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# APPLICATION NOTE INTEGRATED EARTHING SYSTEMS

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## SUMMARY

An Integrated Earthing System (Earthing Grid) aims to protect digital/electronic equipment against the effects of severe electric and magnetic disturbances (such as lightning, short-circuits, et cetera) and enables this equipment to function properly, both on the short- and long-term.

An earthing grid normally has three different primary functions:

1. Preventing electrocution or fire caused by short-circuits or insulation defects
2. Avoiding human injuries and fatalities in case of a direct or nearby lightning strike
3. Protecting electronic equipment against the effects of electromagnetic disturbances so that it can continue to function properly on both the short- and long-term

Historically, those three protection functions were developed separately, under the names 'protective earthing', 'lightning protection', and 'functional earthing'. In the course of time it became clear that these three different earthing systems could influence each other up to the point of hampering each other's proper and efficient functioning. As a result, the only way to ensure that all protective functions are well covered, is to design a single integrated earthing system that deals with all three issues simultaneously.

The Integrated Earthing System (Earthing Grid) is meanwhile embedded in the related safety, lightning protection, and EMC standards, and its reliability has been field proven in many installations. It is the current state of the art solution and an indispensable part of critical IT operations. However, designing such a network is a complex task, to be executed by a specialized engineer.

## INTRODUCTION: A SHORT HISTORICAL OVERVIEW

Lightning protection was invented in 1749 by Benjamin Franklin. It resulted in the establishment of a lightning protection industry, devoted to the fire protection of buildings. The American National Fire Protection Association (NFPA) was founded in 1896. Their first code — NFPA 1 — stipulated how to achieve a reasonable level of fire safety and property protection in buildings.

The electrical power industry had matured considerably by the end of the nineteenth century. The first practical electrical power distribution network was created in 1882. Protective earthing connections were developed to reduce the risks of electrocution and fire. The NFPA published their first National Electrical Code (NEC) in 1897.

Protective earthing and lightning protection were initially developed as totally separated systems, and it took a while before their interconnection — initially only underground — was accepted as a better solution.

With the advent of electronic equipment and computer systems in the 1960s, awareness grew regarding the fact that electromagnetic signals can disturb each other. This gave birth to the concept of electromagnetic compatibility, or in short: EMC. Initially, EMC solutions were developed separately from the lightning and protective-earthing systems. They were part of the so-called clean or functional earthing system, dedicated to protecting electronic devices.

Around 1980, extensive studies revealed that the causes of various shortcomings, which were thought to be inherent to the earthing systems themselves, were actually resulting from the separation of the three systems and the lack of compatibility between them. Out of this understanding emerged the concept of an integrated earthing system.

Integrated earthing concepts were introduced in the IEC and IEEE standards by the end of the 1990s, and European EMC directives were approved that required incorporating those standards (or equivalent alternative methods). This provoked a short-lived hype of EMC awareness.

Subsequently however, this interest began to fade, and today the implementation of the prevailing standards and regulations is often still lacking. There is still considerable confusion about earthing systems and their characteristics, even among specialists. Systems based on outdated technology are still operational, and engineers who have not adopted the latest insights are still influential.

## GROWING IN IMPORTANCE, BUT BARRIERS REMAIN

Integrated earthing for tertiary sector and industrial buildings has been growing in significance over the past decades due to the rapid development of IT systems. As IT systems take on increasingly crucial functions, their reliability and that of their energy supply becomes considerably more critical. Paradoxically, IT devices are at the same time becoming increasingly vulnerable to electromagnetic disturbances. This vulnerability stems from the fact that signal bandwidths are being increased and signal amplitudes reduced, with the aim of processing larger amount of data within shorter time periods. Only a well-designed integrated earthing network can give those IT systems the immunity they require.

IT systems are used more and more in places where reliability is absolutely imperative. Think for instance of public transport facilities such as *digital security systems* and *airline/railway traffic management*. Other examples include data centres and corporate computer systems. For these kinds of systems, failure is not an option. The integrity and reliable functioning of such IT systems has grown in importance to the level of human safety. As a result, functional earthing has become just as 'vital' as traditional protective earthing and lightning protection.

