conductor results in equipotentiality and lower overvoltages but increases earth fault currents
- A separate protective conductor is costly even if it has a small cross-sectional area but it is much more unlikely to be polluted by voltage drops and harmonics, etc. than a neutral conductor is. Leakage currents are also avoided in extraneous conductive parts
- Installation of residual current protective relays or insulation monitoring devices are much more sensitive and permits in many circumstances to clear faults before heavy damage occurs (motors, fires, electrocution). The protection offered is in addition independent with respect to changes in an existing installation

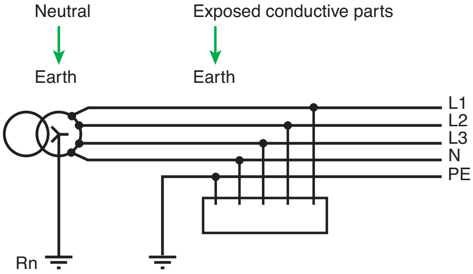


*Fig. E3 : TT System*

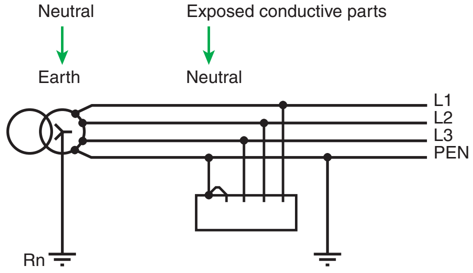


*Fig. E4 : TN-C system*

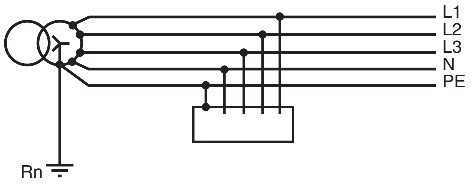


*Fig. E5 : TN-S system*

## TT system (earthed neutral) (see **Fig. E3**)

One point at the supply source is connected directly to earth. All exposed- and extraneous-conductive-parts are connected to a separate earth electrode at the installation. This electrode may or may not be electrically independent of the source electrode. The two zones of influence may overlap without affecting the operation of protective devices.

## TN systems (exposed conductive parts connected to the neutral)

The source is earthed as for the TT system (above). In the installation, all exposed- and extraneous-conductive-parts are connected to the neutral conductor. The several versions of TN systems are shown below.

### TN-C system (see **Fig. E4**)

The neutral conductor is also used as a protective conductor and is referred to as a PEN (Protective Earth and Neutral) conductor. This system is not permitted for conductors of less than 10 mm$^2$ or for portable equipment.

The TN-C system requires an effective equipotential environment within the installation with dispersed earth electrodes spaced as regularly as possible since the PEN conductor is both the neutral conductor and at the same time carries phase unbalance currents as well as 3$^{rd}$ order harmonic currents (and their multiples).

The PEN conductor must therefore be connected to a number of earth electrodes in the installation.

Caution: In the TN-C system, the “protective conductor” function has priority over the “neutral function”. In particular, a PEN conductor must always be connected to the earthing terminal of a load and a jumper is used to connect this terminal to the neutral terminal.

### TN-S system (see **Fig. E5**)

The TN-S system (5 wires) is obligatory for circuits with cross-sectional areas less than 10 mm$^2$ for portable equipment.

The protective conductor and the neutral conductor are separate. On underground cable systems where lead-sheathed cables exist, the protective conductor is generally the lead sheath. The use of separate PE and N conductors (5 wires) is obligatory for circuits with cross-sectional areas less than 10 mm$^2$ for portable equipment.

### TN-C-S system (see **Fig. E6** below and **Fig. E7** next page)

The TN-C and TN-S systems can be used in the same installation. In the TN-C-S system, the TN-C (4 wires) system must never be used downstream of the TN-S (5 wires) system, since any accidental interruption in the neutral on the upstream part would lead to an interruption in the protective conductor in the downstream part and therefore a danger.

