Good Practices Identification for Design Electronic Equipment Grounding Systems to Mitigate Power Quality and EMI Problems.

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Abstract — **The proliferation of electronic loads into industrial, commercial and residential electrical facilities, and their susceptibility to electromagnetic interference, has greatly increased the interest in considering the nature of these loads in addition to the electrical disturbances at the facility, with the purpose of establish design practices that configure a safe and efficient electrical installation. The grounding system as essential part of the electrical installation also fulfills the function of referencing electronic equipment, becoming an important component not only for the safety of the facility but also to ensure a good performance of it and to achieve power quality** [1]**. This paper describes the problems that generate electromagnetic interference in electronic equipment and recommended practices in the design of the grounding system, supported by technical standards, which allow mitigate them.**

Keywords **— Grounding system, electromagnetic compatibility (EMC), electromagnetic interference (EMI) electronic equipment, power disturbances, recommended practices.**

I. INTRODUCTION

THE development of electronic systems has triggered a radical change in the nature of the charges present in electrical installations, making them an important element to perform daily activities. In the industrial field it is common to found microprocessor-based control applications, PLCs, variable speed drives and general operating systems using digital variables, sensors, and other electronic equipment.

In the commercial sector the personal computers (PCs), UPS, copiers, scan, electronic lighting type LED, compact fluorescent lamps and telecommunications equipment are predominant. Even in the residential sector, it is evident the development of electronic equipment in each room, ranging from toys to kitchen tools, TVs, smartphones, tablets, etc.

At the same time, the growth of non-linear and unbalanced loads in the electrical network, besides the presence of lightning, power failures and the operation of another equipment, make the electronic equipment must operate in an environment containing several electromagnetic disturbances or EMI[1] problems.

Additionally the use of low power signals by the electronic equipment makes them sensitive to electromagnetic disturbances far below levels that are perceptible to humans and have no effect on the electric power equipment [2]. These disturbances can affect significantly the performance of electronic equipment and the end use electrical installations.

For this reasons, it is vital to consider the presence of disturbances on the electromagnetic environment [3] and their influence on suitable and convenient operation of the end-use electrical installations[2]. This analysis allow the identification of good practices proposed to be incorporated on the design stage, with the firm intention to mitigate the adverse effects on the operation of the facility, and the consolidation of an electromagnetically compatible end-use electrical installation [4].

Considering that one of the purposes of the grounding system, in addition of ensure the safety of persons and protect installations, is to contribute to the electromagnetic compatibility of the electrical facilities [5], the objective of this research is to identify good engineering practices in the grounding systems design, supported by technical standards, to mitigate the problems of power quality and electromagnetic incompatibility into electronic systems and equipment, inside the end use electrical installations.

The structure of this article is given as follows: In the Section II presents the problems that generate electromagnetic interference in electronic equipment and are directly related to the grounding system. Likewise, in the Section III sets out good practices in the design of the grounding system for electronic equipment to mitigate the problems identified in Section II.

Finally, in the Section IV presents the conclusions and recommendations.

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[1] EMI (Electromagnetic interference): Degradation in the performance of equipment, transmission channel or system, caused by an electromagnetic disturbance [3].

[2] This knowledge can be obtained by several methods, including an inspection of the intended location, projected load type in the new power project, technical evaluation of equipment and systems as well as the recommendations cited in standards and technical documents.

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II. SCENARIOS THAT GENERATE ELECTROMAGNETIC INTERFERENCE IN ELECTRONIC EQUIPMENT.

A. Nonconforming practices for wiring and grounding electronic equipment.

It is common to find in facilities with inadequate wiring practices, multiple neutral-ground connections [6], allowing a portion of the load current to flow through the grounding system which is referenced [6]. This situation generates stray currents and variations in the ground potential levels throughout the grounding system, triggering errors or slow data transfer, lockdown and I/O ports damage on electronic equipment [1]. The Fig. 1 shows the most common unsuitable wiring practices, present inside end-use electrical facilities.