One of the barriers for the fast and widespread implementation of the latest earthing standards is that historically, the three earthing disciplines (Protective Earthing, Functional Earthing, and Lightning Protection) were supervised by different parties (respectively electrical contractors, equipment manufacturers, and lightning protection contractors). It will take time for those parties to combine their insights and develop a common understanding.

It is therefore recommended that an experienced external consultancy be involved to supervise both design and installation, in order to address all aspects of the inherent complexity of this subject. Strategically important for your organization is that maintenance, modifications, and extensions are supervised by the same office.

## THE STAT-OF-THE-ART INTEGRATED EARTHING SYSTEM

The integrated earthing system provides and combines various different functions, which have historically been tackled in different domains:

- 1) Protective earthing (humans):
  - a. Conducting fault currents back to the power source without introducing the risk of local overheating that might lead to fire.
  - b. Protection against *indirect contact*. Indirect contact occurs when a person touches a conductive (metal) part which is normally not live, but which has become live due to a fault in the insulation. Protection against indirect contact requires, among other measures, *equipotential bonding*. This is the connection with each other of all conductive parts of the electrical system and conductive parts extraneous to the electrical system, and subsequently connecting this bonding network to the protective earthing network. Extraneous conductive parts include for instance metal pipes, metal windows, and iron components of reinforced concrete. Equipotential bonding avoids the situation where two metal parts can hold a different electrical potential, entailing the risk on electrocution if they were to be touched simultaneously.
- 2) Lightning protection (humans and equipment):
  - a. Conduct lightning currents to the earth without introducing any risk of electrocution or overheating.
  - b. Prevent direct fires, flashovers. or explosions caused by a lightning strike.
  - c. Apply the necessary interconnections and surge protection devices (SPD) to reduce the extreme voltage and current transients down to the defined levels.
- 3) Functional earthing (equipment), ensuring *electromagnetic compatibility* (EMC). All electric and electronic devices send out electromagnetic signals (waves). Electromagnetic compatibility is ensured when those signals do not disturb the proper functioning of other electronic devices.

Although the requirements for these different aspects are often specified separately, the implementation requires an integrated systems approach, as the solution for one aspect might influence the proper and efficient functioning of another solution.

For example, the danger of electrocution by simultaneously touching different earthing networks was initially solved by connecting a high frequency choke between those networks. It was subsequently discovered however, that this degrades the lightning protection function.

Integrated earthing means that all of the different earthing functions are integrated into a single system: the so-called 'earthing grid'. This earthing grid provides a single metal matrix for the entire facility. It should be noted that the focus is wider than just a single building within a complex; the earthing grid should cover all buildings on a particular site or of a facility.

If an integrated approach is not followed, the various individual protective solutions risk a higher investment cost without ensuring the protection they are designed to provide. In addition, failure of protection can lead to significant claims and legal complications. European directives and local regulations have been tightened considerably in recent years, both in terms of technical requirements and liability. Nonetheless, knowledge regarding these new regulations is often lacking. For example, it is often not understood that the owner of a multi-vendor technical infrastructure is responsible for overall CE compliance. This implies that all equipment design and the corresponding documentation must conform to all prevailing regulations, including earthing.