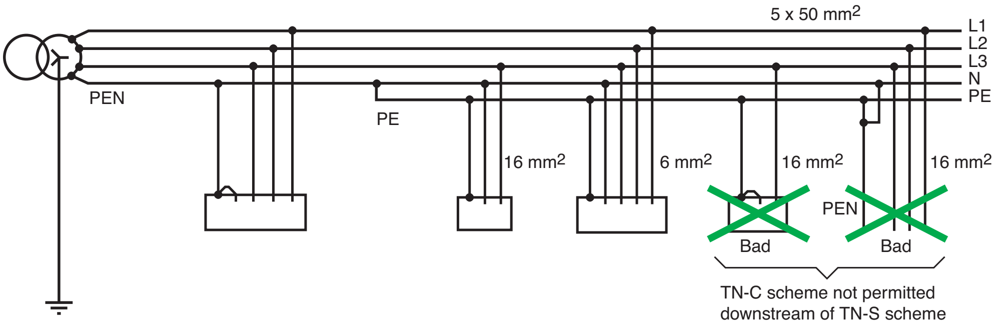


*Fig. E6 : TN-C-S system*

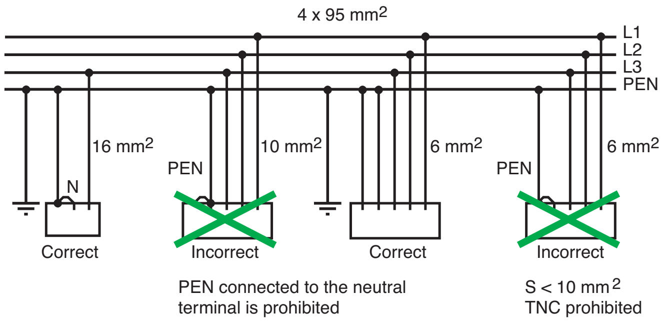


*Fig. E7 : Connection of the PEN conductor in the TN-C system*

## IT system (isolated or impedance-earthed neutral)

### IT system (isolated neutral)

No intentional connection is made between the neutral point of the supply source and earth (see **Fig. E8**).

Exposed- and extraneous-conductive-parts of the installation are connected to an earth electrode.

In practice all circuits have a leakage impedance to earth, since no insulation is perfect. In parallel with this (distributed) resistive leakage path, there is the distributed capacitive current path, the two paths together constituting the normal leakage impedance to earth (see **Fig. E9**).

**Example** (see **Fig. E10**)

In a LV 3-phase 3-wire system, 1 km of cable will have a leakage impedance due to C1, C2, C3 and R1, R2 and R3 equivalent to a neutral earth impedance Zct of 3,000 to 4,000 $\Omega$, without counting the filtering capacitances of electronic devices.

### IT system (impedance-earthed neutral)

An impedance Zs (in the order of 1,000 to 2,000 $\Omega$) is connected permanently between the neutral point of the transformer LV winding and earth (see **Fig. E11**). All exposed- and extraneous-conductive-parts are connected to an earth electrode. The reasons for this form of power-source earthing are to fix the potential of a small network with respect to earth (Zs is small compared to the leakage impedance) and to reduce the level of overvoltages, such as transmitted surges from the MV windings, static charges, etc. with respect to earth. It has, however, the effect of slightly increasing the first-fault current level.

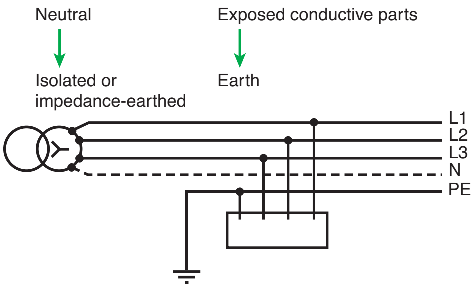


*Fig. E8 : IT system (isolated neutral)*

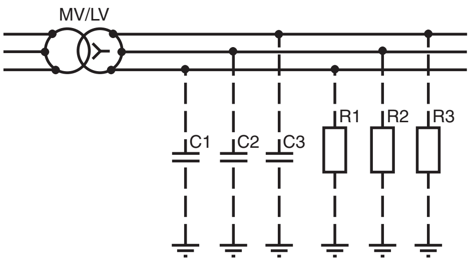


*Fig. E9 : IT system (isolated neutral)*

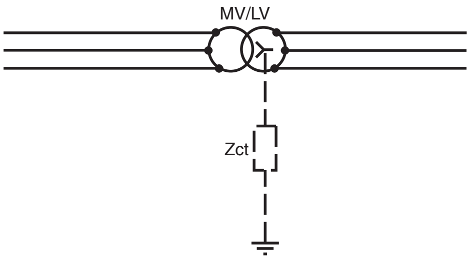


*Fig. E10 : Impedance equivalent to leakage impedances in an IT system*

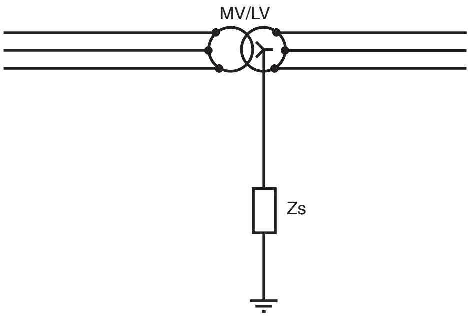


*Fig. E11 : IT system (impedance-earthed neutral)*

## 1.3 Characteristics of TT, TN and IT systems

*The TT system:*

*■ Technique for the protection of persons: the exposed conductive parts are earthed and residual current devices (RCDs) are used*

*■ Operating technique: interruption for the first insulation fault*

### TT system (see **Fig. E12**)

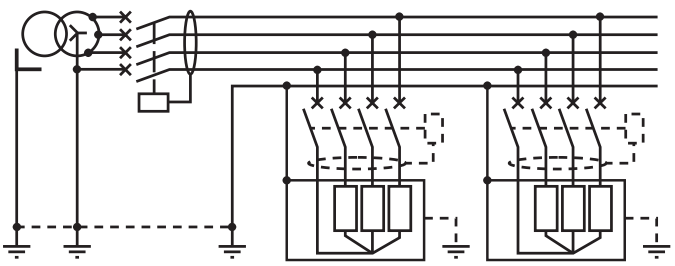


*Fig. E12 : TT system*

**Note**: If the exposed conductive parts are earthed at a number of points, an RCD must be installed for each set of circuits connected to a given earth electrode.

