

Case Study

Leonardo
ENERGY

Electromagnetic compatibility (EMC) study
Breakdown of low voltage electronic
equipment in a 25 kV substation

Conrad Bottu

Laborelec
January 2008



Power Quality

1 Introduction

Description of the site

The Belgian site under study in this paper is connected to the public transmission grid (380 kV) by a High Voltage (HV) station. This HV station incorporates a 25 kV substation linked to a second substation via 25 kV underground cables. The second substation supplies the electric installations on the site.

The substations contain 25 kV circuit breakers in interior type HV cells with a metallic casing (see pictures below). The insulation is realised by SF6 gas. The safety relays and control devices are located in cabinets situated on the front panel of the cells. Their LV supply (110 VDC and 24 VDC) is provided by cabinets situated in an adjacent room.

Description of the problem

When operating the new circuit breakers, the control circuits received over-voltages and broke down. The same thing happened during other operations and events, including in-line short circuits, section switch closures, and above all the connection of the 25 kV cables to the earth to discharge them.

Thousands of Euros were going up in smoke every time one of these events occurred. The poor EMC of the installation was generating voltage surges between the LV equipment and the earth, causing the breakdowns.

Solution

The company called in an EMC consultant to study the phenomenon and propose a solution.

Since the earthing concepts of the HV station with the incorporated substation and the second substation are different, part of the consultant's study had to be executed separately. The first substation contained an earth loop connected to the mesh of the 380 kV public grid earthing system, while the second substation earthing system consisted of earth rods.

The EMC consultant provided the company with a solution to bring the surges below the 500 V limit tolerated by the LV equipment. He recommended, among other things, building a meshed ground grid and improving the continuity of the cable shielding. In the solution, all connections to the earth were kept as short as possible and the installation of data cables and power cables next to each other was avoided.

After implementing the proposed measures, a thorough inspection and test of the substation was carried out. The measures reached their objective and no more breakdowns have occurred.

Picture 1 : 25 kV circuit breakers in interior type HV cells with a metallic casing & SF6 gas insulation



2 Definitions

Earth network = A set of conductors under the ground, in direct contact with the earth and electrically connected with each other. The earth network allows external currents of common mode to drain off into the earth. An earth network should be unique and equipotential.

Ground network = A set of metallic conductors at a site, electrically connected with each other. The ground network normally contains the Protective Earth (PE) safety conductors, metal casings, metal ducts, cable trays, and metal structures.

3 General principles

An unwanted current (fault current, stray current, noise current, etc.) always returns to the source that produced it by the path of lowest impedance.

At low frequencies, the impedance of a conductor is reduced to its electrical resistance. When the frequency rises, the impedance of a conductor becomes increasingly inductive. At high frequencies, a conductor behaves entirely like an inductance.

At low frequencies, equipotentiality can be obtained by grounding all the equipment at a single point (a star grounding connection). This is the principle of the PE conductor with an adequate cross section that ensures human safety in the event of a fault (50 Hz).

In the past, this star-grounding also adequately protected equipment from disturbances, since this equipment had little or no sensitivity to high frequency interferences.

Today, digital electronic equipment has become sensitive to high-frequency interferences. In addition, appliances increasingly communicate with each other and are often controlled remotely.

At high frequencies, equipotentiality is provided by short connections and by the interconnection of the ground conductors (meshed ground network).

In addition to the meshed ground network, the green-yellow conductor (which is in fact a ground conductor) is still distributed to guarantee human safety conventionally.

This document provides recommendations for improving the electromagnetic compatibility of the HV station and substations. It is based on the laws of physics, on experience, and on technical reports (e.g. IEC 61000-5-1 and IEC 61000-5-2).

4 Investigation of the present situation



Picture 2: The shielding for the 25 kV cables is connected to the earth by insulated wires that are more than ten metres long.