## APPLICABLE STANDARDS

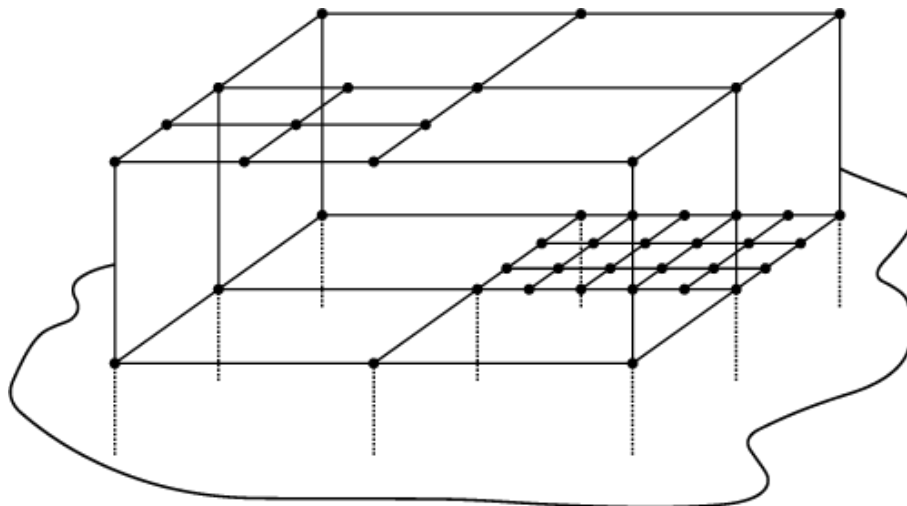
### EUROPEAN STANDARDS

#### IEC 61000 STANDARD SERIES

The applicable harmonized standards are referenced in the *Official Journal of the European Union*, thus not in the European directives themselves. Compliance with these standards should raise a presumption of conformity with the relevant essential requirements, although other means of demonstrating such conformity are permitted. Compliance with these directives is enforced by law in all Member Countries; *they are absolutely not voluntary*. The applicable standards define different EMC environments, and provide clear emission and susceptibility requirements.

#### THE TECHNICAL REPORT IEC TR 61000-5-2

The Technical Report IEC TR 61000-5-2 describes a workmanship code for good EMC. It explains in detail all kinds of installation and mitigation guidelines to obtain Electro Magnetic Compatibility between various devices installed in the same building. The Integrated Earthing System is an important mechanism to avoid the build-up of significant voltage differences between various points in the earthing networks. The following illustration shows a typical Integrated Earthing System with a three dimensional meshed earthing system for the entire building, including finer meshed systems for areas with more sensitive equipment.



Source: Figure 7 from IEC TR 61000-5-2 (1997)

Figure 1 – A typical Integrated Earthing System resulting from IEC TR 61000-5-2

The *Technical Report* also provides recommendations on how to connect equipment to this earthing system, but it does not demand changes to the internal wiring of the equipment.

#### Notes:

- I. Additional earthing connections do not substitute for the power cable protective earthing conductor (PE). The *latter must never be omitted*, for safety and EMC reasons. PE and Neutral conductors should not be combined inside the power cabling network.
- II. Likewise, for EMC reasons, the return conductor for electrical signals must never be omitted. This return conductor must always be included in the corresponding signal cable and not be identical to the return conductor of the power supply.
- III. Figure 8 in TR 61000-5-2 (not shown here) provides a good impression of the Integrated Earthing System for an industrial plant.



- IV. Special note for the (Process) Industry: There is no such thing as *intrinsically safe earthing*. All required earthing points must be connected to a common earthing grid. This is to ascertain that each earthing point is actually at the same potential to prevent arcing and the consequent ignition of an explosive environment. Building steel is infamous as an unsuitable earthing point due to corrosion, et cetera.

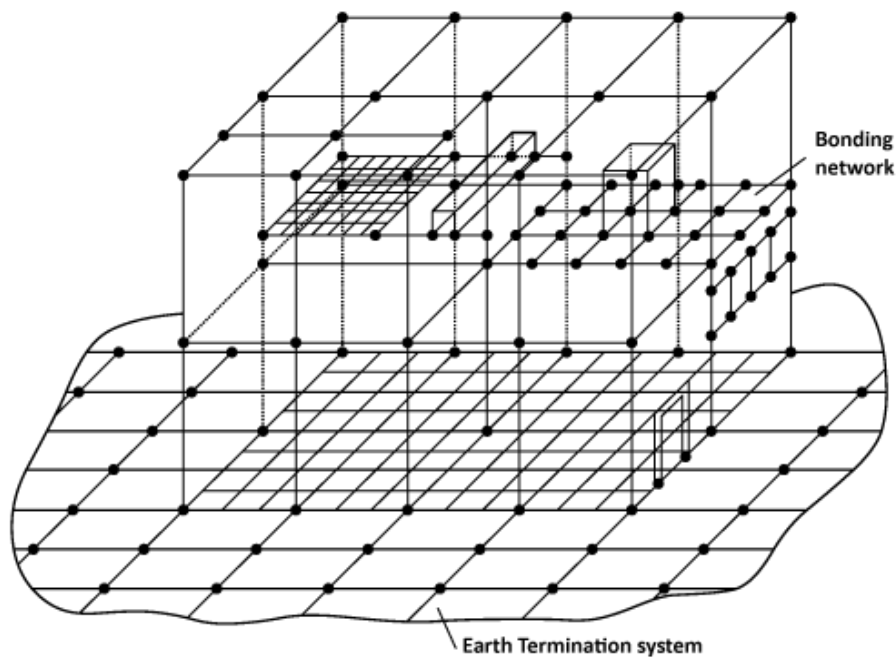
#### THE NEW STANDARD FOR LIGHTNING PROTECTION IEC 62305

