EMC = GROUNDING ON AUTOMATION AND CONTROL SYSTEMS

APPLICATIONS TO ELIMINATE ELECTROMAGNETIC INTERFERENCE IN INDUSTRIAL PLANTS

Summary:

The preservation of signals and equipment are generally characterized by the term Electromagnetic Compatibility (EMC), whose essence will translate in its own grounding system. The proper EMC improvement in the installation of automation and control systems ensures a significant reduction of the risks and costs associated with failure of equipment, whose consequences can be disastrous, thus justifying a systematic

Author´s references:

Roberto Menna Barreto

TKPS - Turn Keys de Processos e Sistemas

This article was published in '2013 EMC DIRECTORY & DESIGN GUIDE, ITEM Interference Technology - 2013, USA'

1 – The Role of the Grounding System and its objectives

Automation and control systems are dependent on electronics to meet their needs in the various processes. When the equipment associated with these processes are damaged or have a malfunction due to electromagnetic disturbances, there will be risks related to safety and financial losses.

The proper operation of automation and control systems is thus directly related to the integrity of the equipment and signals, this integrity being generally characterized by the term Electromagnetic Compatibility (**EMC**), which can be defined as the ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing itself intolerable electromagnetic disturbances to that environment.

The best cost-effective approach to such a proper EMC configuration requires each item of equipment and its interconnections to comply with specific EMC standards which, however, may not be enough to answer for all needs in a particular installation when additional protective measures are so to be implemented.

Practically all protective measures to avoid Electromagnetic Interference (**EMI**) are directly related to the grounding system. Indeed, all different electrical-electronic technologies existing in an Industrial Plant will necessarily converge into the grounding system and it is therefore in the grounding system where the noise coupling problems occur and thus it is in the grounding system where they must to be solved.

The essence of electromagnetic compatibility for automation and control systems will thus be translated into its own **grounding system** which can be understood as an (*single*) electrical circuit, which goes from the earth electrode subsystem to components in printed circuit boards, including all the installed protective measures, whose purpose aims to conciliate different commitments: Safety for the power system, Protection against lightning, and Control of electromagnetic interference.

To meet this goal (safety, protection against lightning and interference control) the grounding system would be an ideal plan with zero impedance where different signal levels could be mixed without any interference. But the ideal is not real, and what is done is the simulation of this ideal behavior through a proper design of the grounding system for a specific installation, aiming at two complementary goals:

1st **Safety Grounding** - to guarantee that dangerous voltages due to power fault or lightning discharge could not cause any harm to people or to the installation itself, being its design based mainly on industrial frequencies and supported by the electrode system;

2nd **EMC Grounding** - to avoid electromagnetic interference, external to the system (both that from a third party into the installed electronic system or vice-verse) as well as internal to the system, being its design no more related to the electrode system but directed to the high frequency behavior of all system interconnections in order to:

a. prevent electromagnetic disturbances to be coupled into the circuitry under consideration;
b. prevent electromagnetic disturbances coupled into the circuitry to cause faults or operating errors.

The grounding system, as the way to assure the electromagnetic compatibility of automation and control systems provided safety, ensures a significant reduction of risks and costs associated with interference problems and/or equipment damage, both direct costs, with replacement of damaged equipment, but mainly indirect costs related to the shutdown or malfunction, whose consequences can be disastrous, thus justifying a systematic approach in this area.

2 - The Grounding System and its relationship with the power system

The electrical potential of the power conductors relative to the Earth's conductive surface is defined by its earthing system, indeed the Neutral earthing scheme, which is identified by three characters **XY-Z**: the 1st Character **X** refers to the connection of Neutral to Earth (**T** - directly connected to earth; **I** – isolated or connected by a high impedance); the 2nd Character **Y** refers to the connection between the electrical device being supplied and Earth (**T** - directly connected to Earth; **N** – connected to Neutral at the origin of installation, which is connected to the Earth); the 3rd Character **Z** refers to the Neutral in relation to the Protective Earth (**PE**), the conductor that connects the exposed metallic parts of the consumer's electrical installation (**S** - Neutral and Protective Earth separated; **C** - Neutral and Protective Earth in a single/combined conductor - **PEN**)

This leads to the acronyms used for the different types of mains power distribution systems, each one fulfilling specific power requirements: **TT**, **IT**, **TN-S**, **TN-C**.