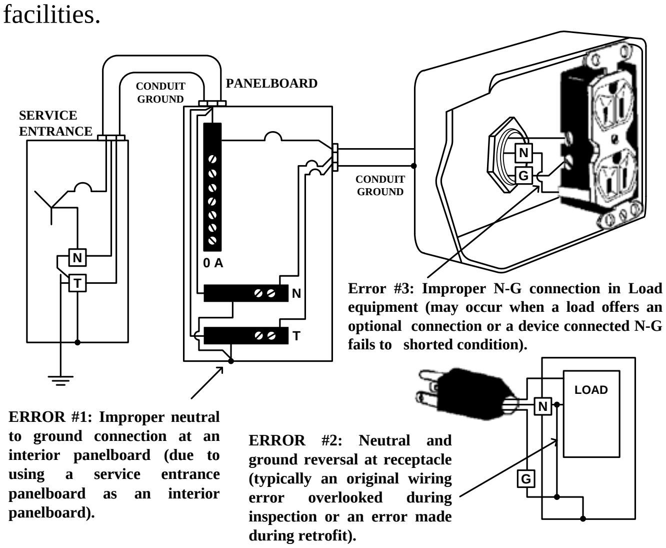

Fig. 1. Typical wiring errors on a branch circuit [1].

B. Separate / Isolated Ground IG.

Not consider the level of susceptibility of electronic equipment to electromagnetic disturbances presents in electrical installations and in particular in the grounding system installation (immunity).

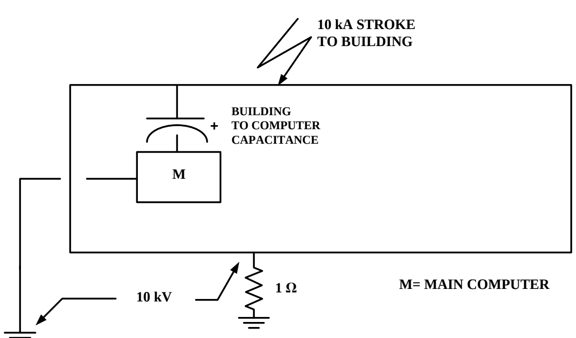

Fig. 2. Effects of stroke to building with isolated grounding electrode [2].

In addition to possible lack of understanding of the function and operation of the neutral conductor and the grounding system by the designers of electrical and electronic equipment manufacturers led to erroneous installation requirements like to ground. For example, the demand for electronic equipment to be grounded using an isolated ground electrode [2], composed of one or more electrodes (isolated from power grounding electrode) as indicated by Fig. 2

Although this configuration reduces disturbances from the power grounding system, introduces serious operational and safety problems due to the additional impedance inserted into the loop, caused by the lack of equipotential bonding between the two grounding systems and did not meet the requirements established in [7].

C. Rising of the grounding impedance at high frequencies.

The earth connection mostly exhibits increasing impedance with frequency [8] (Fig. 3). The particularity of the problem with grounding systems of digital equipment lies in the broad range of frequencies used by these devices, and their interaction with the grounding system, since high frequency signals as short pulses used in signal processors, and even the high frequency noise propagates along the conductors that form the grounding paths, existing among the devices that conform an interconnected digital system [1]. These paths include electronic equipment grounding conductors, and in general any connection with the building grounding network[3] [9].

The consequence of the increasing impedance of the grounding system, significantly limits the effectiveness of the grounding system to control unwanted effects associated with high frequency disturbances.