**Main characteristics**

- Simplest solution to design and install. Used in installations supplied directly by the public LV distribution network.
- Does not require continuous monitoring during operation (a periodic check on the RCDs may be necessary).
- Protection is ensured by special devices, the residual current devices (RCD), which also prevent the risk of fire when they are set to ⩽ 500 mA.
- Each insulation fault results in an interruption in the supply of power, however the outage is limited to the faulty circuit by installing the RCDs in series (selective RCDs) or in parallel (circuit selection).
- Loads or parts of the installation which, during normal operation, cause high leakage currents, require special measures to avoid nuisance tripping, i.e. supply the loads with a separation transformer or use specific RCDs (see section 5.1 in chapter F).

*The TN system:*

*■ Technique for the protection of persons:*
*□ Interconnection and earthing of exposed conductive parts and the neutral are mandatory*
*□ Interruption for the first fault using overcurrent protection (circuit-breakers or fuses)*

*■ Operating technique: interruption for the first insulation fault*

### TN system (see **Fig. E13** and **Fig. E14** )

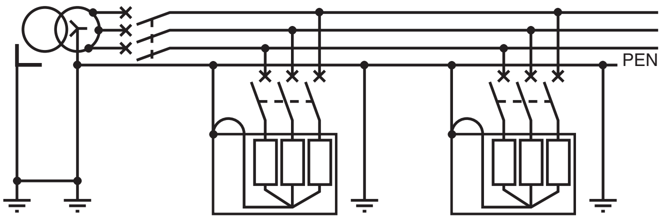


*Fig. E13 : TN-C system*

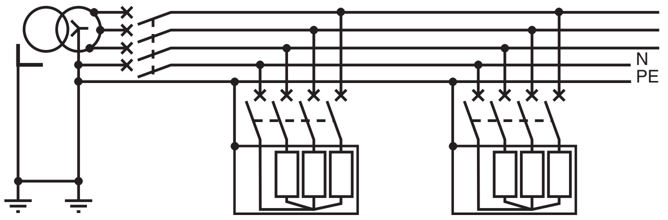


*Fig. E14 : TN-S system*

**Main characteristics**

■ Generally speaking, the TN system:

□ requires the installation of earth electrodes at regular intervals throughout the installation

□ Requires that the initial check on effective tripping for the first insulation fault be carried out by calculations during the design stage, followed by mandatory measurements to confirm tripping during commissioning

□ Requires that any modification or extension be designed and carried out by a qualified electrician

□ May result, in the case of insulation faults, in greater damage to the windings of rotating machines

□ May, on premises with a risk of fire, represent a greater danger due to the higher fault currents

■ In addition, the TN-C system:

□ At first glance, would appear to be less expensive (elimination of a device pole and of a conductor)

□ Requires the use of fixed and rigid conductors

□ Is forbidden in certain cases:

- Premises with a risk of fire
- For computer equipment (presence of harmonic currents in the neutral)

■ In addition, the TN-S system:

□ May be used even with flexible conductors and small conduits

□ Due to the separation of the neutral and the protection conductor, provides a clean PE (computer systems and premises with special risks)

*IT system:*

■ *Protection technique:*

□ *Interconnection and earthing of exposed conductive parts*

□ *Indication of the first fault by an insulation monitoring device (IMD)*

□ *Interruption for the second fault using overcurrent protection (circuit-breakers or fuses)*

■ *Operating technique:*

□ *Monitoring of the first insulation fault*

□ *Mandatory location and clearing of the fault*

□ *Interruption for two simultaneous insulation faults*

## **IT system** (see **Fig. E15**)

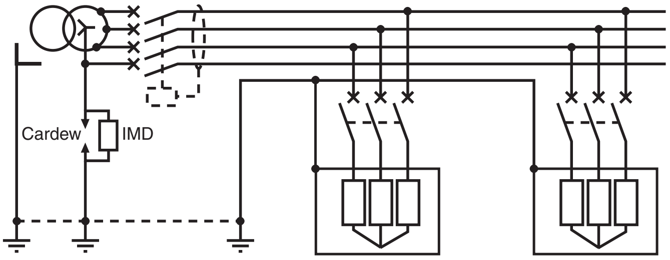


*Fig. E15 : IT system*

**Main characteristics**

■ Solution offering the best continuity of service during operation

■ Indication of the first insulation fault, followed by mandatory location and clearing, ensures systematic prevention of supply outages

■ Generally used in installations supplied by a private MV/LV or LV/LV transformer

■ Requires maintenance personnel for monitoring and operation

■ Requires a high level of insulation in the network (implies breaking up the network if it is very large and the use of circuit-separation transformers to supply loads with high leakage currents)

■ The check on effective tripping for two simultaneous faults must be carried out by calculations during the design stage, followed by mandatory measurements during commissioning on each group of interconnected exposed conductive parts

■ Protection of the neutral conductor must be ensured as indicated in section 7.2 of Chapter G

*Selection does not depend on safety criteria. The three systems are equivalent in terms of protection of persons if all installation and operating rules are correctly followed.*
*The selection criteria for the best system(s) depend on the regulatory requirements, the required continuity of service, operating conditions and the types of network and loads.*

## 1.4 Selection criteria for the TT, TN and IT systems

In terms of the protection of persons, the three system earthing arrangements (SEA) are equivalent if all installation and operating rules are correctly followed. Consequently, selection does not depend on safety criteria.

