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ELECTRICITE DU CAMBODGE

TECHNICAL POLICY

EDC-TP-002

EARTHINGS for MV and LV Distribution Networks

VERSION 2: July 2021

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Version 2: July 2021

Modifications from Version 1 December 2018

The modification concerns the cross bounding of cable screens at straight joints

The paragraph 2.2.3 and 2.2.4 are modified: screens cross bounding and screens earth connection at joints locations are cancelled.

The technical corresponding data sheets (10.a and 11) are cancelled.

Content

EARTHINGS for MV and LV Distribution Networks

1 Principles of earthings

1.1 Purpose of earthings

1.1.1 Definitions

The earthing of an electrical network consists in connecting its masses, or its neutral conductors, to a grounding point by means of one or more protective conductors.

A grounding consists of a set of buried conductors, in direct contact with the ground and electrically connected to each other.

For a small structure (pole) or structure (MV/LV substation etc..), the term **"earthing"** is used, and for major structures (such as HV / MV substations) the term **"earthing grid"** is used.

This document deals with some parts of the earthing of the MV network neutral conductor that is explained and developed in EDC-TP-001 technical policy.

1.1.2 Role of an earthing/grounding

The role of earthing on electrical work is to allow the flow of various fault currents inside the ground, as lightning currents, fault currents at 50 Hz. or electrostatic charge flow currents.

During the flow of such currents through a grounding point or an earthing, potential differences may occur between certain points, such as between two distinct metallic masses, or between the earth electrode and the surrounding ground, or between two points of the ground.

The design of earthing and earthing grid must be such as to ensure:

- the safety of people,
- the protection of power installations,
- the protection of sensitive equipment,
- the fixing of a reference potential.

1.1.2.1 The safety of people

When high currents flow into the ground, safety must be ensured:

- inside the electrical installation, limiting to non-hazardous values the potential difference between simultaneously accessible masses;
- in its immediate surroundings, by limiting the step voltage and the contact (or touch) voltage to values that are not dangerous for people.

This limitation is achieved through knowledge and control of the distribution of potential at the soil surface. In the case of an extended electrical installation, the ideal situation is that one that can seek to approach is the equipotentiality of all the masses.

1.1.2.2 Protection of power installations and equipment operating at low levels of equipotentiality

The earth network of an electrical structure must limit the effects of potential increases caused by:

- faults at 50 Hz;
- switch operations in generation stations, substations or distribution network;
- Overvoltage of atmospheric origin (surges).

This limitation is the more effective when this earthing facilitates the flow of the current in the ground, that is to say it has a low earth impedance as well for slow phenomena (50 Hz faults) only and for fast (high frequency) phenomena, such as those caused by lightning.

In addition to power structures, equipment or stations operating at much lower voltage levels are often found in substations or power plants: electronic or electromechanical relaying equipment, telecommunications installations, etc.

These equipment are also exposed to the overvoltage effects experienced by the power structures, with which they can be linked by resistive (or galvanic), inductive, capacitive or more generally electromagnetic coupling.

Different equipment placed in the same structure must, when electrically connected, remain attached to the same potential, including during the disturbances mentioned above. This shows the importance of the earth resistance and the equipotentiality quality of the earthing grid, especially for low-level equipment.

1.2 The different types of earthing

In electrical power distribution systems, earthing is usually referred to the part to which it is connected. Thus, the following earths are identified:

- Earthing of the masses of electrical installations,
- earthing of the neutral conductor,
- earthing for overvoltage protections of the network.

These earthing are the subject of prescriptions described in several articles of the General Requirements of Electric Power Technical Standard of the Kingdom of Cambodia of July 2004 including all amendments.

Nevertheless some important information not clearly mentioned in the PROKAS needs to be explained as follow:

1.2.1 Earthing of the masses of electrical installations

"The resistance of the earth electrode shall have an appropriate value for the use to which the corresponding earth connection is intended. (Class of earthing)

Protect people against the risks that will result for them from simultaneous contact with masses and conductive elements."

The main purpose of these provisions is the protection of persons intervening or approaching the vicinity of the installations.

These persons must be protected against the risks which would result for them from simultaneous contacts between two points brought to different potentials (masses and metal parts in connection with them, floors and walls, etc.).

It is therefore necessary to fix the potential of the earth all the metal parts of an installation. It is for this purpose that we seek to connect all conductive elements or conductive parts simultaneously accessible.

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A low value of the earth resistance of the masses also makes it possible to limit the rise in local potential.

1.2.2 Earthing of the neutral conductor

"For LV distribution networks the three-phase distribution must include a neutral conductor connected to a neutral point and grounded. The single-phase distribution must have a neutral point placed directly to the ground."

This arrangement makes it possible to set the potential of the LV network.

"For MV networks, earthing, via a low value impedance of the neutral point of power transformers of MV networks ... "."

In the case of a single-phase MV fault, the impedance inserted in the neutral earthing limits the earth fault current value to control:

- the rise in local potential;
- induction phenomena on telecommunications installations;
- the electrodynamic and thermal forces on the equipment.

1.2.3 Earthing for protections of MV network overvoltage

The characteristics (shape, extent, etc.) of the earthing surge arresters shall be provided to discharge the surge voltages of atmospheric origin as they are connected to the surge arrester, as well as the overvoltage to 50 Hz.

The grounding of spark gaps and surge arresters ensures the protection of the equipment by controlling the rise in potential that may lead to internal ignitions in the transformer or LV equipment of the MV / LV substation during the flow of atmospheric overvoltage.

The shape of the grounding must therefore be adapted to the flow of high frequency currents.

This point must be integrated in the choice of the forms of the selected grounding. The recommended technical solution is the multidirectional surface grounding.

These earth connections must also flow industrial currents in the same conditions as the earthing of masses.

1.3 Taking into account the proximity between earthing/grounding

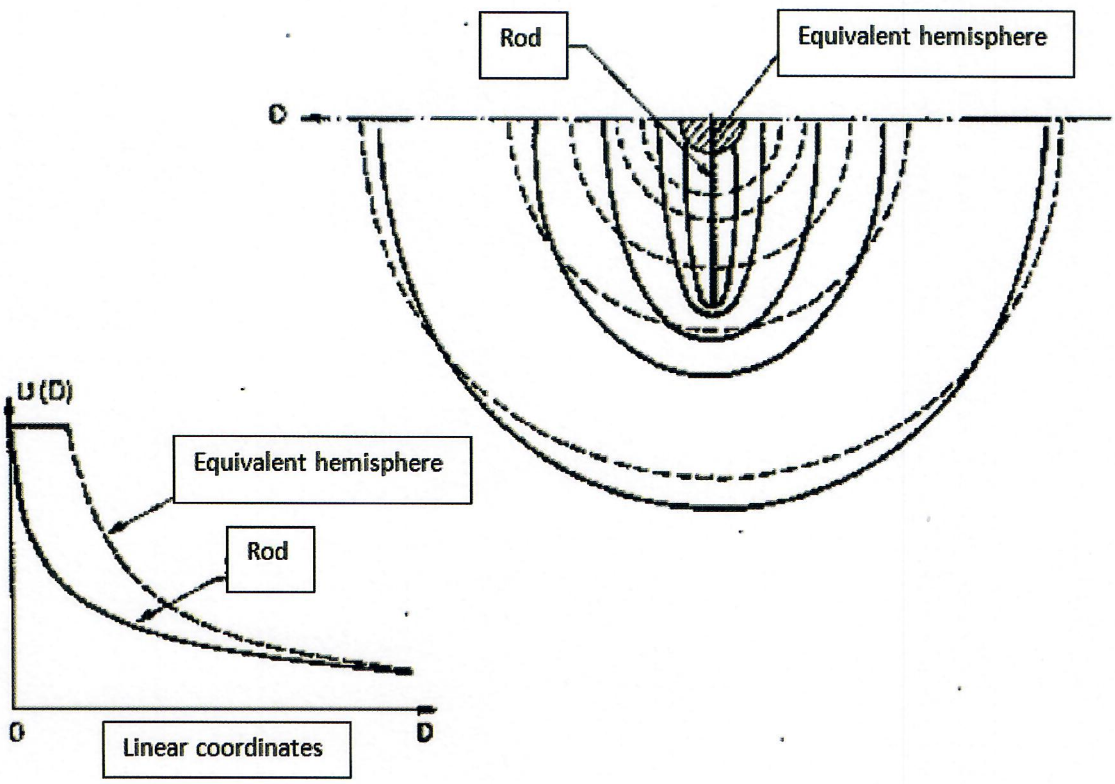
During the potential rise of a grounding, another nearby grounding is likely to rise to potential as well.