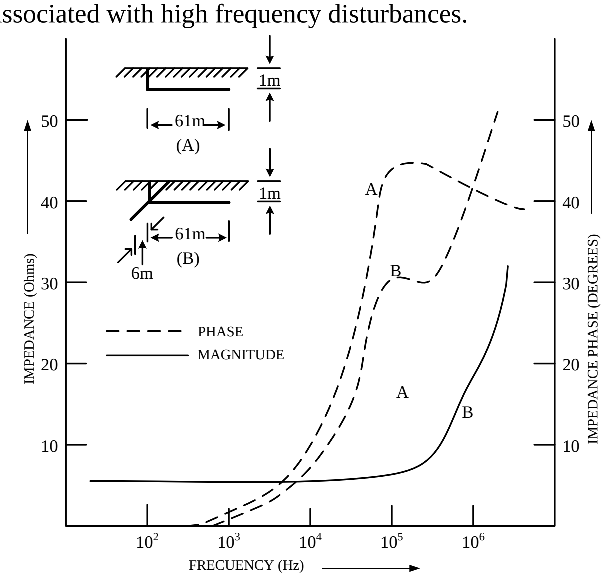

Fig. 3. General earth grounding electrode system impedance vs. frequency using two comparative earth grounding electrode configurations, A and B [1].

[3] The set of metallic components those are intentionally or incidentally interconnected to form the (earthed) bonding network (a mesh) in a building. These components include structural steel or reinforcing rods, metallic plumbing, ac power conduit, equipment grounding conductors (EGCs), cable racks, and bonding conductors [1].

D. EMI generated by self-resonance in grounding system conductors.

Resonance occurs on the conductors due to the distributed capacitance and inductance along grounding system conductors. The resonance frequency depends of the conductor inductance and capacitance and in most cases is much higher than the operating frequency (60 Hz) or its harmonics. However, the self-resonance becomes relevant in bonding and grounding conductors in the MHz range, near the operating frequencies of the equipment related to information technology.

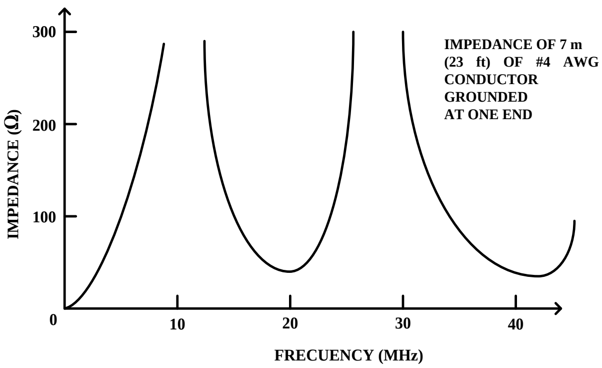

Fig. 4. Resonance characteristics of conductor [10].

Self-resonance occurs when the conductor length is equal an even or odd multiple of ¼ of the wavelength λ of the voltage signal applied. When a conductor is under conditions of self-resonance, the result is a virtual open circuit, with almost infinite impedance, and a high potential difference between the conductors ends [10]. This situation is illustrated in Fig. 4.

E. Parasitic inductance and capacitance on the grounding/bonding conductor's path.

Both grounding conductors and bonding conductors are subject to electromagnetic effects product of transient impulse currents that circulate through them, such as those associated with disturbances and lightning. For this reason, the conductor must be arranged so as to minimize the generation of transient voltages along its length, when carrying transient pulse currents.

The relationship -e = L (di / dt) is useful to represent the voltage developed across an inductor when a current is forced to flow in it. When the flowing current through it is interrupted abruptly, may present current pulses flowing through the inductive grounding paths, and tension that can be developed through distributed or loop capacitance.

In practice, the problem is represented by the following expression [1].

$$E_{max} = I_{peak}\sqrt{\frac{L_{path}}{C_{stray\ path}}}$$

Where:

E_{max} : is the maximum voltage developed across the ground path.

I_{peak}: is the maximum current flowing in the ground path.

L_{path}: is the inductance of the ground path in Henries.

$C_{parasita-circuito}$: is the stray capacitance of the ground path in Farads.

The mathematical expression above, takes into account the fact that the parasitic capacitance associated with typical paths and connections in grounding system should not be ignored. In few words, the problem is not a theoretical inductance in free space coupled to anything, because the parasitic capacitance can be quite large depending on whether there is metal cabinets, closely spaced, facing each other and with a significant area. This forms a dielectric layer (air) between the metal faces and hence a capacitance which is essential in the analysis of the circuit and can not be ignored [1].