It is by combining all requirements in terms of regulations, continuity of service, operating conditions and the types of network and loads that it is possible to determine the best system(s) (see **Fig. E16**).
Selection is determined by the following factors:

- Above all, the applicable regulations which in some cases impose certain types of SEA
- Secondly, the decision of the owner if supply is via a private MV/LV transformer (MV subscription) or the owner has a private energy source (or a separate-winding transformer)

If the owner effectively has a choice, the decision on the SEA is taken following discussions with the network designer (design office, contractor)
The discussions must cover:

- First of all, the operating requirements (the required level of continuity of service) and the operating conditions (maintenance ensured by electrical personnel or not, in-house personnel or outsourced, etc.)
- Secondly, the particular characteristics of the network and the loads (see **Fig. E17** next page)

| | TT | TN-S | TN-C | IT1 | IT2 | Comments |
|---|---|---|---|---|---|---|
| **Electrical characteristics** | | | | | | |
| Fault current | - | - - | - - | + | - - | Only the IT system offers virtually negligible first-fault currents |
| Fault voltage | - | - | - | + | - | In the IT system, the touch voltage is very low for the first fault, but is considerable for the second |
| Touch voltage | +/- - | - | - | + | - | In the TT system, the touch voltage is very low if system is equipotential, otherwise it is high |
| **Protection** | | | | | | |
| Protection of persons against indirect contact | + | + | + | + | + | All SEAs (system earthing arrangement) are equivalent, if the rules are followed |
| Protection of persons with emergency generating sets | + | - | - | + | - | Systems where protection is ensured by RCDs are not sensitive to a change in the internal impedance of the source |
| Protection against fire (with an RCD) | + | + | **Not allowed** | + | + | All SEAs in which RCDs can be used are equivalent.<br>The TN-C system is forbidden on premises where there is a risk of fire |
| **Overvoltages** | | | | | | |
| Continuous overvoltage | + | + | + | - | + | A phase-to-earth overvoltage is continuous in the IT system if there is a first insulation fault |
| Transient overvoltage | + | - | - | + | - | Systems with high fault currents may cause transient overvoltages |
| Overvoltage if transformer breakdown (primary/secondary) | - | + | + | + | + | In the TT system, there is a voltage imbalance between the different earth electrodes. The other systems are interconnected to a single earth electrode |
| **Electromagnetic compatibility** | | | | | | |
| Immunity to nearby lightning strikes | - | + | + | + | + | In the TT system, there may be voltage imbalances between the earth electrodes. In the TT system, there is a significant current loop between the two separate earth electrodes |
| Immunity to lightning strikes on MV lines | - | - | - | - | - | All SEAs are equivalent when a MV line takes a direct lightning strike |
| Continuous emission of an electromagnetic field | + | + | - | + | + | Connection of the PEN to the metal structures of the building is conducive to the continuous generation of electromagnetic fields |
| Transient non-equipotentiality of the PE | + | - | - | + | - | The PE is no longer equipotential if there is a high fault current |
| **Continuity of service** | | | | | | |
| Interruption for first fault | - | - | - | + | + | Only the IT system avoids tripping for the first insulation fault |
| Voltage dip during insulation fault | + | - | - | + | - | The TN-S, TNC and IT (2nd fault) systems generate high fault currents which may cause phase voltage dips |
| **Installation** | | | | | | |
| Special devices | - | + | + | - | - | The TT system requires the use of RCDs. The IT system requires the use of IMDs |
| Number of earth electrodes | - | + | + | -/+ | -/+ | The TT system requires two distinct earth electrodes. The IT system offers a choice between one or two earth electrodes |
| Number of cables | - | - | + | - | - | Only the TN-C system offers, in certain cases, a reduction in the number of cables |
| **Maintenance** | | | | | | |
| Cost of repairs | - | - - | - - | - | - - | The cost of repairs depends on the damage caused by the amplitude of the fault currents |
| Installation damage | + | - | - | ++ | - | Systems causing high fault currents require a check on the installation after clearing the fault |