1.3.1 Elevation of soil potential around a ground

The flow of a current **I** in an earthing causes a rise in potential of the surrounding ground, which is function of the resistivity **ρ** of the ground and the distance **d** with respect to the ground.

The value of this potential can be determined by the following approximate formula

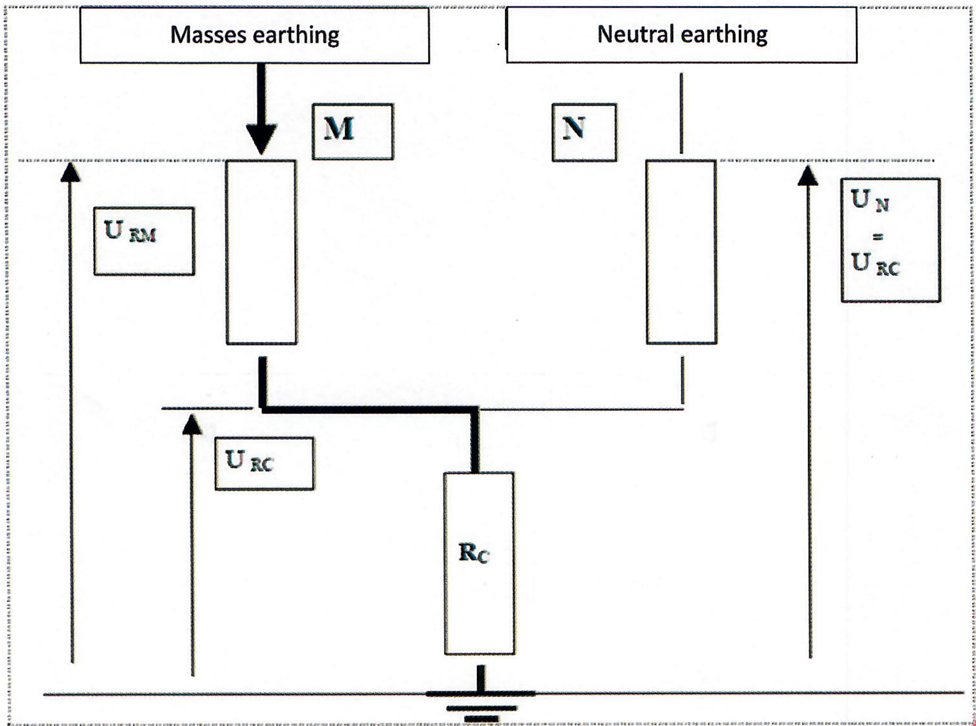
$$U = \frac{\rho I}{2\pi d}$$



Voltage distribution around a rod and its equivalent hemisphere

1.3.2 Electrical Coupling of earthing

With two neighbours earthing M and N, with respectively resistance RM and RN; the influence of the flow a current through the earthing M on the earthing N can be represented by the following figure where RC is the common part of two earth, called coupling resistance.



Numerical example - Measured values RM = 28 Ω, RN = 38 Ω and NMR = 60 Ω

- The calculation (developed in 4.3.4.1) indicates an RC coupling resistance of 3 Ω and a coupling coefficient between earth of the masses and earth of the neutral of about 10%;

- In relation to a distant earthing, the point N will therefore undergo a potential rise of about 10% of that in the point M.

2 Earthings connections of the MV and LV structures:

The grounding rules for MV and LV electrical installations are described below; they are detailed in the data sheets attached to this document.

2.1 Metal of earthing

Considering copper stealing in many areas, the conductors used for earthing are different according the earthing location.

2.1.1 Copper conductor

35 mm² copper conductor is used for all "indoor" earthings as built substations, OPS, RMU cabinets, prefabricated substations, etc.... and for MV and LV underground networks. The whole earthing circuit is made of copper (outside and inside the soil)

2.1.2 Mild steel galvanised conductor

50 mm² mild steel hot dip galvanized conductor is used for all earthing installed all along a pole. This is the case for pole mounted substations, load break switches, recloser, surge arresters, LV neutral earthing, etc... The whole earthing circuit is made of mild steel hot dip galvanized conductor (outside and inside the soil).

2.2 MV overhead lines and underground cables

2.2.1 MV OHL with bare conductors

2.2.1.1 Poles without apparatus

	Mass earthing	Pole earthing	Cross arm earthing	Data sheet ref.
Metallic pole	YES	YES (1)	By design	TDS N°4
Concrete pole	NO	NO	NO	NO

(1) loop at the bottom of the excavation connected at the bottom of the support

Table 1: Regulatory Provisions for the grounding of MV OHL poles with bare conductors

2.2.1.2 Poles with surge arresters and cross arm only

Surge arresters	Cross arm earthing	Data sheet ref.
Origin of the earthing	Tap connected to the main earthing circuit from the surge arresters	TDS N°9

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Table 2: Grounding of pole with surge arrester

2.2.1.3 Line poles with switch and recloser

The earthing of the masses of these pole is intended to ensure the protection of persons and apparatus. The conditions are described in Table 2 below.

	Air load break switch	GIS load break switch	GIS recloser
Surge arresters	----------------------------	Origin of the earthing	Origin of the earthing
Cross arms, frames, equipment support, operating rods and bevel,....	Tap connected to the main earthing circuit from the top cross arm	Tap connected to the main earthing circuit from the surge arresters	Tap connected to the main earthing circuit from the surge arresters
Apparatus	Tap connected	Connected at the earthing origin using 35 mm^2 copper insulated conductor with two forged tin copper lugs between earthing origin and apparatus. (1)	Connected at the earthing origin using 35 copper insulated conductor with two forged tin copper lugs between earthing origin and apparatus. (1)
Control box	----------------------------	Tap connected to the main earthing circuit from the surge arresters	Tap connected to the main earthing circuit from the surge arresters
Masses and One secondary LV terminal of supply transformer	----------------------------	Tap connected to the main earthing circuit from the surge arresters	Tap connected to the main earthing circuit from the surge arresters
Operating platform (reinforces concrete or additional)	Tap connected to the main earthing circuit from the surge arresters	Tap connected to the main earthing circuit from the surge arresters	Tap connected to the main earthing circuit from the surge arresters
DATA SHEET	TDS N°5	TDS N°7	TDS N°8

(1) In case the surge arresters are installed **on the apparatus frame**, the origin of the earthing circuit is the apparatus frame. There is no need of connection using copper insulated cable (see TDS N°6).

Table 3: Grounding of MV switchgear on overhead networks

Nota: The LBS or recloser supporting cross arm or bracket is not connected to the earthing circuit because the equipment is bolted on and is already connected.

2.2.2 Particular point of shield wires

Shield wire is sometime used in area densely hit by lightning. It is to be reminded that a shield wire only protects OHL against direct stroke and not against indirect strokes. So, installing surge arresters is mandatory for efficient OHL equipment protection.

It is also necessary to compare the cost of the complete shield wire earthing system **(it is reminded that the wire must be earthed on each pole with an earthing value ≤ 10Ω)** with the cost of surges arresters sets (every 400m as example). **Most of time the advantage efficiency/cost is at the advantage of surge arresters sets**

In all case, the decision to install shield wire shall be taken by EDC Head office in Phnom Penh.

2.2.3 MV ABC overhead network

The cable consists of an insulated steel messenger surrounded by twisted, isolated phase conductors, and the following provisions are made:

- the steel messenger must be grounded at each end of the line;
- phase conductor metallic screens shall be grounded at each end of the line

2.2.4 Underground MV network

To allow the flow of one part of the capacitive and inductive current between phase and ground in normal service and secondly of short circuit currents in the event of a ground fault, the phase metallic screens are connected to the ground at the cable ends.