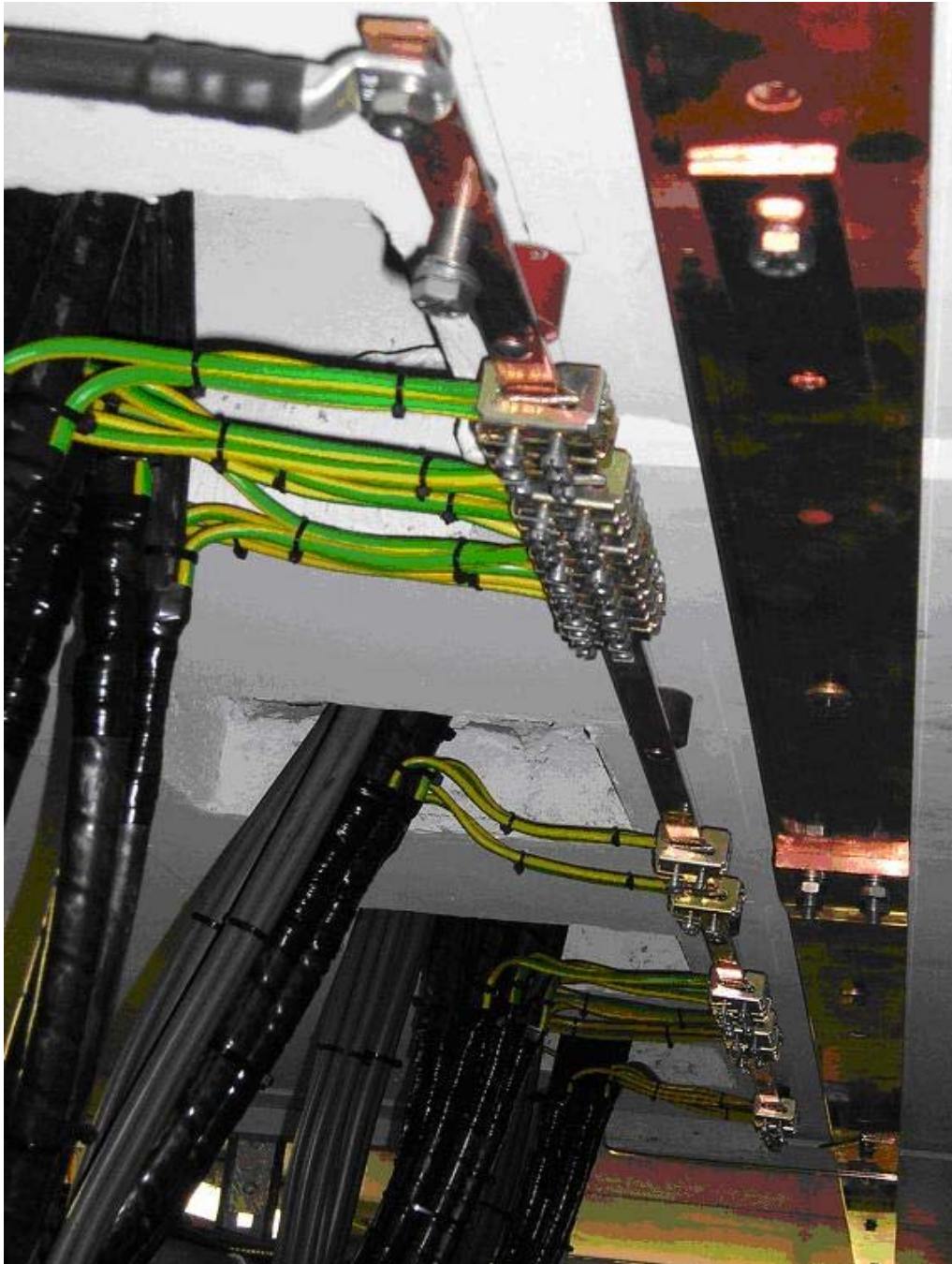


Picture 3 : The earthing wires are placed on cable ladders that also contain data and power cables.

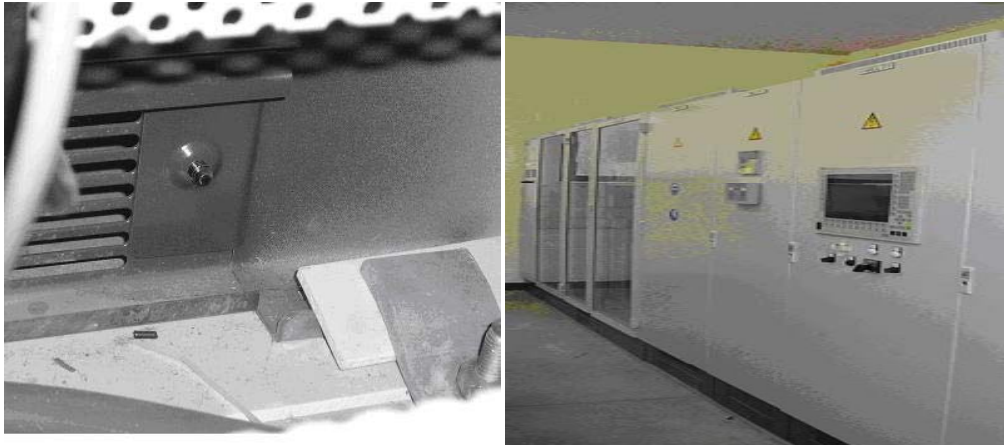
Power Quality

www.leonardo-energy.org

When the circuit-breakers are operating, a high frequency (HF) current will circulate in the shielding and consequently in the earthing wires. By mutual inductance, a current will be induced in the data and power cables situated on the ladders. Moreover, the cable ladders provide very little attenuation of this electromagnetic interference since their metallic surface is not continuous.



Picture 4 : All earthing wires are connected to an earthing bar (medium-sized cross section), which is itself connected to a larger earthing bar. This concept is typical and known as star earthing.