*Fig. E16 : Comparison of system earthing arrangements*

| **Type of network** | **Advised** | **Possible** | **Not advised** |
|---|---|---|---|
| Very large network with high-quality earth electrodes for exposed conductive parts (10 Ω max.) | | TT, TN, IT (1)<br>or mixed | |
| Very large network with low-quality earth electrodes for exposed conductive parts (> 30 Ω) | TN | TN-S | IT (1)<br>TN-C |
| Disturbed area (storms)<br>(e.g. television or radio transmitter) | TN | TT | IT (2) |
| Network with high leakage currents (> 500 mA) | TN (4) | IT (4)<br>TT (3) (4) | |
| Network with outdoor overhead lines | TT (5) | TN (5) (6) | IT (6) |
| Emergency standby generator set | IT | TT | TN (7) |
| **Type of loads** | | | |
| Loads sensitive to high fault currents (motors, etc.) | IT | TT | TN (8) |
| Loads with a low insulation level (electric furnaces, welding machines, heating elements, immersion heaters, equipment in large kitchens) | TN (9) | TT (9) | IT |
| Numerous phase-neutral single-phase loads<br>(mobile, semi-fixed, portable) | TT (10)<br>TN-S | | IT (10)<br>TN-C (10) |
| Loads with sizeable risks (hoists, conveyers, etc.) | TN (11) | TT (11) | IT (11) |
| Numerous auxiliaries (machine tools) | TN-S | TN-C<br>IT (12 bis) | TT (12) |
| **Miscellaneous** | | | |
| Supply via star-star connected power transformer (13) | TT | IT<br>without neutral | IT (13)<br>with neutral |
| Premises with risk of fire | IT (15) | TN-S (15)<br>TT (15) | TN-C (14) |
| Increase in power level of LV utility subscription, requiring a private substation | TT (16) | | |
| Installation with frequent modifications | TT (17) | | TN (18)<br>IT (18) |
| Installation where the continuity of earth circuits is uncertain (work sites, old installations) | TT (19) | TN-S | TN-C<br>IT (19) |
| Electronic equipment (computers, PLCs) | TN-S | TT | TN-C |
| Machine control-monitoring network, PLC sensors and actuators | IT (20) | TN-S, TT | |

(1) When the SEA is not imposed by regulations, it is selected according to the level of operating characteristics (continuity of service that is mandatory for safety reasons or desired to enhance productivity, etc.)
Whatever the SEA, the probability of an insulation failure increases with the length of the network. It may be a good idea to break up the network, which facilitates fault location and makes it possible to implement the system advised above for each type of application.
(2) The risk of flashover on the surge limiter turns the isolated neutral into an earthed neutral. These risks are high for regions with frequent thunder storms or installations supplied by overhead lines. If the IT system is selected to ensure a higher level of continuity of service, the system designer must precisely calculate the tripping conditions for a second fault.
(3) Risk of RCD nuisance tripping.
(4) Whatever the SEA, the ideal solution is to isolate the disturbing section if it can be easily identified.
(5) Risks of phase-to-earth faults affecting equipotentiality.
(6) Insulation is uncertain due to humidity and conducting dust.
(7) The TN system is not advised due to the risk of damage to the generator in the case of an internal fault. What is more, when generator sets supply safety equipment, the system must not trip for the first fault.
(8) The phase-to-earth current may be several times higher than In, with the risk of damaging or accelerating the ageing of motor windings, or of destroying magnetic circuits.
(9) To combine continuity of service and safety, it is necessary and highly advised, whatever the SEA, to separate these loads from the rest of the installation (transformers with local neutral connection).
(10) When load equipment quality is not a design priority, there is a risk that the insulation resistance will fall rapidly. The TT system with RCDs is the best means to avoid problems.
(11) The mobility of this type of load causes frequent faults (sliding contact for bonding of exposed conductive parts) that must be countered. Whatever the SEA, it is advised to supply these circuits using transformers with a local neutral connection.
(12) Requires the use of transformers with a local TN system to avoid operating risks and nuisance tripping at the first fault (TT) or a double fault (IT).
(12 bis) With a double break in the control circuit.
(13) Excessive limitation of the phase-to-neutral current due to the high value of the zero-phase impedance (at least 4 to 5 times the direct impedance). This system must be replaced by a star-delta arrangement.
(14) The high fault currents make the TN system dangerous. The TN-C system is forbidden.
(15) Whatever the system, the RCD must be set to $\Delta n \leqslant 500$ mA.
(16) An installation supplied with LV energy must use the TT system. Maintaining this SEA means the least amount of modifications on the existing network (no cables to be run, no protection devices to be modified).
(17) Possible without highly competent maintenance personnel.
(18) This type of installation requires particular attention in maintaining safety. The absence of preventive measures in the TN system means highly qualified personnel are required to ensure safety over time.
(19) The risks of breaks in conductors (supply, protection) may cause the loss of equipotentiality for exposed conductive parts. A TT system or a TN-S system with 30 mA RCDs is advised and is often mandatory. The IT system may be used in very specific cases.
(20) This solution avoids nuisance tripping for unexpected earth leakage.

***Fig. E17** : Influence of networks and loads on the selection of system earthing arrangements*

## 1.5 Choice of earthing method - implementation

After consulting applicable regulations, Figures E16 and E17 can be used as an aid in deciding on divisions and possible galvanic isolation of appropriate sections of a proposed installation.

### Division of source

This technique concerns the use of several transformers instead of employing one high-rated unit. In this way, a load that is a source of network disturbances (large motors, furnaces, etc.) can be supplied by its own transformer.
The quality and continuity of supply to the whole installation are thereby improved.
The cost of switchgear is reduced (short-circuit current level is lower).
The cost-effectiveness of separate transformers must be determined on a case by case basis.