N.B: These provisions concern **twisted** cables with a cross-section of less than or equal to 240 mm². Any other realization (bigger section, layering of unipolar conductors, doubling of cables, ...) must be the subject of a specific study taking into account **in particular the permanent flowing of heavy currents in core and screens.**

2.2.5 MV overhead/underground interface

The combined grounding circuit of the masses/surge arrester is made of bare 50 mm² mild steel galvanized conductors. It consists of an equipotential bonding conductor connecting the support bracket of the surge arresters and cable termination screens to the earth electrode.

The main earthing circuit start at the surge arrester cross arm.

This grounding is done at the foot of the pole respecting a geometry adapted to lightning currents flows and the resistivity of the ground.

The following elements are tap connected the earthing circuit:

- the grounding braids of the MV cable screens at the terminations;
- the cross arms of the MV conductors.

There is no need to install an equipotential loop around the pole.

See TDS N°12

2.3 RMU cabinets, one pillar substations and MV / LV substations

2.3.1 MV RMU Cabinets and one pillar substations

The equipment must be connected individually by a **35 mm² copper conductor to an equipotential bonding conductor forming the earthing collector circuit of the RMU cabinet or one pillar substation.**

The latter, must terminate at a point easily accessible (near the door) on a main earth terminal, or earth collector, provided with a 12 mm diameter copper terminal and 40 mm length in order to allow the measurement of earth resistance and the installation of short-circuiting and grounding clamps.

No interrupting device (connector, switch, disconnector, ..) is allowed in this equipotential bonding conductor.

Using the metallic envelop or body of OPS and RMU cabinet as equipotential bonding conductor is STRICTLY FORBIDEN. Metallic envelop or body MUST BE CONNECTED to the 35 mm² copper conductor equipotential bonding conductor.

The elements to be connected to this equipotential bonding conductor are described in the data sheets N° 14.

The following main elements can be mentioned: the cabinet envelope if it is metallic, the MV panel envelope from the terminal provided for this purpose, the transformer is any, the metal screens and the terminations or separable connectors of the MV cables, the metal reinforcement of the concrete of the basement, the slab and the operating sidewalk (if it exists), the doors,....

The grounding of the cabinet is carried out at the bottom of the excavation during the execution of the foundations or if no foundations this grounding is done under the cabinet (40 cm deep). A bare 35 mm² copper conductors, forming a grid and a closed loop on itself, is arranged on the perimeter of the cabinet. This conductor emerges inside the cabinet at a height of 0.3 m above the floor near the door and it is **connected to the main earth terminal board** (see TDS N°16).

In order to control touch voltages, an equipotential belt is also connected to the main earth terminal board. This belt (loop) consists of a bare 35 mm² copper conductors, looped on itself in the immediate vicinity of its connection to the main earth terminal board. It is buried at a minimum distance of 1 m around the cabinet between 0.5 m and 1 m (in case of impossibility at a depth of about 0.3 m minimum).

Earthing circuit is described in the data sheet N° 15

Note: Earthing Conductors inside the ground must be as close as possible to direct contact with the original soil

2.3.1.1 OPS LV Neutral

A 35 mm² cross section **insulated** copper conductor connection is made between the LV distribution board (from the neutral busbar downstream of the switch or a specific terminal of the switchboard) and the **main earthing terminal board** (see data sheet N°16) of the OPS.

The conditions for connecting or not connecting the LV neutral to the earth ground circuit are described in paragraph 2. 4 of this chapter.

2.3.2 MV / LV built or prefabricated substations

2.3.2.1 Masses of equipment

The device masses must be connected individually by a 35 mm² copper conductor to an equipotential bonding conductor forming the earthing collecting circuit of the substation.

The earth circuit, consisting of a 35 mm² cross section copper conductor, shall terminate at an easily accessible point on a main earth terminal board or earth collector with a copper terminal of 12 mm. mm in diameter and 40 mm in length to allow measurement of earth resistance and installation of clamping devices for short-circuiting and earthing.

No interrupting device (connector, switch, disconnector, ...) is allowed in this equipotential bonding conductor.

Using the metallic envelop of the prefabricated substation as equipotential bonding conductor is STRICTLY FORBIDEN. Metallic envelop or body MUST BE CONNECTED to the 35 mm² copper conductor equipotential bonding conductor.

The elements to be connected to this equipotential bonding conductor are described in the corresponding data sheets.

The following main elements can be mentioned:

- Steel reinforcement of the concrete by a connection connecting one of the bars of the reinforcement to the main equipotential bonding conductor
- the MV cable screens via the protective conductor of the MV switchboard;
- the MV RMU via a terminal provided for this purpose;
- the frame of LV switchboards;
- metal cable trays;
- the transformer tank;
- earth terminals of measurement transformers, capacitors, etc.;
- protective metal screens and panels;
- the cell fences, the control panel of the devices and the various fittings in the open type substations
- the doors;
- the masses of control equipment
- envelop of metallic prefabricated substation
- any other metal masses.

The grounding of the substation is carried out at the bottom of the excavation during the execution of the foundations or if no foundations this grounding is done under the substation basement.

A bare 35 mm² copper conductor, forming a grid and a closed loop on itself, is arranged on the surface of the substation. This conductor emerges inside the cabinet at a height of 0.3 m above the floor and it is connected to the **main earthing terminal board** (see data sheet N°16)..

In order to control touch voltages, **an equipotential belt** is also connected to the main earth terminal board. This belt consists of a bare 35 mm² copper conductors, looped on itself in the immediate vicinity of its connection to the main earth terminal board. It is buried at a minimum distance of 1 m around the cabinet between 0.5 m and 0.8 m depth (in case of impossibility at a depth of about 0.3 m minimum).

Earthing circuit is described in technical data sheet N° 15

2.3.2.2 LV Neutral

A 35 mm² cross section **insulated** copper conductor connection is made between the LV distribution board (from the neutral busbar downstream of the switch or a specific terminal of the switchboard) and the main earthing terminal board of the substation (see data sheet N°16).

The conditions for connecting or not connecting the LV neutral to the earth ground circuit are described in paragraph 2. 4 of this chapter.

2.3.3 MV / LV substations in buildings or with adjoining premises

When the substation is integrated into a building civil engineering structure, and in particular because of the existence of an earthing network for this building, the equipotential belt is not necessary.

When the surface of the substation is predominant in relation to the built-up unit (adjoining room, ??) or if this set does not have an earthing network, an equipotential belt is to installed around the building (substation and premise).

2.3.4 Pole mounted MV / LV substation

The origin of the earthing circuit of the masses and surge arresters (combined both) is the support bracket (or cross arm) of the surge arresters.

A bare 50 mm² mild steel galvanized conductor starts from this fitting until the grounding inside the ground at the bottom of the support.

The transformer **tank** is to be connected to the origin of this circuit by an **insulated** copper conductor of 35mm² of cross section using two tin copper forged lugs.

The other masses to be connected individually to this earth circuit, in derivation by a conductor of the same section, are the following:

- the cross arm of the line conductors
- The FCO cross arm
- the fixing system for the LVDB
- the metal frame of the operating platform (if any)
- ...

The transformer supporting cross arm or bracket is not connected to the earthing circuit.

See technical data sheet N°17

NB. : The installation of an equipotential loop for the pole mounted MV/LV substation is not required.

2.4 LV network

2.4.1 General

In order for the equipment to have no mass, it must be double insulated or reinforced by construction or installation.

This provision is part of the design of LV networks at ELECTRICITY du CAMBODGE and most of utilities. Thus, a level of isolation, by design or implementation, of at least 6 kV of equipment used on the networks was chosen. Under these conditions, earthing only concerns the neutral conductor.

The Cambodia PROKAS set the neutral earthing value to a maximum of 10 or 5 Ω without mentioning if this value is the global value for the whole LV neutral or if this is a maximal individual value.

Nevertheless, considering the network development in Cambodia and the troubles encountered on the network in case of MV fault that could flow through the LV neutral, it is then propose to set up to 10 Ω the maximum resistance value of an individual grounding neutral and to a maximum of 5 Ω for the LV neutral global value.

This value must therefore be respected in all circumstances. However, in areas where there are few individual neutral groundings, it is recommended to have a maximum individual value of 10 Ω, the goal being that all interconnected neutral grounding points is in accordance with the value requested for the overall resistance of the neutral.

2.4.2 LV overhead networks

An aerial LV structure concerns the aerial LV network in bare conductors and the aerial LV network made with LV aerial bundled conductors.