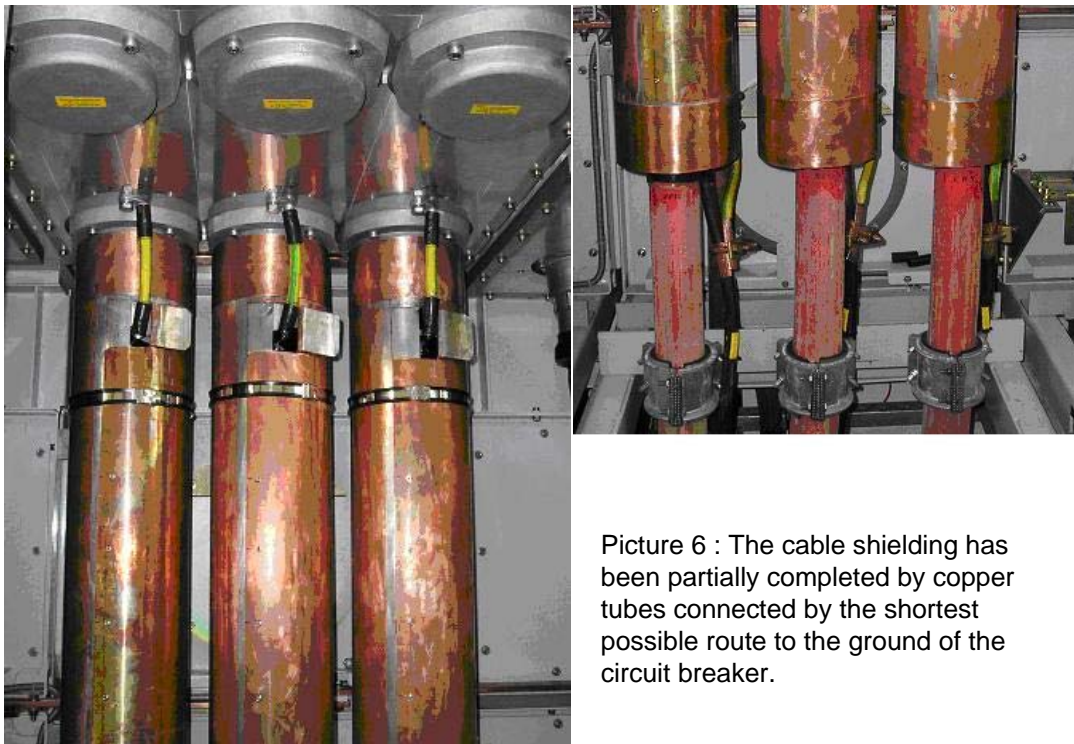


Picture 5 : The electrical cabinets are placed on the concrete floor and electrically insulated.

The earthing of the cabinets is accomplished by long wires connected to an earthing terminal in the basement.

5 Solutions and their implementation

5.1 Ensuring the continuity of the shielding at high frequency of HV cables in the substations.



Picture 6 : The cable shielding has been partially completed by copper tubes connected by the shortest possible route to the ground of the circuit breaker.

Recommendations

1. Cable shielding must be connected to the ground of the circuit-breaker by the shortest possible route. Cable shielding should be extended in a manner that enables them to surround (360°) each cable and be connected to the ground of the circuit-breaker.
2. The cables must be placed in perforated cable trays.
3. The data cables must be placed in different cable trays than the power cables.
4. The cable trays must accompany the cables all the way to the cabinets, and be bolted to the cabinets.

5.2 Investigation into how to establish meshed grids for the grounding and earthing of the substations

5.2.1 Construction

Solution 1

One solution is to install a meshed grounding grid of thin conductors bolted directly to the ground. The conductors consist of welded copper strips 10 to 15 centimetres wide (see Figure 1). The thickness can be between 0.3 and 0.5 mm and of less importance. A mesh should consist of cells at most 2 meters wide. Any additional link to a metal structure (steel beams, metal ducts, etc.) benefits the equipotentiality of the site. Welded brackets allow the grid to be connected to the various grounding conductors. If necessary, the grid can be covered by flooring. The grid may not contain interruptions: the wall must be pierced to cover all areas.

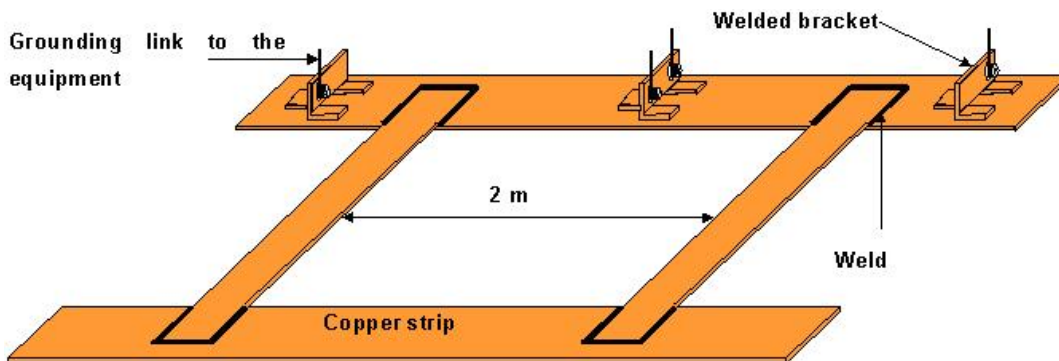


Figure 1 : Example of a grounding grid consisting of thin strips

Solution 2

A second solution is to install a meshed grounding grid suspended from the basement ceiling. Such a grid consists of bare copper wires with a cross section of 16 mm² welded or crimped at the intersections (see Figure 2).