F. Common mode disturbances.

Common mode disturbances are defined as unwanted potential differences between any or all current-carrying conductors with respect to the earth conductor [11], which is connected to certain electronic equipment. This type of disturbance should never be confused with the disturbances in interconnected computers earth conductor, such as ground wires that supply two computers connected by data cables.

Common mode disturbances on the supply lines are generated from multiple sources. They may include natural sources, as well as electrical devices that inject noise into neutral conductors as grounding conductors, spreading through the electrical power system affecting other equipment. The sources of such disturbances are compact fluorescent lamps (CFL), which often create high frequency disturbances, while motors, pumps and fans create transitory disturbances during start or turning off [12], as well as Switched-mode power supply (SMPS) supplies feeding into electronic equipment [13].

III. Good Practices for Design Electronic Equipment Grounding Systems to Mitigate Power Quality and EMI Problems.

The following will address good practices in grounding systems design aimed at attenuating disturbances that generate electromagnetic incompatibility in electronic equipment. These practices have been identified from standards and relevant technical publications.

There are three types of system grounding configurations used in electronic equipment to improve system operation [1].

1) Single Point Grounding SPG.
2) TREE configuration.
3) Signal Reference Structures SRS.

Sometimes a combination of these configurations may be used in different parts of the installation. It is important to understand the purpose along with the advantages and disadvantages of each configuration in order to select the proper ground for a specific application.

A. Single Point Grounding.

The single point grounding SPG configuration aims to minimize problems caused by noise currents flowing through the loops formed by grounding system, which cause interference and affect the overall operation of electronic equipment.

For that propose it is necessary to keep separate the electronic equipment grounding system from other grounded elements of the installation, and connect with each other only at the point where the neutral and ground are connected, or in the main distribution panel or secondary of a separately derived system (isolation transformer). This configuration is shown in Fig 5**.**

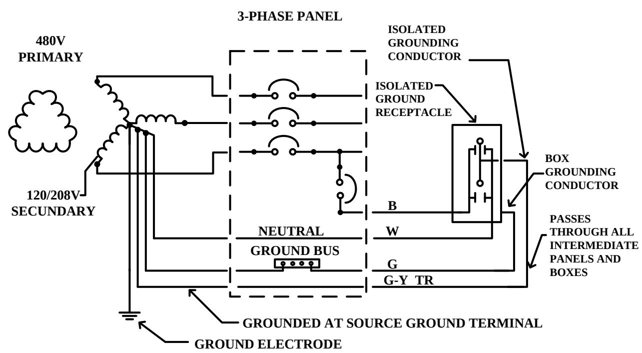

Fig. 5. Insulated grounding conductor for sensitive plug-in equipment [2].

To accomplish this configuration (Fig. 5) it is used an isolated ground conductor (Equipment Grounding Conductor EGC), in order to control where are made the required connections with the grounding system.

This conductor starts from a special receptacle, whose ground is isolated from the receptacle ground. This kind of receptacle is called Insulated Grounding Receptacle IGR (Fig. 6).

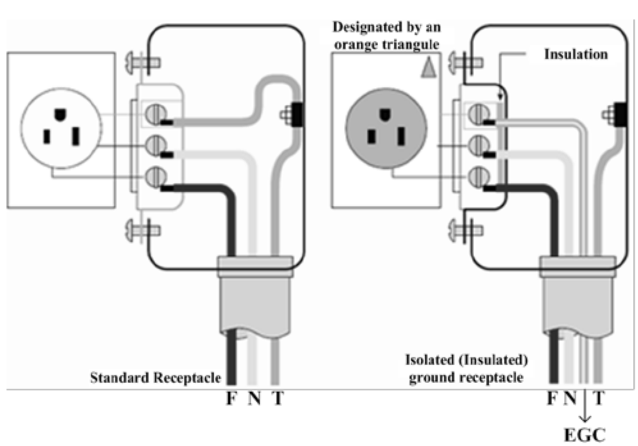

Fig. 6. Standard receptacle-insulated Grounding Receptacle [14].