### Network islands

The creation of galvanically-separated “islands” by means of LV/LV transformers makes it possible to optimise the choice of earthing methods to meet specific requirements (see **Fig. E18** and **Fig. E19** ).

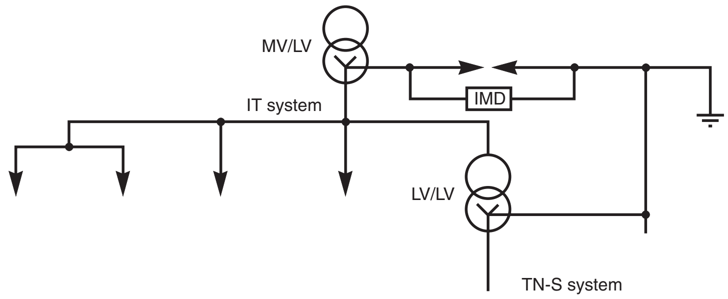


*Fig. E18 : TN-S island within an IT system*

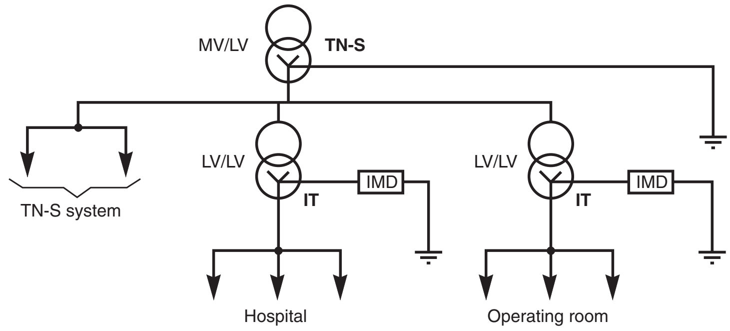


*Fig. E19 : IT islands within a TN-S system*

### Conclusion

The optimisation of the performance of the whole installation governs the choice of earthing system.

Including:

- Initial investments, and
- Future operational expenditures, hard to assess, that can arise from insufficient reliability, quality of equipment, safety, continuity of service, etc.

An ideal structure would comprise normal power supply sources, local reserve power supply sources (see section 1.4 of Chapter E) and the appropriate earthing arrangements.

*A very effective method of obtaining a low-resistance earth connection is to bury a conductor in the form of a closed loop in the soil at the bottom of the excavation for building foundations.*
*The resistance R of such an electrode (in homogeneous soil) is given (approximately) in ohms by:* $R = \frac{2\,\rho}{L}$ *where*

*L = length of the buried conductor in metres*
*$\rho$ = soil resistivity in ohm-metres*

## 1.6 Installation and measurements of earth electrodes

The quality of an earth electrode (resistance as low as possible) depends essentially on two factors:

- Installation method
- Type of soil

### Installation methods

Three common types of installation will be discussed:

**Buried ring** (see **Fig. E20**)

This solution is strongly recommended, particularly in the case of a new building. The electrode should be buried around the perimeter of the excavation made for the foundations. It is important that the bare conductor be in intimate contact with the soil (and not placed in the gravel or aggregate hard-core, often forming a base for concrete). At least four (widely-spaced) vertically arranged conductors from the electrode should be provided for the installation connections and, where possible, any reinforcing rods in concrete work should be connected to the electrode.

The conductor forming the earth electrode, particularly when it is laid in an excavation for foundations, must be in the earth, at least 50 cm below the hard-core or aggregate base for the concrete foundation. Neither the electrode nor the vertical rising conductors to the ground floor, should ever be in contact with the foundation concrete.

For existing buildings, the electrode conductor should be buried around the outside wall of the premises to a depth of at least 1 metre. As a general rule, all vertical connections from an electrode to above-ground level should be insulated for the nominal LV voltage (600-1,000 V).

The conductors may be:

- Copper: Bare cable ($\geqslant$ 25 mm$^2$) or multiple-strip ($\geqslant$ 25 mm$^2$ and $\geqslant$ 2 mm thick)
- Aluminium with lead jacket: Cable ($\geqslant$ 35 mm$^2$)
- Galvanised-steel cable: Bare cable ($\geqslant$ 95 mm$^2$) or multiple-strip ($\geqslant$ 100 mm$^2$ and $\geqslant$ 3 mm thick)

The approximate resistance R of the electrode in ohms:

$$R = \frac{2\,\rho}{L}$$

where

L = length of conductor in metres

$\rho$ = resistivity of the soil in ohm-metres (see “Influence of the type of soil” next page)

*For n rods:* $R = \frac{1}{n}\frac{\rho}{L}$

**Earthing rods** (see **Fig. E21**)

Vertically driven earthing rods are often used for existing buildings, and for improving (i.e. reducing the resistance of) existing earth electrodes.

The rods may be:

- Copper or (more commonly) copper-clad steel. The latter are generally 1 or 2 metres long and provided with screwed ends and sockets in order to reach considerable depths, if necessary (for instance, the water-table level in areas of high soil resistivity)
- Galvanised (see note (1) next page) steel pipe $\geqslant$ 25 mm diameter or rod $\geqslant$ 15 mm diameter, $\geqslant$ 2 metres long in each case.