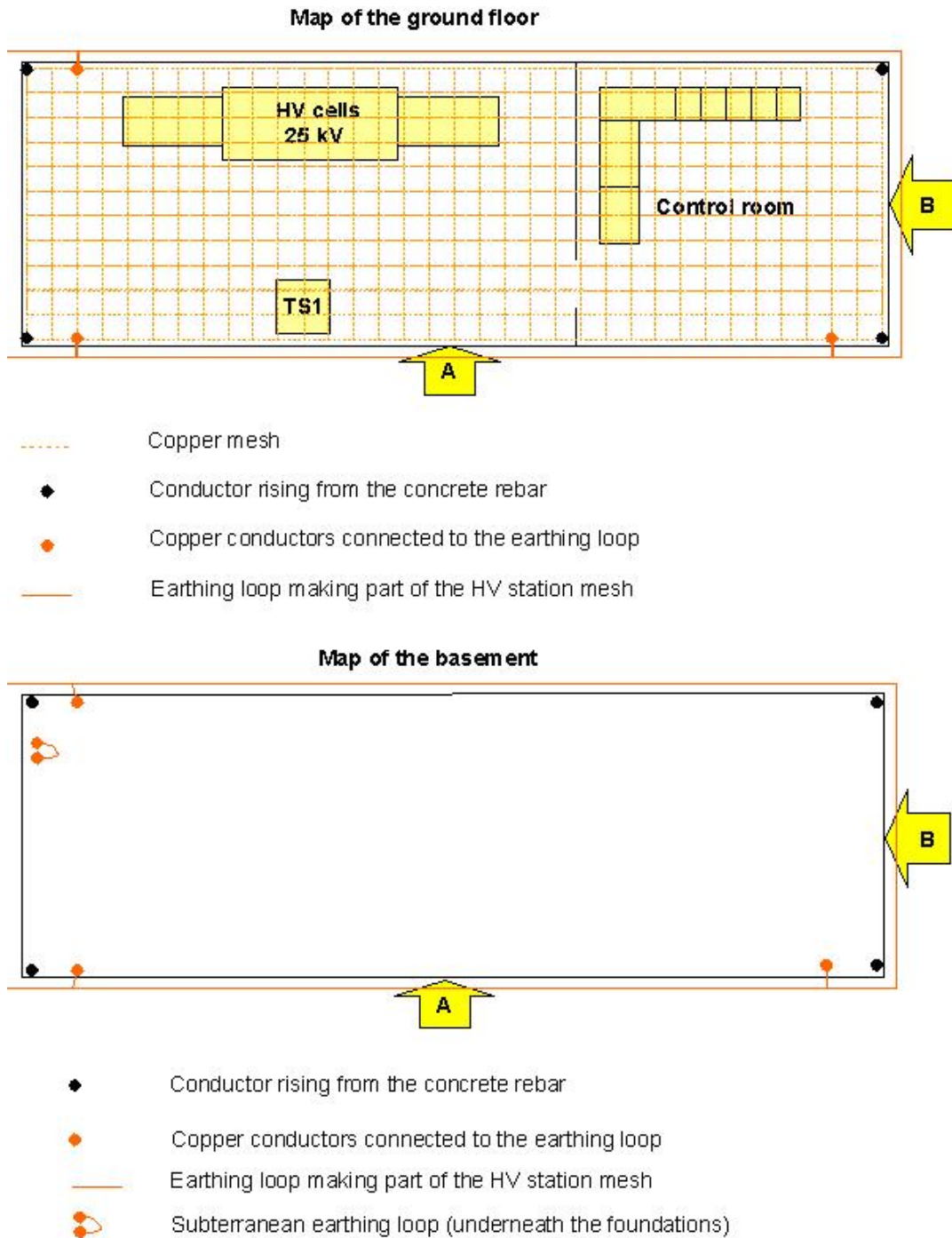
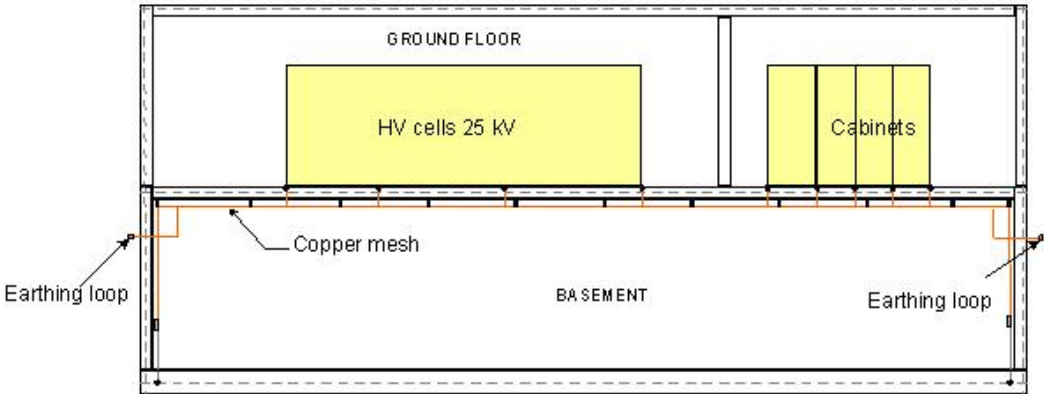


Figure 2 a, b and c: Example of a meshed grid suspended from the basement ceiling

Power Quality

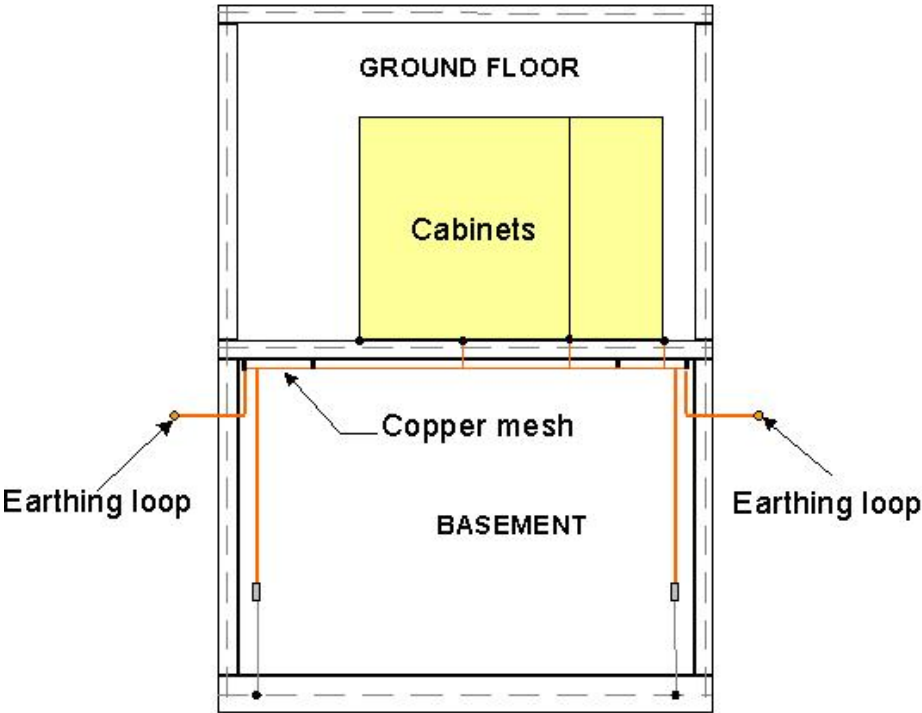
www.leonardo-energy.org

Longitudinal profile (section A)



- Copper
- Concrete rebar
- Fittings of the copper mesh
- Joint of Copper mesh/concrete rebar

Transverse profile (section B)



- Copper
- Concrete rebar
- Fittings of the copper mesh
- Joint of Copper mesh/concrete rebar

Connection to the earth network

The meshed grounding grid is connected to the buried earth network via earthing bars at each accessible connection point in the basement.