In 2006, the new IEC 62305 standard for lightning protection of electrical and electronic systems within buildings was published. Since then, protective earthing, functional earthing, and lightning protection have all been integrated into a single protection concept.

The IEC 61000-5-2 technical report published earlier explained many general lightning protection aspects. More specific details covered by IEC 62305 can be found in the following documents:

- IEC 62305-1: General principles
- IEC 62305-2: Risk management
- IEC 62305-3: Physical damage to structures and life hazard
- IEC 62305-4: Electrical and electronic systems within structures

The following illustration shows a typical example of a resulting Integrated Earthing System (grid):



NOTE: All drawn connections are either bonded structure metal elements or bonding connections. Some of them may also serve to intercept, conduct and disperse the lightning current into the earth.

Source: Figure 5 from IEC 62305-4 (2006)

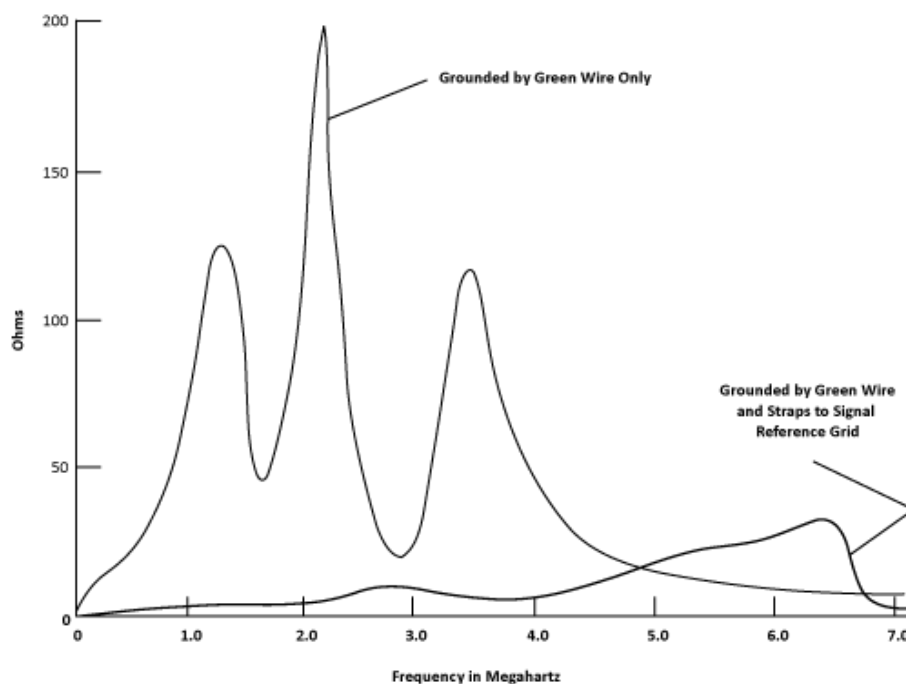
Figure 2 – A typical Integrated Earthing System resulting from IEC 62305

IEC 62305-4 also requires that engineers who are implementing the protection system have mastered all three disciplines concerned: protective earthing engineering, lightning protection engineering, and EMC engineering.