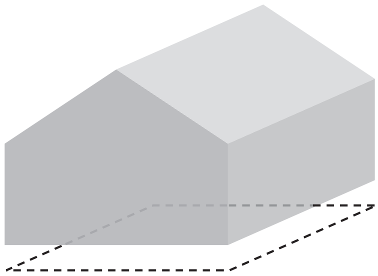


*Fig. E20 : Conductor buried below the level of the foundations, i.e. not in the concrete*

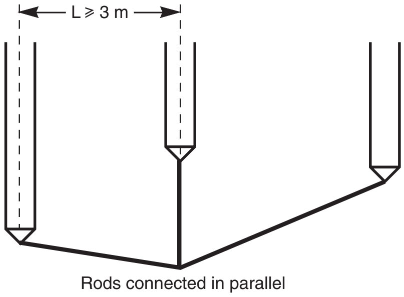


*Fig. E21 : Earthing rods*

It is often necessary to use more than one rod, in which case the spacing between them should exceed the depth to which they are driven, by a factor of 2 to 3.

The total resistance (in homogeneous soil) is then equal to the resistance of one rod, divided by the number of rods in question. The approximate resistance R obtained is:

$R = \frac{1}{n}\frac{\rho}{L}$ if the distance separating the rods > 4L

where

L = the length of the rod in metres

$\rho$ = resistivity of the soil in ohm-metres (see "Influence of the type of soil" below)

n = the number of rods

*For a vertical plate electrode:* $R = \frac{0.8\ \rho}{L}$

**Vertical plates** (see **Fig. E22**)

Rectangular plates, each side of which must be ⩾ 0.5 metres, are commonly used as earth electrodes, being buried in a vertical plane such that the centre of the plate is at least 1 metre below the surface of the soil.

The plates may be:

- Copper of 2 mm thickness
- Galvanised [1] steel of 3 mm thickness

The resistance R in ohms is given (approximately), by:

$R = \frac{0.8\ \rho}{L}$

L = the perimeter of the plate in metres

$\rho$ = resistivity of the soil in ohm-metres (see "Influence of the type of soil" below)

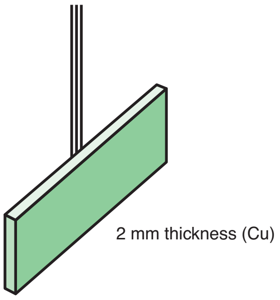


*Fig. E22 : Vertical plate*

## Influence of the type of soil

*Measurements on earth electrodes in similar soils are useful to determine the resistivity value to be applied for the design of an earth-electrode system*

| **Type of soil** | **Mean value of resistivity in Ωm** |
|---|---|
| Swampy soil, bogs | 1 - 30 |
| Silt alluvium | 20 - 100 |
| Humus, leaf mould | 10 - 150 |
| Peat, turf | 5 - 100 |
| Soft clay | 50 |
| Marl and compacted clay | 100 - 200 |
| Jurassic marl | 30 - 40 |
| Clayey sand | 50 - 500 |
| Siliceous sand | 200 - 300 |
| Stoney ground | 1,500 - 3,000 |
| Grass-covered-stoney sub-soil | 300 - 500 |
| Chalky soil | 100 - 300 |
| Limestone | 1,000 - 5,000 |
| Fissured limestone | 500 - 1,000 |
| Schist, shale | 50 - 300 |
| Mica schist | 800 |
| Granite and sandstone | 1,500 - 10,000 |
| Modified granite and sandstone | 100 - 600 |

*Fig. E23 : Resistivity (Ωm) for different types of soil*

| **Type of soil** | **Average value of resistivity in Ωm** |
|---|---|
| Fertile soil, compacted damp fill | 50 |
| Arid soil, gravel, uncompacted non-uniform fill | 500 |
| Stoney soil, bare, dry sand, fissured rocks | 3,000 |

*Fig. E24 : Average resistivity (Ωm) values for approximate earth-elect*

[1] Where galvanised conducting materials are used for earth electrodes, sacrificial cathodic protection anodes may be necessary to avoid rapid corrosion of the electrodes where the soil is aggressive. Specially prepared magnesium anodes (in a porous sack filled with a suitable "soil") are available for direct connection to the electrodes. In such circumstances, a specialist should be consulted

## Measurement and constancy of the resistance between an earth electrode and the earth

### The resistance of the electrode/earth interface rarely remains constant

Among the principal factors affecting this resistance are the following:

- Humidity of the soil

The seasonal changes in the moisture content of the soil can be significant at depths of up to 2 meters.

At a depth of 1 metre the resistivity and therefore the resistance can vary by a ratio of 1 to 3 between a wet winter and a dry summer in temperate regions

- Frost

Frozen earth can increase the resistivity of the soil by several orders of magnitude. This is one reason for recommending the installation of deep electrodes, in particular in cold climates

- Ageing

The materials used for electrodes will generally deteriorate to some extent for various reasons, for example:

☐ Chemical reactions (in acidic or alkaline soils)

☐ Galvanic: due to stray DC currents in the earth, for example from electric railways, etc. or due to dissimilar metals forming primary cells. Different soils acting on sections of the same conductor can also form cathodic and anodic areas with consequent loss of surface metal from the latter areas. Unfortunately, the most favourable conditions for low earth-electrode resistance (i.e. low soil resistivity) are also those in which galvanic currents can most easily flow.