In all cases, the neutral conductor must be grounded in more than one point.

At a minimum, neutral grounding must be done by start under the following conditions:

- in addition to a point if the length of the network exceeds 100 meters,
- with a minimum average number of neutral earths of one for every 200 meters of network.

In practice, the LV neutral is grounded in the following places:

- the first support after the MV / LV substation;
- at the network ends;
- at each network branch;
- close to important nodes of customer connections.

See Technical Data Sheets N°18 and N°19

2.4.3 LV Underground networks

Grounding of the neutral on an underground LV network is located at the following points:

- to each junction or branch accessory on the network,
- Cabinet: connection, cut-off, sectioning cabinet, protection cut-off box.

The earth electrode consists of an earthing net made of copper with a total cross section of about 35 mm^2 placed in the bottom of the trench directly in contact with the natural ground; this net is electrically connected to the neutral conductor of the network **incoming** cable.

These provisions are such that for each section of LV cable between two connection accessories includes at least one neutral earthing so that the grounding of the neutral is maintained regardless of the operating scheme; thus, when disconnect a cable section, the short-circuiting of the conductors at the same time ensures the grounding through the neutral.

See Technical Data Sheets N°20 and N° 21

2.5 Interconnection and separation conditions between the earthing of the MV/LV masses and the LV neutral earthing of MV / LV substations

2.5.1 General

The design of the networks must be such that the earth flowing of a MV fault current does not generate a rise in potential of the LV conductors beyond 1500 volts compared to a distant earth.

According the network structure, the following rules, applied to three categories of MV / LV substations:

2.5.2 Transformation substation located in urban area

An area is called **urban** if, the **MV feeder being entirely underground**, there is continuity of the protective conductors and equipotential links (screens and / or armour of the MV cables) from the HV/MV station to the considered MV/LV substation. **An equipotential network is thus constituted. In addition, this underground network is not subject to atmospheric currents.**

In this zone, the overall value of earthing of the masses is considered to be less than 1 ohm: a **connection is made between the neutral of the LV switchboard, downstream of the main switch, and the grounding circuit of the substation masses.**

See technical data sheet N°22.

2.5.3 MV / LV substation located in peri-urban area

In a so-called peri-urban zone, the continuity of the cable screens from the HV/MV station to the MV / LV substation is not assured, but there is electrical continuity in more or less extensive areas (underground networks, sub-urban zones, craft or industrial, ...). In addition, the electrical separation between earth connections is sometimes difficult to reach.

Also, if all of the following conditions are true:

- earthing of neutral MV of type 800 amps (phase/ground fault current) at least,

  - earthing value of considered the MV / LV substation is ≤ 10 Ω,
  - overall earthing value of the LV neutral of the considered MV / LV substation is ≤ 5 Ω,
  - global grounding value of the interconnected masses plus LV neutral (MV cable network, MV / LV, LV neutral) of the zone is ≤ 1 Ω:

The LV neutral and the substation masses can be interconnected in a manner identical to that one specified in 2.5.2.

If this is not the case, the electrical grounding of the neutral LV and earth ground of the MV masses is carried out under the conditions described below in 2.5.4. and are electrically separated.

See technical data sheet N°22.

2.5.4 Transformation substation located in peri-urban or rural area

If the provisions mentioned above are not observed, the mass earthing of the MV / LV substation is electrically separated from the LV neutral earthing.

The grounding of the LV neutral is then carried out with clear separation from mass earthing and at a distance such that, depending on the resistivity of the ground and its environment, the coupling coefficient between the **grounding of the MV masses and the first earthing of the LV neutral is less than 15%.**

The measurement conditions and the calculation of the coupling coefficient are detailed in § 4. 3. 4

So, in case of LV ABC network, the first LV neutral earthing is located at the first pole after the substation. This is the case for all LV feeders.

In case of LV underground network, the first LV neutral earthing is located at the first connecting accessory inside a cabinet.

2.6 Specific locations

2.6.1 MV / LV joint pole

A mixed line pole with an MV network and a LV network must not have a neutral LV earthing.

2.6.2 Common support: LV / telecommunications network or video communication

In order to limit the potential rise associated with the coupling between earth connections, an individual grounding of the LV neutral must not be carried out on a support comprising a telecommunication or video network grounding.

2.7 Proximity between MV and LV network earthing and other facilities of electrical energy

2.7.1 MV and LV distribution networks and HV transmission structures

The general characteristics of realization of the earthing of HV towers are the following ones:

- the earth of the HV pylons (115kV, 220 kV and 500 kV) is made by three loops on each of the four feet, with an overall resistance of the grounding less than 10 Ω.

These characteristics make the radius of the equivalent hemisphere of the widest loop is of the order of 5 meters for the towers.

Now, in general, we consider that two earthing networks are electrically distinct if their distance is greater than ten times the radius of the equivalent hemisphere of the largest.

Also, to guard against an excessive potential rise by coupling on MV and LV neutral earthing of distribution facilities a minimum distance of 50 meters from an HV steel tower must be respected.

N.B : These values may be lower if the HV line has a shield wire

2.7.2 MV and LV networks and public lighting installations

Public lighting installations are installed in accordance with the Cambodia recommendations. In particular the candelabra drums are either grounded individually or interconnected by a ground conductor providing equipotential bonding.

In the event of a ground fault on a nearby power distribution system, the potential for ground-level candelabra drums must be controlled, resulting in recommendations to the extent practicable. The following separation rules between distribution networks and public lighting networks.

2.7.2.1 Ground connections of MV masses and public lighting installations

In urban or peri-urban areas, and when the LV neutral and the MV masses are interconnected, there are no separation conditions to be respected, nor a particular search for equipotentiality between the networks.

In other areas, the arrangements to be made are those ensuring the separation between a MV masses grounding and a LV neutral earthing (see chapter 1.3.2).

2.7.2.2 LV neutral grounding and public lighting installations

In urban or peri-urban areas, and when the LV neutral and the MV masses are interconnected, there are no separation conditions to be respected, nor a particular search for equipotentiality between the networks.

In the other zones, a minimum distance of 2 meters between an earthing of the LV neutral and a public lighting installation connected to the ground (candelabra, equipotential bonding, ??) is to be taken into account as far as possible.

2.7.3 Earthing of the LV network neutral and LV installations

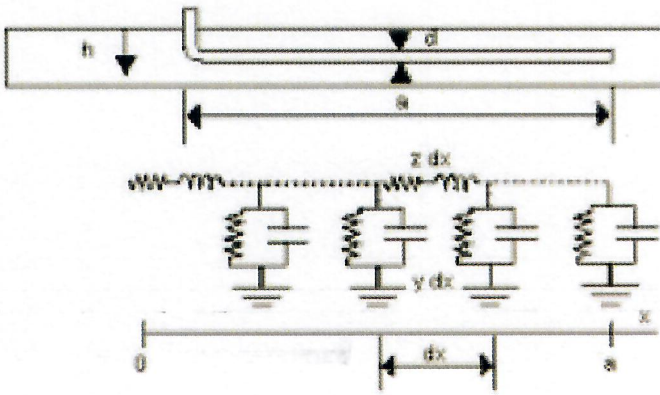
In urban and peri-urban areas, when the LV neutral and the MV masses are generally interconnected (see § 2.5), there are no separation conditions to be respected, nor any particular search for equipotentiality.

In the other zones, a 10-meter protective distance between an earthing of the LV neutral and the earth ground of the customer must be respected as far as possible.

3 Practical realization of earthing/grounding

3.1 Characterization of a grounding

From an electrical point of view, a buried conductor in the ground can be compared to an electrical circuit comprising resistors, inductors and capacities.