The subterranean earthing loop in the basement is connected to the meshed grounding grid.

The steel rebar used to reinforce the concrete structures of the building, can also be connected to the meshed grounding grid.

Connection to the electrical systems and equipment

The following elements must be connected to the meshed grounding grid by the shortest possible route (direct bolting or straps of at most 15 to 30 cm):

- The cabinets (racks) and various related systems (telephony, fire alarm, etc.)
- The cable trays
- The various earthing bars
- The distribution box earth
- The metal ducts (water)
- The surge protections

Connection to the green/yellow safety conductor

Human safety must be guaranteed by a PE safety conductor (which is in fact an additional ground conductor). This conductor must have a sufficient cross section, related to the short circuit power of the system. It is linked on one side to the electrical cabinets, systems and equipment and on the other side to the earthing bars. The connection should also be as short as possible.

5.2.2 Implementation

It is preferable that all copper strips or copper wires be welded, crimped, or bolted to each other.

If two different types of conductors must be connected, this should be done by crimping. Any galvanized steel at the connection point must be protected from electrochemically corrosion caused by the copper (battery effect). Therefore an intermediate metal must be used. The electrochemical potential of this metal in relation to copper and galvanized steel should not exceed 600 mV.

5.2.3 Solution chosen by the client

Solution 2 was chosen by the client.



Picture 7 : Implementation of a meshed copper grounding grid suspended from the ceiling.

All grounding conductors are connected by the shortest possible route.

5.3 Cable trays

5.3.1 Principle

A metallic cable tray can contribute to the electromagnetic compatibility of the site in two ways:

1. Joining the groundings of the cables, thereby reducing the surface of the loops between a conductor and the ground; this is the shielding effect
2. Contribution to the equipotentiality of the grounding between two communicating systems

5.3.1.1 Type of cable tray

Perforated metallic cable trays are recommended (cf. Figure 3)

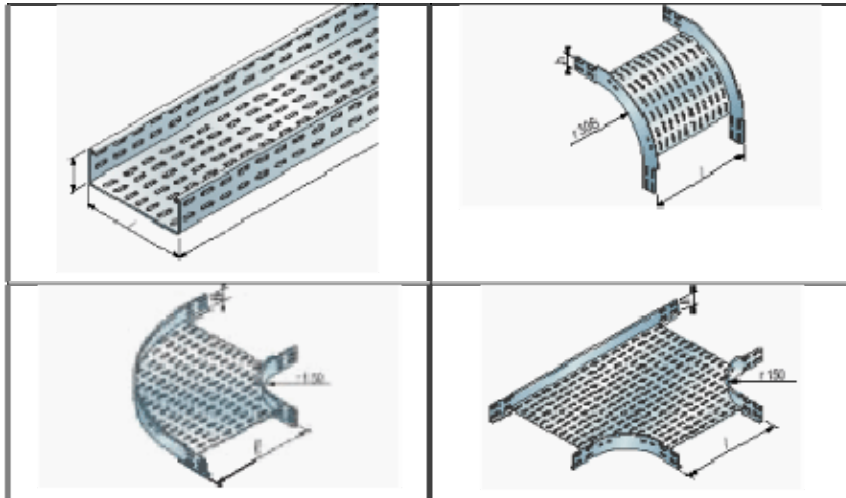


Figure 3 :
Perforated
cable
trays

5.3.1.2 Implementation

If correctly implemented, cable trays significantly attenuate electromagnetic interference.

It is crucial not to interrupt the electrical conductivity of a cable tray over the entire distance that it is carrying a cable.

This continuity is guaranteed by:

1. Bolting down the tables and sides of the various parts of the cable tray
2. Bolting the tray to the cabinets

Perforated metal power cable trays and data cable trays must be bolted together at various points; these measures improve the ground equipotentiality.

Painting of the contact surface is not permitted at any connection between metal elements.

The implementation rules in the figures below must be followed.