B. TREE Configuration.

The TREE arrangement consists of a variation of the SPG configuration described above (Section A). It is used when a system of electronic equipment consists of several receptacles where the isolated ground conductor EGC must be sent to a common bonding point within the grounds of the facility. This will take several SPG points together and meet in a central ground, similar to a tree with branches (Fig. 7). Finally, the common junction point is connected to ground. The union of these individual grounds should be done similar to radial distribution system, without any parallel earth paths.

This is a popular design in buildings where there are multiple floors and areas, which contain separate groups of computers that there is a need to be referenced to a single central ground point. The TREE configuration is typically found in specialized telecommunication facilities, which employ large DC power plants and telephone switching and data systems [1].

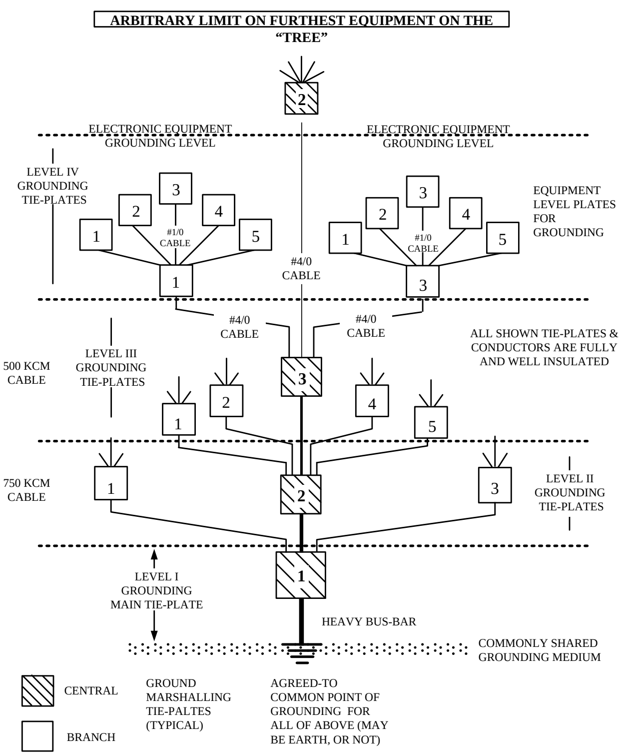

Fig. 7. TREE grounding system configuration [1].

In general, the designs of single point grounding (SPG) and TREE are known to be useful for grounding equipment with continuous analog operating signals of low frequency and narrow bandwidth and low-level signals with frequency ranges from DC to about 30 kHz or slightly higher. In the frequency ranges up to 300 kHz, since this is still relatively low frequency with respect to the transition times on typical signals bandwidths and signal circuits as those found in digital logic systems, the application of both SPG and TREE configurations become totally unsuitable for these kind of systems.

C. Signal Reference Structures SRS.

For frequencies above 300 KHz is required the existence of a ground structure that behaves similarly to an equipotential ground plane, ensuring a low impedance over a wide frequency spectrum of interest (often from DC to several tens of megahertz).

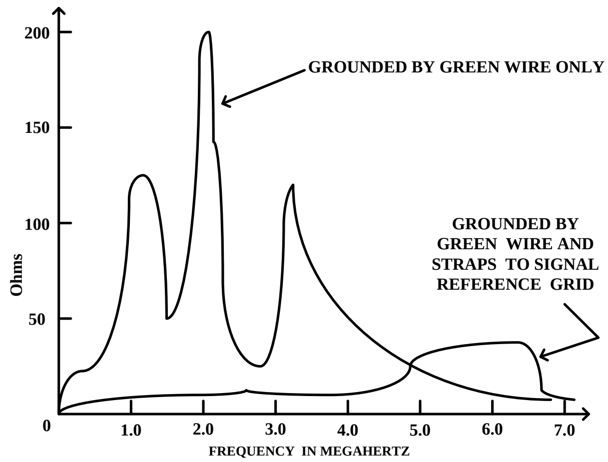

Fig. 8. Resonance of power equipment ground conductors in typical site [10].