- Oxidation

Brazed and welded joints and connections are the points most sensitive to oxidation. Thorough cleaning of a newly made joint or connection and wrapping with a suitable greased-tape binding is a commonly used preventive measure.

### Measurement of the earth-electrode resistance

There must always be one or more removable links to isolate an earth electrode so that it can be tested.

There must always be removable links which allow the earth electrode to be isolated from the installation, so that periodic tests of the earthing resistance can be carried out. To make such tests, two auxiliary electrodes are required, each consisting of a vertically driven rod.

- Ammeter method (see **Fig. E25**)

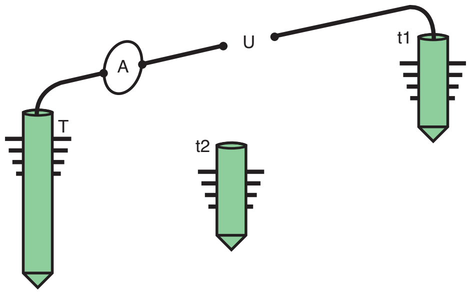


*Fig. E25 : Measurement of the resistance to earth of the earth electrode of an installation by means of an ammeter*

$$A = R_T + R_{t1} = \frac{U_{Tt1}}{i_1}$$

$$B = R_{t1} + R_{t2} = \frac{U_{t1t2}}{i_2}$$

$$C = R_{t2} + R_T = \frac{U_{t2T}}{i_3}$$

When the source voltage U is constant (adjusted to be the same value for each test) then:

$$R_T = \frac{U}{2}\left(\frac{1}{i_1} + \frac{1}{i_3} - \frac{1}{i_2}\right)$$

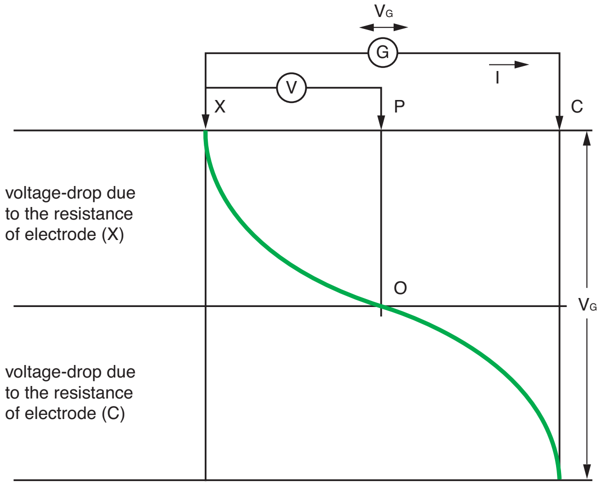
In order to avoid errors due to stray earth currents (galvanic -DC- or leakage currents from power and communication networks and so on) the test current should be AC, but at a different frequency to that of the power system or any of its harmonics. Instruments using hand-driven generators to make these measurements usually produce an AC voltage at a frequency of between 85 Hz and 135 Hz.

The distances between the electrodes are not critical and may be in different directions from the electrode being tested, according to site conditions. A number of tests at different spacings and directions are generally made to cross-check the test results.

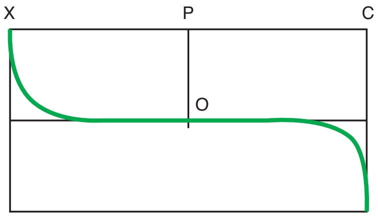
- Use of a direct-reading earthing-resistance ohmmeter

These instruments use a hand-driven or electronic-type AC generator, together with two auxiliary electrodes, the spacing of which must be such that the zone of influence of the electrode being tested should not overlap that of the test electrode (C). The test electrode (C) furthest from the electrode (X) under test, passes a current through the earth and the electrode under test, while the second test electrode (P) picks up a voltage. This voltage, measured between (X) and (P), is due to the test current and is a measure of the contact resistance (of the electrode under test) with earth. It is clear that the distance (X) to (P) must be carefully chosen to give accurate results. If the distance (X) to (C) is increased, however, the zones of resistance of electrodes (X) and (C) become more remote, one from the other, and the curve of potential (voltage) becomes more nearly horizontal about the point (O).

In practical tests, therefore, the distance (X) to (C) is increased until readings taken with electrode (P) at three different points, i.e. at (P) and at approximately 5 metres on either side of (P), give similar values. The distance (X) to (P) is generally about 0.68 of the distance (X) to (C).



**a)** the principle of measurement is based on assumed homogeneous soil conditions. Where the zones of influence of electrodes C and X overlap, the location of test electrode P is difficult to determine for satisfactory results.



**b)** showing the effect on the potential gradient when (X) and (C) are widely spaced. The location of test electrode P is not critical and can be easily determined.

***Fig. E26** : Measurement of the resistance to the mass of earth of electrode (X) using an earth-electrode-testing ohmmeter.*