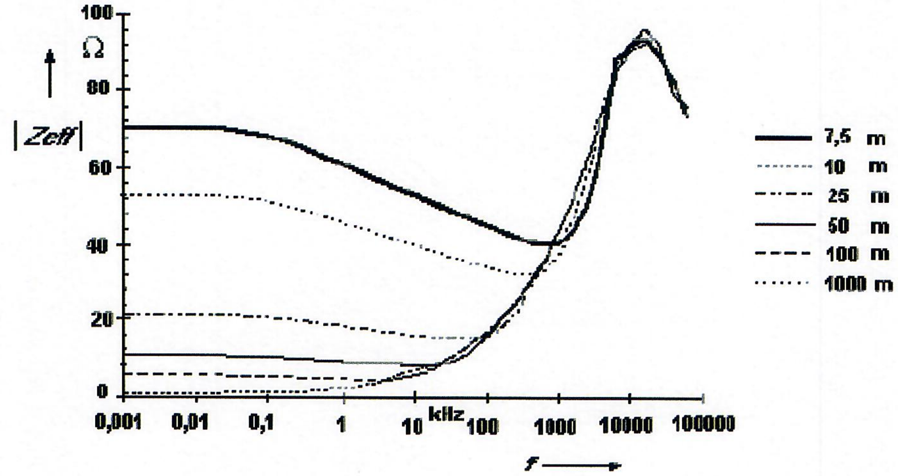
Electrical representation of a buried conductor

Depending on the nature of the currents to flow (HF currents due to lightning or 50 Hz currents due to electrical faults) and the type of soil, some of these circuits become predominant.

3.1.1 Current origin

It has been demonstrated that the geometry of the earth electrode has an influence on its effectiveness in draining currents generated by lightning (surge); this allowed to state the following recommendations illustrated in the figure here after.

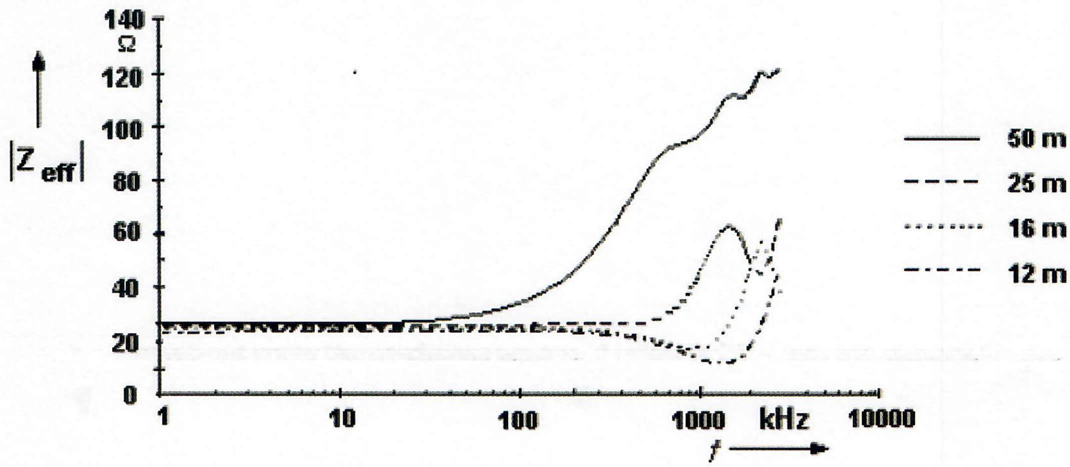
Impact of the conductor length



Frequency response of a buried horizontal conductor of variable length in a medium soil resistivity (100 Ω.m)

For a given frequency, there is a length beyond which the efficiency of a linear grounding conductor no longer increases.

3.1.2 Impact on the number of earthing wires



Frequency response of a grounding stranded (1 x 50 m, 2 x 25 m, 3 x 16m and 4 x 12 m) in a high resistivity of soil (1000 Ω / m)

For a low frequency (50Hz) earthing resistance and the same total length of buried conductor in the ground, a high frequency earthing made with several conductors with a central point of current injection is more effective than a grounding made with a single conductor.

So, an earthing intended for flowing high frequencies current (about 1 MHz) is to be designed by taking into account these two parameters.

An earthing that only drain current at 50 Hz must consider only a low frequency impedance matched to its use.

On facilities connected to overhead lines such as earthing connections will flow these two types of current, the earthing design must take all this into account.

As summary, earthing rods are efficient to flow 50Hz currents only and an earthing comprising three 120° earthing conductors of 10 m length is efficient to flow atmospheric and 50 Hz currents.

3.1.3 Type of soil

The impedance of a grounding and the distribution of the potential in the ground depend on the electrical characteristics of the ground that is to say on its resistivity. This is why the design of the earth network of an electrical installation must begin with a study of the nature of the soil in which it will be realized.

The resistance of an earthing network is proportional to the resistivity of the soil and subsoil in which it is buried. However, the resistivity of the natural grounds presents the following peculiarities:

- it is extremely variable from one place to another depending on the nature of the soil and the moisture content. Extreme values encountered in practice can vary from a few ohm-meters for greasy and wet ground to a few thousand ohm-meters for very healthy and very dry granites (see § 5.2.3);
- at a given location, the soil is often heterogeneous, both horizontally and vertically;
- the resistivity of the surface layers of a site presents seasonal variations under the effect of frost and drought (which increase it) or humidity (which decreases it). This action can be felt to a depth of several meters in extreme and prolonged climatic conditions.

3.1.4 Maintenance of the characteristics of the earthing

A grounding must be strong enough and designed to withstand mechanical, thermal, chemical and electrochemical degradation.

Earthing and equipotential bonding conductors must be protected against mechanical and chemical damage; their connections to the ground, in the ground, the neutral point or the neutral conductor and to each other must be made in such a way as to avoid untightening or loosening.

3.2 Methodology of realization of a grounding

The realization of a grounding must be the subject of a preliminary study integrating the nature of the currents to be discharged, the ohmic value of grounding to obtain, the resistivity of the ground, its location and its proximity to the neighbouring networks, its form and the components to be used (the results of this study must be part of the implementation design file).