Power Quality

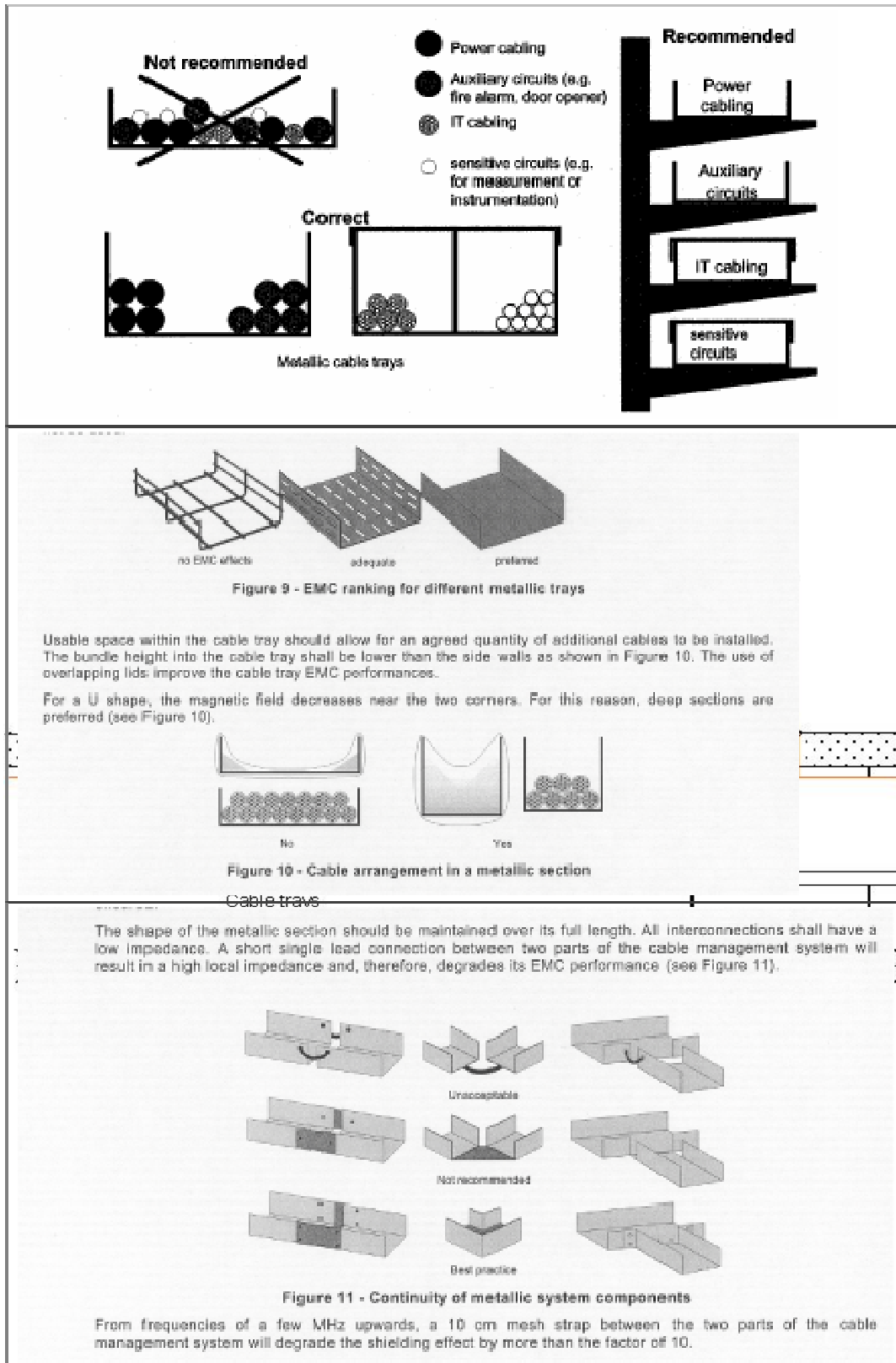


Figure 4 : Implementation of cable trays

The cable trays and cable ladders are placed in the basement.

Two fixing methods are possible:

- Suspend the cable trays from the basement ceiling
- Place the cable trays on tripods provided for this purpose

In both cases, the cable trays should be connected to the meshed copper grounding grid at several points (cf. Figure 4).

If the existing cable trays and cable ladders are retained, it is recommended that metal plates be fitted at the bottom of the cable trays. When doing so, ensure that the plates are properly bolted to the cable trays to guarantee electrical continuity.

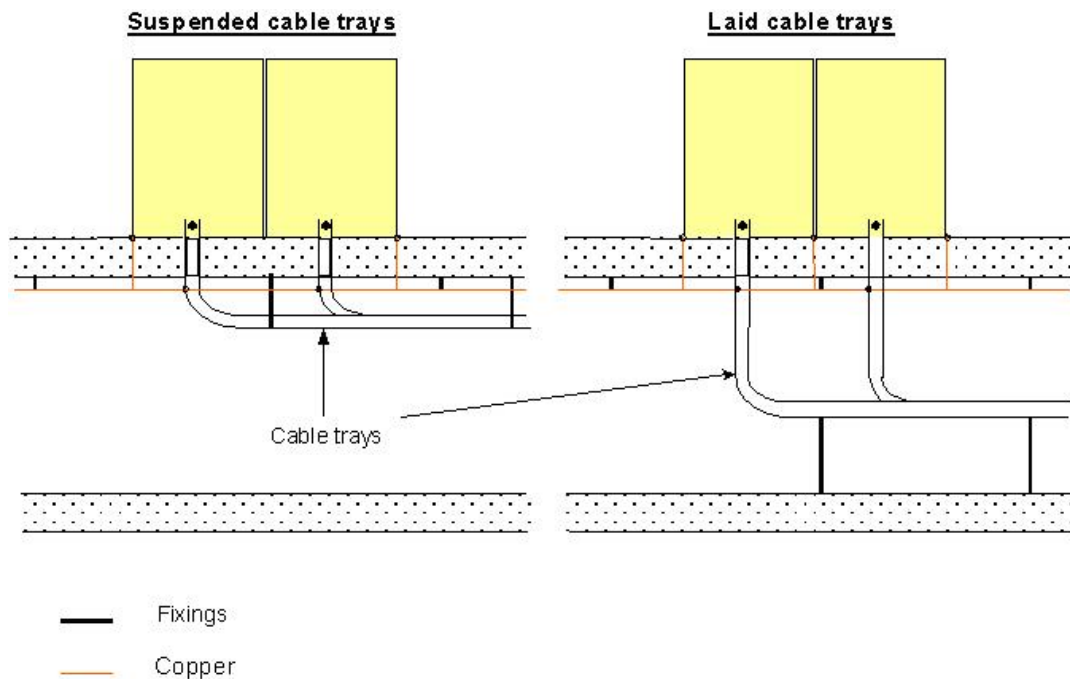


Figure 5: Securing cable trays

5.3.1.3 Installing the cables

- Place the power cables and data cables in two different cable trays. Similarly, be sure to keep digital and analogue cables distant.
- A cloverleaf laying of three-phase power cables is preferred.
- Install the PE safety cable in the power cable tray.
- Install the return conductor next to the outgoing conductor.
- Install the cables in the corners of the cable trays to benefit from a more efficient attenuation effect.