In order to ensure, low impedance for frequencies above 300 kHz (Fig. 8), it is recommended to supplement the electronic grounding conductors, connected in a single point SPG, with the installation of a signal reference structure (SRS).

The signal reference structure consists of a mesh or reference plane or a network of conductors placed down the room to interconnect: frames, cabinets, enclosures or common reference terminals within a electronics power system (Fig. 10).

Thus, the purposes of the SRS are mainly four:

- Improving the reliability of signal transfer between interconnected elements of the system in the facility, by reducing the common mode interference between units, under a wide range of frequencies.
- Prevent damage to signal circuits between units, providing a low inductance and therefore an effective ground reference for the entire system, AC and DC, ie in the case of surge protection devices, telecommunications and general circuits that operate with these signal levels.
- Avoid or mitigate signal level damage between circuits units when occurs a ground fault event in the power system.
- Reduce EMI in and between equipment, generated by near electric and magnetic fields.

The application of the Signal Reference Structure (SRS) may be in the form of a signal reference plane (SRP) or a signal reference grid (SRG), ideally connecting by direct means the corresponding electrical and electronic equipment grounded. Although in practice it is more likely to use multiple connections by connecting short length and low inductance bands. Details about each of these practices are outlined below.

Signal Reference Planes SRP.

SRP corresponds to a body or connected bodies of conductive material which provide uniformly low impedance to current flow over a large range of frequencies.

In addition to reduce the voltage drop, the current dispersion along the SRP area reduces the effects of near magnetic fields directly related with the amplitude of the current, reducing significantly EMI in the connected equipment.

As indicated in Fig. 9, a typical SRP is constructed using galvanized steel metal roofing, which are connected to the equipment cabinet by unions or bonding bridges of different lengths (Section II, subsection D).

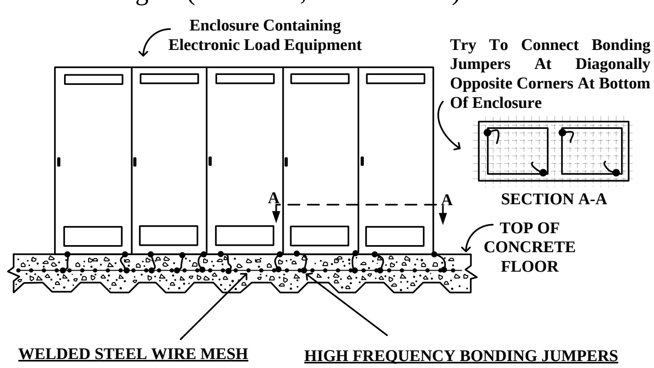

Fig. 9. SRP utilizing galvanized steel sheet floor decking [1].

Signal Reference Grids SRG.

Signal reference grids can be regarded as an SRP with holes in its surface, where the length of the conductors at the perimeter of the holes, defining the cutoff frequency from which the SRG quickly begins to lose its effectiveness compared with SRP. While the frequency is kept below the cutoff frequency, the SRG behave in a manner very similar to the SRP providing an economical and practical alternative for electrical installations involving electronic equipment disposed in areas such as computer rooms.

Typically, a signal reference grid is constructed by intersections conductors with modules of approximately 0.6 m x 0.6 m. This configuration provides an effective passband for frequencies ranges from DC to approximately 25 to 30 MHz, which is useful in most applications. These structures can be prefabricated or built on the site and generally do not require routine maintenance.

Practical examples of SRG use the following methods (in decreasing order of effectiveness):

- Copper sheets connected by exothermic welding, arranged on structural concrete under false floors or similar flooring without being appreciably noticeable.
- Grids in copper or aluminium wire.

• Grids made of sheet or copper conductor, arranged on the concrete structure or suspended using pedestals raised floor substructure. An example of this configuration is shown in Fig. 10.
The separation of 0.6 m x 0.6 m is ideal for this practice and consistent with standardized dimensions of raised floors.