## NON-EUROPEAN STANDARDS

Other standards, such as those of the IEEE, may be the (legally) preferred standards in other countries (i.e. the Middle East and other locations outside the USA). A good guide to this situation is the IEEE Emerald book (IEEE Std 1100 – 2005) titled *Powering and Grounding Electronic Equipment*. Section 4.8.5.3 discusses the Integrated Earthing System using different terminology.

- Modern signal reference structures [SRS]. An SRS is the external installed network of conductors used to interconnect the metal frames, enclosures, and logic or signal level power supply common terminals of the subject electrical and electronic equipment to one another. This network may be a recommendation from, or an actual part of, the equipment's OEM installation package. Most often it may be part of an aftermarket, field-installed wiring effort.
- The SRS is an integral part of any SPD [Surge Protection Device] network system that is used on either ac or dc power, or signal (including telecommunications) circuits connected to the electronic equipment that is also attached to the SRS.
- The SRS is not intended to be dielectrically or galvanically insulated or isolated from the building electrical system's EGC [Equipment Ground Conductor] system that is part of the fault/personnel protection grounding subsystem.



Source: Figure 4-66 from IEEE Std 1100 (2005)

Figure 3 – IEEE standard Std 1100 compares the superior low impedance of a SRS (thus also of the Integrated Earthing System) with an ordinary earthing conductor (green coloured in the USA).

## COPPER VERSUS (GALVANIZED) STEEL

The Integrated Earthing System should preferably be constructed from conventional copper-based materials to obtain a low and long lasting impedance, also for very fast phenomena such as lightning or high frequency signals. Copper assures that the potential differences are kept to a minimum and prevents corrosion problems. As a result, in the large majority of the cases, the most reliable and durable solution will be the all copper Integrated Earthing System.

The commonly used (galvanized) steel has the disadvantage of increased impedance at higher frequencies, caused by the higher permeability (magnetic property) of steel. Moreover, protective measures against electro-corrosion are required when connecting different metal materials with each other.

Flat conductors are to be preferred to round conductors, as they have lower impedance at higher frequencies. A minimum thickness is required for ensuring lightning protection and for construction reasons.

## UPGRADE EXISTING INSTALLATIONS OR NOT?

Should existing installations that were not conceived according to the latest standards be upgraded immediately?

They should be upgraded, but caution is advisable. Existing installations are likely to be based on outdated EMC insight. They should be carefully inspected by specialists understanding both old and new concepts before any changes are considered. *Otherwise, there is a risk of creating involuntary earthing loops in the signal path, which is to be avoided in every case!*

## CONCLUSIONS

- 1) Although historically developed as separate systems, protective earthing, functional earthing, and lightning protection should be provided by a single integrated earthing grid. If not, compatibility problems between the three protection networks can occur.
- 2) A well-conceived earthing grid is of growing importance, as electronic devices become increasingly sensitive to disturbances. Moreover, IT systems are increasingly used for critical operations for which failure is not an option.
- 3) The integrated earthing system concept is explained in international standards (i.e. IEC 61000 series, the technical report IEC TR 61000-5-2, and the IEC 62305 series, et cetera). The Official Journal of the European Union documents their applicable harmonized standards. Compliance with the standards (or an equivalent method of demonstrating conformity) is compulsory.
- 4) Knowledge of the prevailing standards and regulations is often poor, even among engineers. There is still a great deal of confusion about earthing systems and their characteristics. As a result, the implementation of the appropriate standards is often lacking. Company standards (suppliers, contractors, end-users) may still be based on outdated concepts, and the engineers involved (electrical engineers, process engineers, instrument engineers, lightning engineers, maintenance engineers, et cetera) may still be unaware of the latest insights. It is therefore recommended that an external consultant experienced in the matter be contacted and utilized.
- 5) The Integrated Earthing System should be constructed from conventional copper-based materials to obtain the lowest resistance and to avoid corrosion problems.
- 6) Upgrading existing installations should be undertaken with care. Specialists that understand both old and new earthing concepts should first meticulously inspect them.