Power Quality

www.leonardo-energy.org

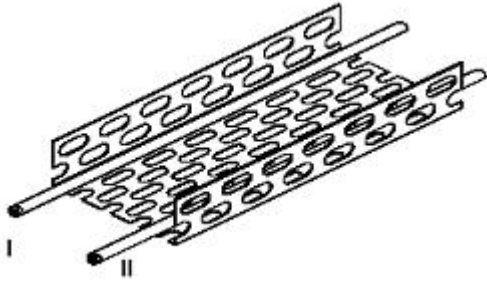


Figure 6 : Installing the cables in the corners

5.3.2 Solution chosen by the client



Picture 8 : Fitting a plate against cable trays to accompany the cables entering cabinets



Picture 9 & Picture 10 : Installing metal plates at the bottom of cable ladders to transform them into cable trays

5.4 Electricity and telecommunication cabinets

5.4.1 Interconnecting the cabinets

Adjacent cabinets are connected by being bolted together through their walls at two points at the top and two points at the bottom

A wide, short strap not more than 30 cm in length bolted to each cabinet is also acceptable (see Figure 7).

It is vital to remove paint from the contact surfaces to ensure metallic continuity.

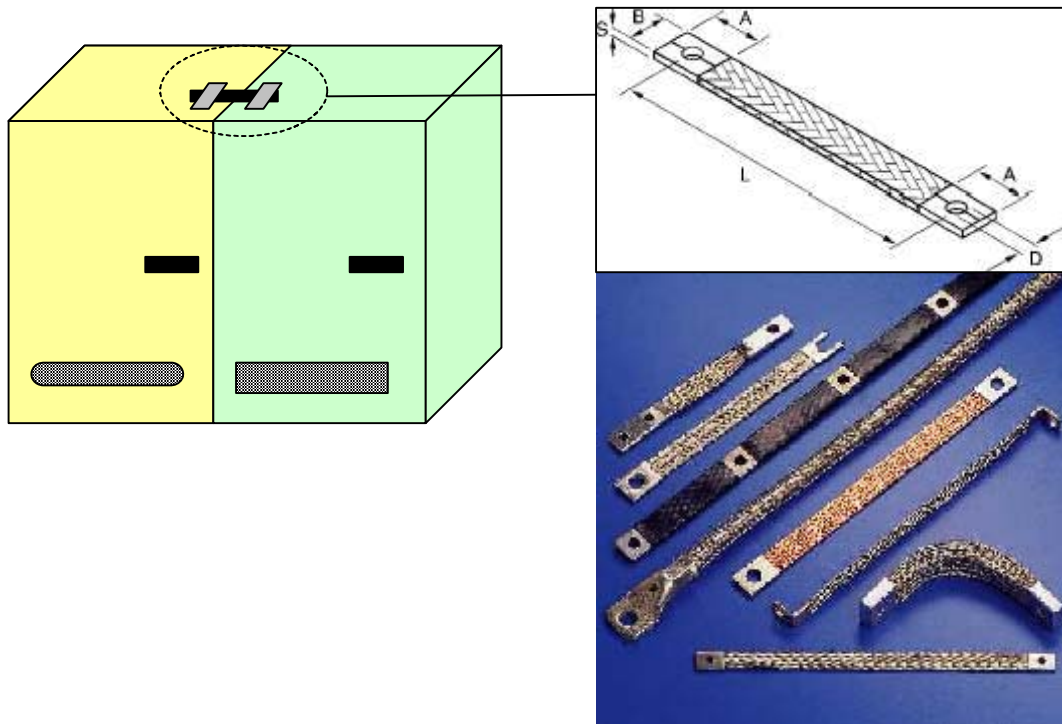


Figure 7 : Connecting cabinets using straps

5.4.2 Connecting cabinets to the meshed grounding grid

Cabinets are connected directly to the meshed grounding grid: the cabinets are placed on the meshed grounding grid and connected to this by the shortest possible route by using a strap.

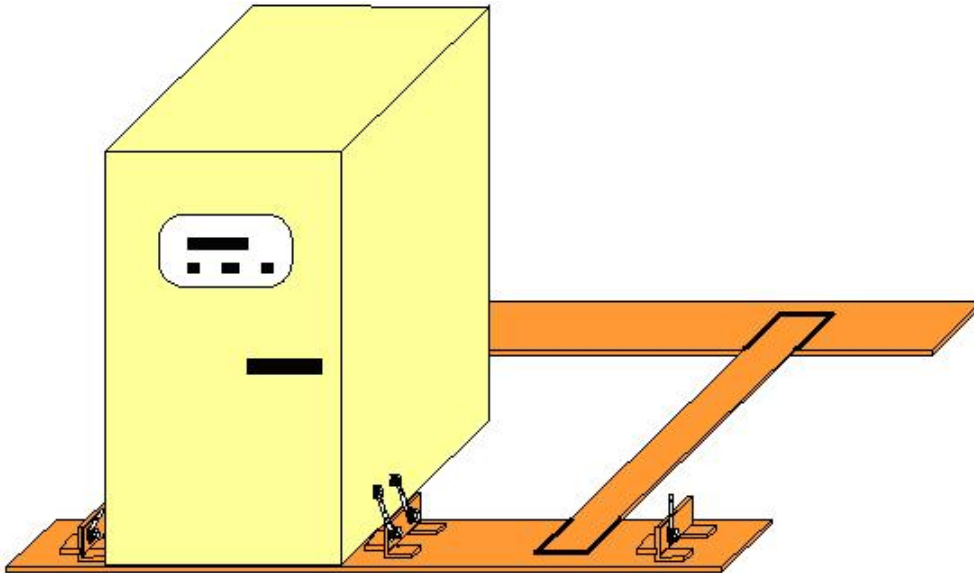


Figure 8 : Connecting cabinets to the meshed grounding grid

5.4.3 Earthing the cable shielding

Except in a few rare situations, the data cable shielding must always be connected to the ground network on both sides (making sure that these groundings are equipotential).