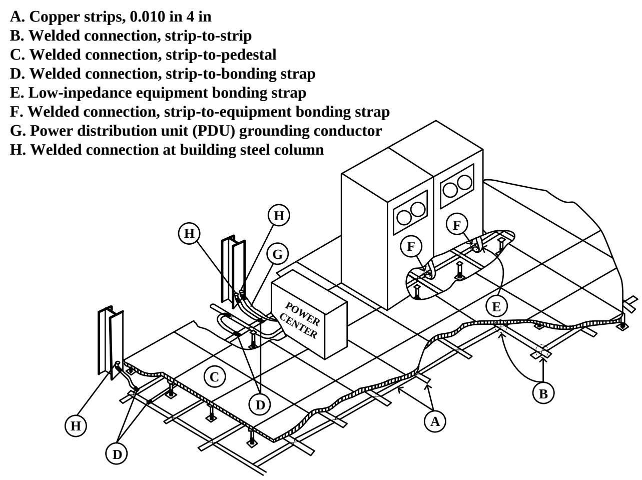

Fig. 10. Signal reference grid fabricated from copper strips [1].

Separations greater than 0.6 mx 0.6 m between SRG conductors are not recommended because the upper frequency limit of such designs, degrades rapidly with increasing spacing. Furthermore, arrangements with smaller separations may be used to improve the performance of the SRG, according to the needs of installation.

However, the use of a smaller module implies that the SRG cannot be installed in a suspended mesh just below the level of the tile on a raised floor system, making access to the wires and other support elements located under the floor.

D. Sizing equipotential conductors in grounding systems

Multiple interconnection conductors between SRS and equipment, and generally bonding conductors are also subjected to electrical components within a wide frequency range. The aim in the sizing of these conductors is that together form a useful low impedance path to current flow through them at all frequencies of interest.

If this sizing, is done properly can be successfully used to limit the development of unwanted potential across the ends of these junctions.

D.1. Sizing bonding conductors to reduce low impedance at high frequencies.

To reduce the interconnections impedance between the SRP's or SRG's and equipment at high frequencies, it is recommendable to use sheet-like geometry conductors. Additionally, it is required that the electrical length[4] of these conductors be a wavelength λ fraction of the highest frequency sinusoidal signal in the circuit, not to exceed (λ / 20) for the highest frequency expected.

Although this is an appropriate restriction for most commercial applications, the most critical applications may require approximately limits (λ / 50) or less.

Moreover, according to [1], it is recommended that connections be made preferably by exothermic welding. This allows minimizing its impedance at high frequency.

In this regard it is recommended to use strips of copper, aluminum or steel (steel has the advantage of not creating the galvanic couple is welded to cabinet when the same material) as shown in Fig. 11.

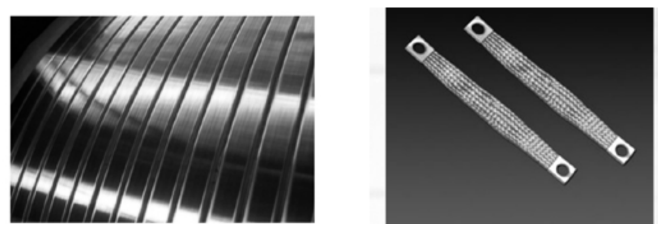

Fig. 11. Laminar bonding conductors [15].

D.2. Sizing equipotentialization conductors to mitigate autoresonance phenomena.

Considering the problem of resonance in section II subsection D above, the relationship between integer multiples of ¼ of the wavelength and the length characteristics for conductor resonance on bonding conductors are determined by the following expression [1].

$$L_{resonance} = \frac{cn}{4\, f_{resonance}}$$

Where:
$L_{resonance}$: is the resonant conductor length (m).
n: is any odd integer (1, 3, 5 ...).
c: is the speed of light in free space (3 x 10^8 m/s).
$f_{resonance}$: is the frequency of excitation in the conductor (Hz).