The diagram below summarizes this implementation approach

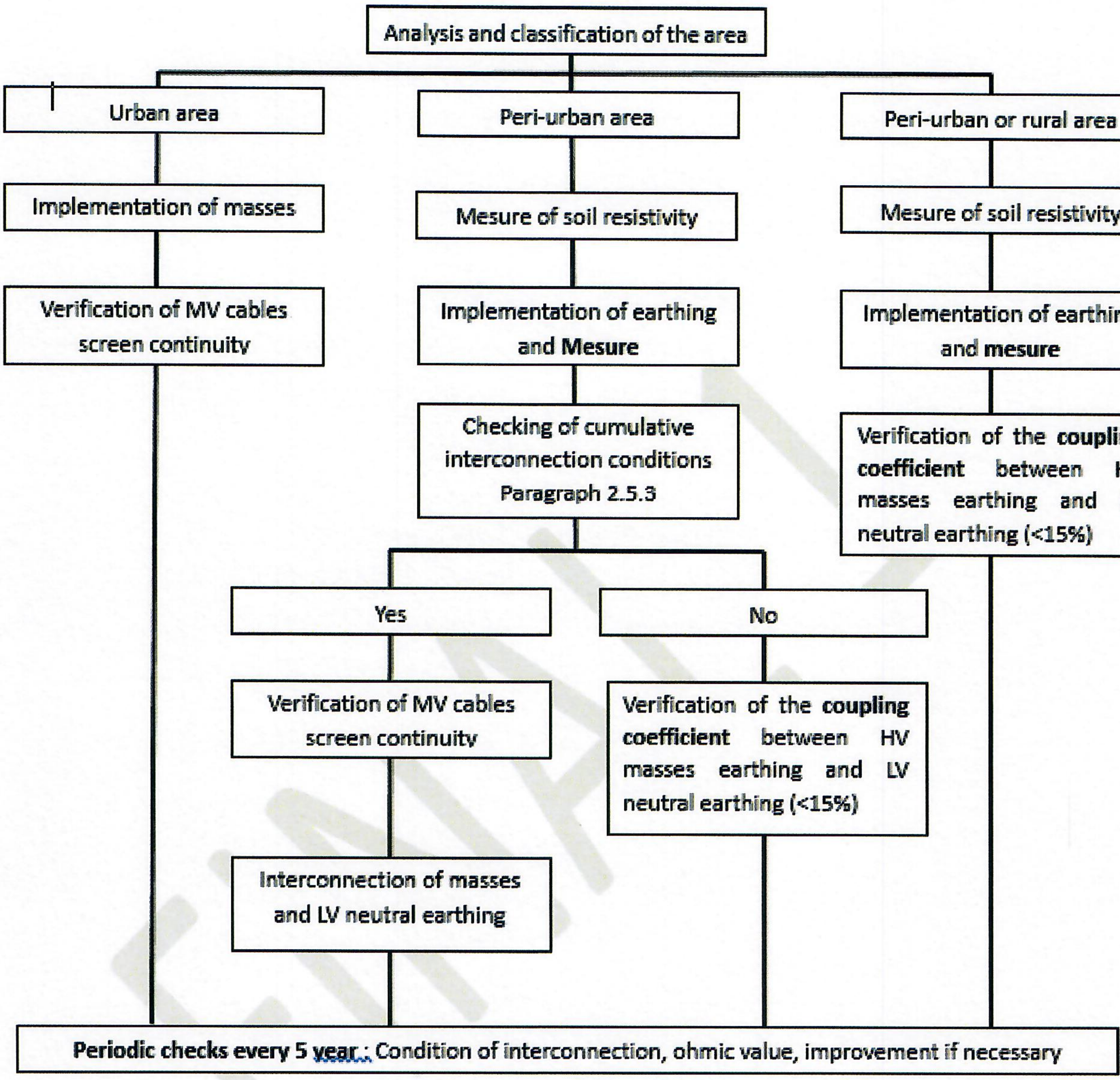


Figure 6: Diagram of step of realization of a grounding

3.3 Choice of techniques and equipment

Once the shape of the grounding has been determined (see Technical data sheet N°3), we use:

- For soil of low resistivity:
    - Earthing rods. In order to overcome the seasonal variations of humidity the length of rods shall be of at least 3 meters (3 meters rods or self-expandable rods). The connection of the earthing cable to the rod is imperative to be done by an approved or authorized equipment or technique in particular, the use of the "car battery terminal" is forbidden. **It is reminded that this kind of earthing done with rods is efficient only for 50Hz currents so rods cannot be used for surge arrester earthing.**
    - Grounding made by earthing net or/and folded bare conductor at the bottom of a 80 cm deep trench.

- in areas of medium and high resistivity soil,

- Grids of earthing nets; these increase the surface of contact between earthing circuit and soil and allow to lower substantially the ohmic values; arranged in a star form with at least 3 earthing nets, they also provide a satisfactory answer in high frequency current flow, by their capacitive coupling.
- Conductive modules, with "chemical" coating, arranged in line or in star; these modules give good results for both types of current to flow (50 Hz and lightning); for a good ohmic value search, it is also possible to use them in deep drilling, associated with bentonite.

Depending on the nature of the soil and the use of the earthing, the realization of a "deep" grounding by drilling, can allow the lowering of the ohmic value at **low frequency (and only this one)** ; before any commitment of realization, it is essential to know the resistivity of the various layers of ground (measurements, geological maps, ...). These deep earthings are effective only for currents at 50 Hz.

It is to be noticed that for some specific cases, the ohmic values can be drastically lowered by using specifically minerals salts and component added in the bottom of the trenches in case of folded earthing wire or earthing nets. The right value is obtained after several weeks but in case of very wet soil the ohmic value will decrease after several months or year because water wash the components. This is why this kind of earthing must be **verified each 2 years**

NB: use of conductive modules with chemical product or mineral salts for solving some specific cases, EDC head office must be informed and only EDC head office will take the decision for using such products.

4 Resistance, resistivity and coupling measurements - Control policy

4.1 Conditions for intervention on earthings

4.1.1 Reminder of the risks to be controlled.

A ground fault current flowing causes its rise in potential; at this moment, a person touching this earthing or being close to, may be subject, depending on the circumstances, to a potential difference called touch voltage or step voltage respectively.

Touching a metallic piece not connected to a ground and accidentally carried to a potential is an electrical hazard. **This is why it is forbidden, except special precautions, to open the earth circuit of a structure in service.**

In addition, the earth connections of certain installations may be "influenced" by the presence in the vicinity of other installations, for example railway networks, cathodic protections, etc.

4.1.2 Individual protections

In the case of a structure in service, the operator must wear LV protection equipment equivalent to that of the LV hot line work (helmet, facial screen, insulating gloves, specific wear, safety shoes, etc....) and use the LV insulating mat.

4.1.3 Authorizations

The operator responsible for taking measurements on the earthing circuits or on the neutral conductor must be authorized to work on networks in the voltage range (MV and / or LV) and for the type of structure concerned.

4.1.4 Operating process

It is forbidden to intervene during thunderstorms on the earthing circuit of a structure in service.

In case the work requires the opening of the earthing circuit of a structure in service, the continuity of the grounding of each circuit element to be separated must be ensured: either by placing a shunt maintained throughout the intervention, either by connecting the part to be separated from the earth ground to an existing or created auxiliary earth ground.

4.2 Method of measuring the soil resistivity

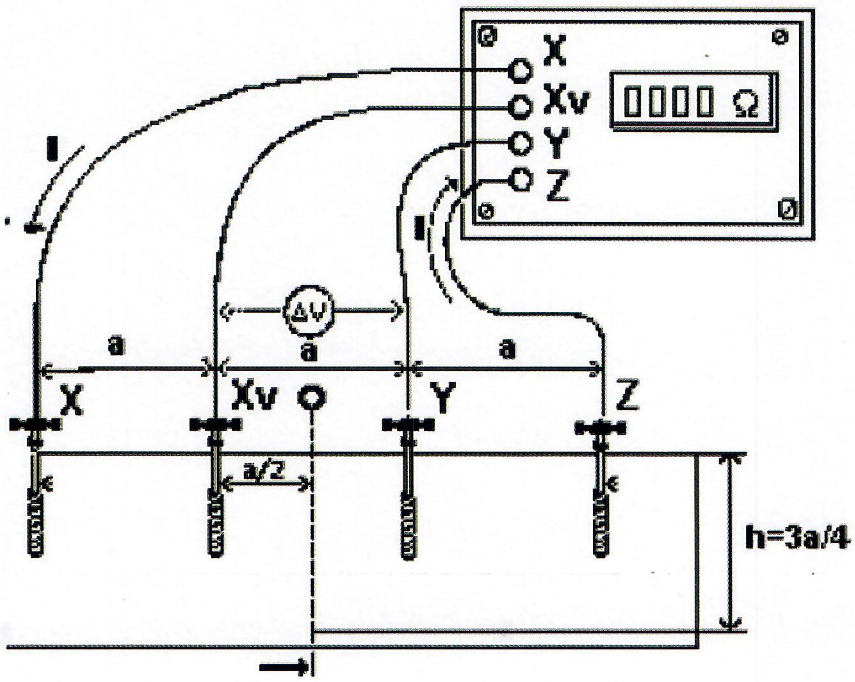
4.2.1 Wenner method

The method for measuring the apparent soil resistivity to be used is the method of Wenner, in which the four electrodes are arranged in line and equidistant.

The measuring device is a four-terminal earthing measurement apparatus approved or authorized for use. The two end electrodes are those of injection of the measurement current I; the two central electrodes are those for measuring the potential ΔV.

The point 0 of the resistivity measurement is in the middle of a symmetrical system, between the potential electrodes.

The distance "a" between two adjacent electrodes is called "measurement base"; the distance between the end electrodes on the "transmission line" is "3 a".



Measure of soil resistivity

Equipment: 4 wires earthing measurement apparatus

O : position of the future grounding

Note: All measuring rods must be installed in straight line

Figure 7: Measurement of soil resistivity

General formula giving the value of the apparent resistivity:

$\rho = 2\pi .a .R$

ρ = resistivity in ohm. meter (Ω.m)

a = distance in meters (m)

R = value in ohm read on the earthing measurement apparatus (Ω)

Example: for a depth of investigation of three meters, a is 4 m and two measurements in two directions, if possible, perpendicular is to realize.

In this case, $\rho = 25$ R

Knowing that the value obtained from ρ is an average value for a depth approximately equal to 0.75 x "a", it is possible by varying the distance "a" to deduce the profile of the resistivity variations at depth.

For example, the values of "a" recommended to verify the validity of the possible use of rods of 3 meters and 6 meters are 4 meters and 8 meters.

In practice, two measurements will be made with a = 4 meters in two perpendicular directions.

These indications make it possible to predetermine a satisfactory solution for the realization of a grounding and thus avoid successive improvements.

4.2.2 Resistivity of soils

The typical resistivities according to the nature of the soil are given in the table below.