The data cable shielding is grounded by a compression gland, allowing a 360° connection at the cabinet entrance. Grounding by simple conductors is not recommended, since at high frequencies they have high impedance, preventing the shielding effect (see Figure 9).

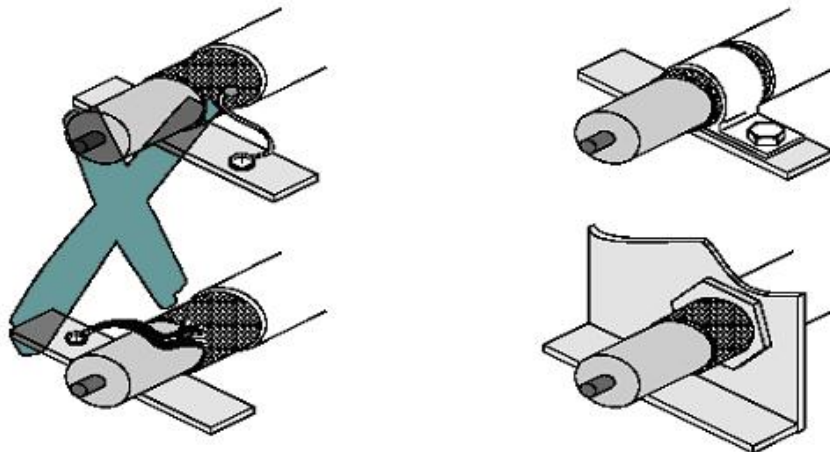


Figure 9 : The grounding of data cables at the cabinet entrance

Power Quality

www.leonardo-energy.org

In the cabinet, the shielding of a pair of conductors is connected by the shortest possible route to the grounding of the equipment (as indicated by the manufacturer). A metallic attachment on the back of the equipment is inserted into the metallic DIN rail, which is itself bolted directly onto the metallic base of the cabinet.

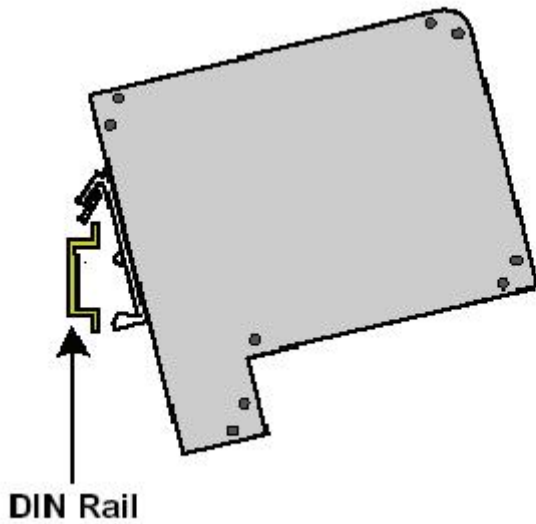


Figure 10 : Fixing the equipment to the DIN rail

5.4.4 Recommendations for cabinet wiring

Inside the cabinet, the following recommendations should be followed:

- Outgoing and incoming conductors should be installed next to each other
- Avoid creating loops with conductors (the most direct route is recommended)
- Avoid installing power conductors next to data conductors; do not lay them in the same cable tray
- Keep sensitive electronics as far away from interfering electronics as possible
- Connect any unused conductor to the ground (see Figure 11)

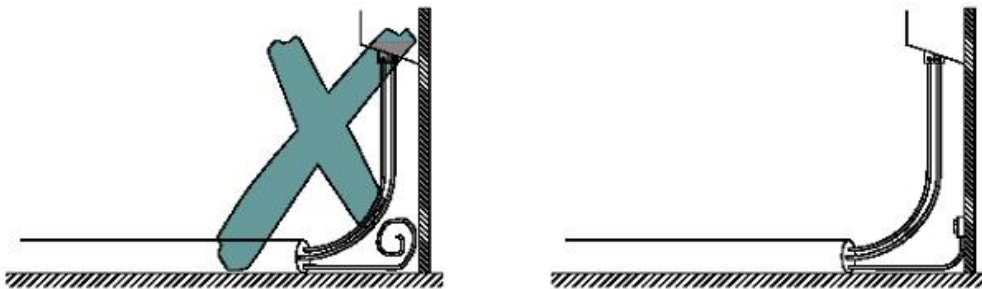


Figure 11 : The grounding of unused conductors

Conclusion

A new inspection of the substations was carried out after implementing the above recommendations. More than forty different operations were executed, including the operation that used to cause the LV equipment to break down (connecting the 25 kV cables to the earthing network to discharge them).

After each of those operations, no electrical equipment had been damaged.

In a highly disturbed environment, it is recommended that a proper meshed grounding network be installed, that all connections to the earth be kept as short as possible, and that the installation of cables parallel to each other be avoided to reduce mutual inductance. Perforated cable trays also help to reduce interferences in common mode.