In practice, designers should care about the lowest frequency at which a certain ground connection resonate (n = 1). Therefore, these conductors must have lengths that are not close to the resonance, or not corresponding to odd multiples of ¼ wavelengths for the electrical noise frequencies that might be imposed on the conductor.

In this way to avoid resonance, it is recommended to employ multiple bonding conductors of different lengths. So while a route can be subjected to the conditions of resonance, the other not. Usually a 20% difference in the lengths of the conductors will be sufficient so there is no resonance.

[4] Is considered to be a small circuit, only when the length of the current loop is much smaller than the wavelength of the sinusoidal signal of a higher frequency in the circuit

Additionally, to minimize the undesirable effects of mutual coupling (due to the nearby fields, mainly inductive); the best practice is to install grounding conductors at opposite corners of the equipment cabinets.

Thus, the grounding conductor paths have relatively independent inductive current and since they are in parallel, will present lower impedance through this connection. In the Fig. 9 are seen the foundations of electronic equipment cabinets, connected to ground via two conductors located on opposite corners.

D.3. Sizing grounding conductors to minimize the parasitic inductance and capacitance.

As described in Section II, the paths and typical grounding system connections have a parasitic inductance and capacitance that should not be ignored. The best alternatives for reducing electromagnetic interference associated with these parameters consists of gathering and tighten directly together the electronic units surface of adjacent casings, in order to eliminate the need of separate bonding conductors [1].

This action addresses the problem from two perspectives:

- Minimizing the parasitic capacitance between the units.
- Virtually eliminates the inductance across the grounding path connection.

As a result, even for high transient currents, the voltage developed should be low. Thus, signal circuits different equipment will not be subjected to high levels of common-mode disturbances [10].

When the surfaces of the equipment cannot be joined, the application of Signal Reference Structures (SRS) provides good results, reducing common mode voltages and transients.

E. Isolation transformer.

Isolation transformers (Fig. 12), creating a separately derived system, are one of the most widely used power correction devices [16].

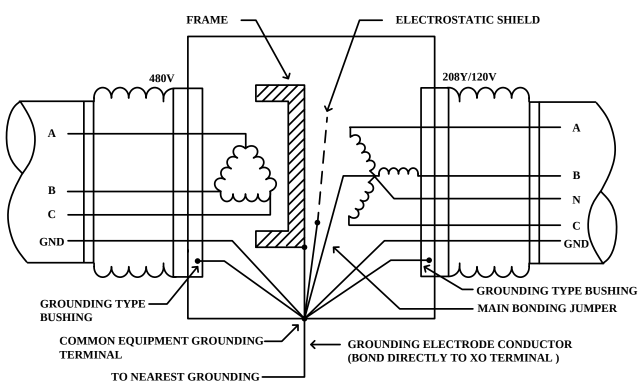

Fig. 12. System grounding requests of isolation transformer [1].

Another function of their separate windings is to provide for creating the power ground reference close to the point of use. This greatly reduces the problem of common-mode noise coming from the supply lines [17], induced through "ground loops" or multiple current paths in the ground circuit upstream of the established reference ground point [1].

As shown in the figure, the construction of the transformer includes a frame whose capacitive coupling with the primary winding provides a ground path to deflect the common mode disturbances and additionally an electrostatic shielding which prevents the transmission of parasite currents to the secondary. To be effective this configuration needs that, the screen, the transformer core, and the grounded conductors be joined together at one point.

IV. CONCLUSIONS

During designing stage of end use electrical installation, it is essential to consider the electromagnetic environment in which the system will be involved in order to achieve a safe design, reliable, cost effective and electromagnetically supported.

The grounding system as an essential part of an electrical system whose main objective is to achieve a safe and efficient configuration also permitted to provide a critical tool to address problems of electromagnetic compatibility and power quality.

Understand the various electromagnetic disturbances present in electrical systems, their sources and their coupling mechanisms are of great interest to manufacturers of electrical and electronic equipment and designers of electrical installations.

V. ACKNOWLEDGEMENTS

The authors thank the Universidad Industrial de Santander for their support of this research through the project DIEF VIE-5566.

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