Soil type	Resistivity (Ω.m)
Wetland and rich in plant debris	
Swampy land	5 to 30
Limon	20 to 100
Humus	10 to 150
Peat	5 to 100
Clays and marl-limestone	
Plastic clay	50
Compact marls and clays	100 to 200
Jurassic marls	30 to 40
Sand and gravel	
Clay sand	50 to 500
Silty sand	200 to 3000

Bare stone floor	1500 to 3000
Stony soil covered with turf	300 to 500
Limestone and shale	
Limestone	100 to 300
Compact limestones	1000 to 5000
Cracked limestones	500 to 1000
Schists	50 to 300
Micaschiste	800
Igneous rocks	
Granite and sandstone more or less altered	1500 to 10 000
Granites and very weathered sandstone	100 to 600
Compact Granites	10,000 to 15,000

Table 4 : Typical resistivity of soils

It is recalled that seasonal variations affect the resistivity of the layers of the soil.

4.3 Control and measurement of the earth

"Verification of earthing and protective conductors:"

4.3.1 In urban areas (see § 2.5.2)

In urban areas it is not possible to perform a correct earthing measurement, given the strong coupling existing between the auxiliary rods and the earth to be measured. However, it is important to check that the earth circuits are well connected in each MV / LV substation with the grid of the MV cables.

The measurement of the resistance of the earthing in urban area is not significant and reliable because:

- the difficulty of finding a clear ground for the implantation of the auxiliary measuring electrodes;
- the practical realization of the MV masses of a station in the cabin which does not generally allow to isolate electrically the grounding of the MV masses of the other conductors of masses of the work.

Under these conditions, the arrangement adopted is to control the good continuity of the screens (or armor) of the MV cables; it allows the paralleling of all the earth connections of the various MV / LV structures fed by the same underground feeder.

Also, with a **periodicity of 5 years**, a visual check is made to verify that the different equipment is connected to the station's earthing circuit. This visual control mainly concerns the screens (or armor) of the MV cables, as well as the connection of the LV neutral to the grounding circuit.

4.3.2 Other areas

Two cases considered:

4.3.2.1 MV masses and LV neutral earthings interconnected

- Masses earthing of a new substation must be measured before connection of the MV cables;
- the value of the overall grounding of the zone must be checked every 5 years, as well as the continuity of the screens and the connection of the neutral (according to the same provisions as those described in § 5.3.1)

4.3.2.2 Separate MV masses and LV neutral earthings

Are to be measured:

- Mass earthing of the MV / LV substation
- the overall grounding value of the LV neutral (all LV neutral earthing connected to LV network)
- the coupling between the first earthing of the LV neutral and the earthing of the masses of the MV / LV substation

The conditions of measurement and control are specified in Technical data sheets N°24.a and 24.b. below.

4.3.3 Measuring the resistance of a grounding

The method to be used is that known as the potential drop, applied with an authorized four-terminal earthing measurement apparatus with an on-line arrangement of the auxiliary electrodes.

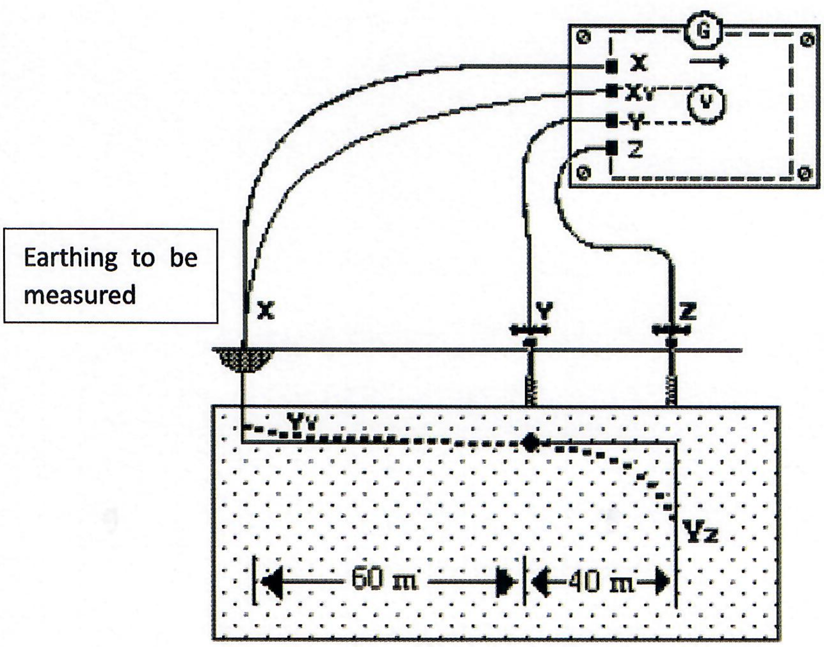


Figure 8: Measuring the resistance of a grounding

NB: in the case of the measurement of the overall earthing of the LV neutral, the X point may be a measurement terminal in the substation (earth plate, specific terminal of a LVDB switchboard, etc.)

or the direct connection to a bar of a LV feeder. The voltage between the mass earthing of the MV/ LV substation and the LV neutral must be measured before connection to point X and shall not exceed 20 volts to allow the measurements to be carried out; If more, it should be eliminated beforehand.

The device injects a current I, measure V, calculates V / I and thus gives directly: R = V / I

X, Y, Z must be aligned and spaced according to the diagram above (distance XY = 60% of distance XZ).

Wherever possible, Y and Z should not be located on an area where the presence of other existing earth or buried metal conduit would distort the measurement.

N.B .: experience feedback has shown that the use of a shunt between terminals X and Xv of the measurement apparatus is likely to generate measurement errors, especially for low values; in this situation, when calculating the coupling coefficient, inconsistencies may appear (negative coupling, ...).

4.3.4 Measurement of the coupling coefficient

4.3.4.1 Coupling between the MV masses earthing and LV neutral earthing

In order determine the coupling coefficient the following measurement are carried out:

- Resistance measurement of the Rm value of the masses earthing,
- Resistance measurement of the Rn neutral earthing the LV,
- Rmn measurement of the resistance between the neutral earthing and the masses earthing.

Then coupling the resistance is calculated using the following formula: $Rc = \frac{RM+RNi-RMN}{2}$

The coupling coefficient C is then equal to Rc / Rm rate. It must remain below 15%.

We must therefore ensure that: RC <0.15 * Rm.

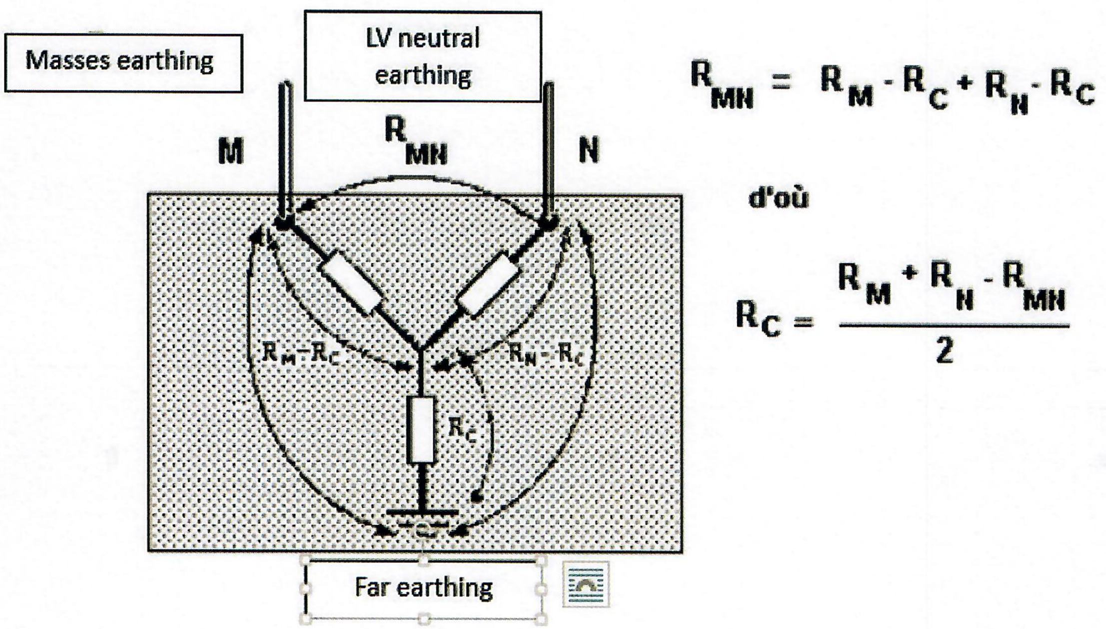


Figure 9: Measurement of the coupling resistance

4.3.4.2 Coupling between a MV masses earthing and a telecommunication line grounding

The measurement of the coupling coefficient between an MV masses earthing and a telecommunication line earthing is similar, with a coupling coefficient however limited to 5% (RC <0.05 * RM).

4.3.5 Chronology of a coupling measure

Measurement of MV masses earthing	Measurement of LV neutral earthing	Measurement of coupling between MV masses earthing and LV neutral earthing
Precaution to take		Determination of coupling coefficient
* X, Y, Z rods must be aligned and spaced according to the diagram above. The distance XY = 60% of the distance XZ. * Move away from all earthing, metal pipes or cables. * In any case, it is prudent to carry out at least two measurements by moving the auxiliary rods to ensure that the value obtained is independent of the position of the rods. * The location of the measurement apparatus and the position of the auxiliary electrodes can be judiciously chosen from the beginning of the measurement (Masses - Neutral – Coupling)		1 - Measure the resistance RM of the masses earthing 2 - Measure the resistance RN of the first grounding of LV neutral 3 - Measure the NMR resistance between the two earthings. (see diagram above) 4 - Calculate the coupling resistance Rc: $Rc = (Rm + Rn - Rmn)/2$ 5 - The coupling coefficient is equal to: c = Rc / RM Check that c <0.15

Figure 10: Chronology of a coupling measurement

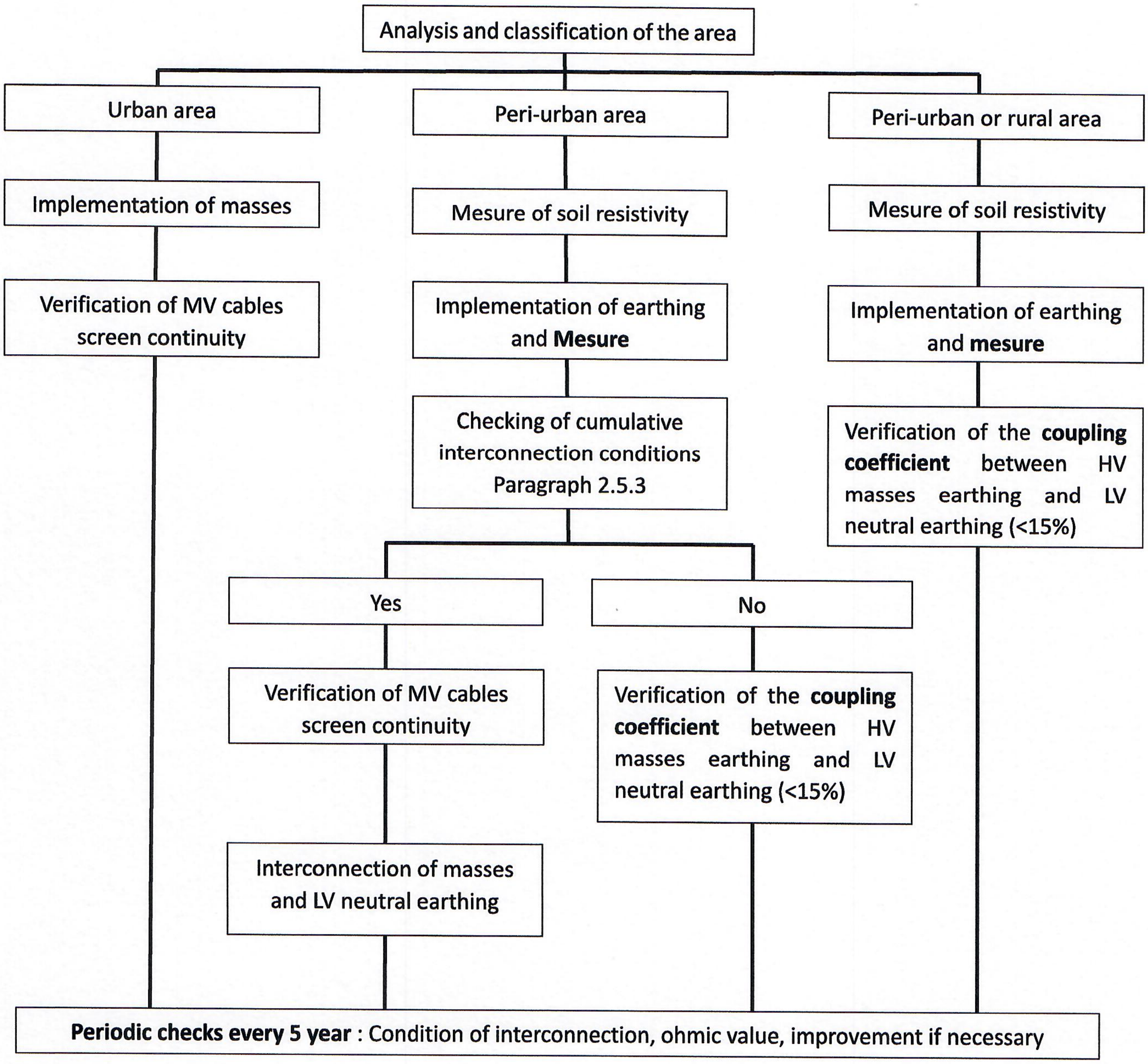
5 Technical management of the earthing

Earthing must be periodically checked and the results of the checking and measurements must be recorded in a computerized file.

6 Terminology

Main earthing board Terminal or Main earthing Bar	Board with terminal or bar provided for connection to the main conductor ground protection, and possibly the LV neutral conductor
Protective conductor	Conductor intended to electrically connect all or some of the following elements: ground, conductive elements, earth main terminal, grounding point, power point connected to earth or to the artificial neutral point. A protective conductor may be common to several circuits.

Main protective conductor	Protective conductor to which earth protection conductors, earth conductors and possibly equipotential bonding conductors are connected.
Equipotential bonding conductor	Protective conductor providing an equipotential bonding.
Ground conductor	Protective conductor connecting the earthing board terminal or ground bar to the grounding.
Elevation of earth potential	Voltage between a grounding installation and the earth.
Impedance of the earthing	Impedance at a given frequency of the earthing system, relative to the reference earth.
equipotential bonding	Primary Electrical connection bringing to the same potential, or to neighbouring potentials, masses and conductive elements. A main equipotential bonding makes it possible to ensure that, during an external fault on the installation, no potential difference appears between elements connected of the installation
Grounding or earthing	Conductor or conductive body assembly in intimate contact with the ground and providing an electrical connection with it.
Separated or independent earthing/grounding	Earthing/grounding sufficiently distant from one another so that the maximum current likely to be flown by one of them does not significantly change the potential of others.
Overall resistance of earthing	Resistance between the main earthing board and the earth.
Earthing/grounding Resistance	Resistive component of the grounding impedance
Contact voltage (or touch voltage)	Part of the elevation of ground potential created by a ground fault and applied to a person, the current crossing the human body between a hand and the feet (conventional horizontal distance of one meter).
Step voltage	Part of the earth potential rise due to a ground fault and applied to a person with a step length of one meter, the current flowing through the human body from foot to foot.
Earthing	The conductive mass of the earth whose potential at each point is taken by convention, equal to zero.
Resistivity of the soil	Specific electrical resistance of the soil


Analysis and classification of the area
Urban area
Peri-urban area
Peri-urban or rural area
Implementation of masses
Mesure of soil resistivity
Mesure of soil resistivity
Verification of MV cables screen continuity
Implementation of earthing and **Mesure**
Implementation of earthing and **mesure**
Checking of cumulative interconnection conditions Paragraph 2.5.3
Verification of the **coupling coefficient** between HV masses earthing and LV neutral earthing (<15%)
Yes
No
Verification of MV cables screen continuity
Verification of the **coupling coefficient** between HV masses earthing and LV neutral earthing (<15%)
Interconnection of masses and LV neutral earthing
Periodic checks every 5 year : Condition of interconnection, ohmic value, improvement if necessary