From the Electromagnetic Compatibility point of view, notably where lightning activity is high, the best configuration is the **TN-C-S** earthing system where the combined neutral and earth occurs between the nearest transformer substation and the service cut out (the fuse before the meter) and, after this, separate earth and neutral cores are used in all the internal wiring. On the TN-C distribution section the Neutral is earthed at many points but at the consumer´s installation the Neutral is connected to Earth only at the entrance of the facility (just one single connection of Neutral to Earth) from where the cabling of a power circuit should form a compact group, including the Protective Earth conductor. Common mode voltages Neutral – PE that may exist from the power distribution system to local earthing system are so eliminated at the consumer´s entrance by the use of a TN-C-S power distribution system.

For some critical situations it may be advisable to use a power transformer to create a new independent earthing system (TN-S) to overcome problems due to common mode voltage. A new independent earthed power system can also be created at panels in Industrial Plants to avoid such problems, where a shielded transformer is used to provide a better isolation for such common mode voltages (ground loops).

The value of the earth resistance for the electrode subsystem, which can be defined as the relationship between the resulting potential of the electrode and the current which is injected into the soil through it, is not critical for EMC. Although a low resistance should be the basic goal whenever possible (for Safety and Lightning protection reasons) it is not necessary to guarantee the proper EMC performance of electronic systems.

The way how the "Protective Earth" is distributed in the installation is the main factor to guarantee the correct performance of automation and control systems, what can be configured as the single point grounding or the multipoint grounding.

The single point grounding is characterized by a single Earth/Ground connection, from which it is distributed throughout the facility, in a concept of "tree or star," i.e. always opening without ever closing loops. This configuration is suitable for low frequencies, which means the length of the wires are no longer than 1/10th of the wavelength of the signal, and is quite used for panels in Industrial Plants and also even for high frequency electronic systems installed in small areas, as is the case of telecommunication stations (shelters).

However we must be quite carefully when considering such a low frequency grounding system - the point to be considered is that even if the desired transmitted/processed signal of our system is under a low frequency category, the same certainly will not apply to the undesired ambient noise, or to the conducted noise originating from items of electronic equipment, due to the high frequency content of digital processing and communication devices spread all around, and the increasingly widespread use of radio (i.e. wireless) communications for voice and data.

The multipoint grounding (meshed) is preferable for high frequencies, where it is implemented through a Signal Reference Grid whose mesh size should be less than 1/10th of the wavelength of the highest frequency that is required to be controlled by the ground structure (to better perform like an imaginary "*equipontential ground plane*" for those frequencies), favoring in this way lower noise communication between equipment (signal cables run along the mesh).

The use of such Signal Reference Grid for the Equipment Room is always recommended, notably for environments with high levels of radiated electromagnetic disturbances, though not always necessary due to its own circuitry, as new technologies provide a higher immunity level to noise (Ethernet or fiber optic, for example) so eliminating that need for a more comprehensive treatment of the local grounding structure, originally required to compensate for the poor susceptibility of RS-232 data connections.

Where very high intensity electromagnetic fields are to be present in the ambient or even when intentional EM fields can constitute a security threat a (architectural) shielded room may also be necessary besides the Signal Reference Grid for some Industrial Plants.

3 - The Grounding System and its relationship with the protection against lightning

Industrial Plants are often situated in remote locations and spread over a large area, which makes their instrumentation circuitry particularly exposed to any lightning stroke occurring in the region.

Automation and control systems must so be protected against lightning and its effects, using two complementary approaches:

- the protection of structures against lightning;
- and the protection of electronics against lightning.

For the protection of structures against direct discharges a Lightning Protection System (**LPS**) should be implemented, comprised of captors to intercept lightning strokes: down conductors to conduct the resulting lightning currents to the earthing system, and the earth electrode system to spread the lightning currents into the soil.

The Lightning Protection System should comply with international standard IEC 62305 – Protection against Lightning, Edition 2: 2010, which includes risk assessment to define level of protection taking into account the different structures to be protected (buildings, antenna towers, tanks, etc..) in a particular location (soil resistivity, keraunic level/lightning density, topography, etc.) and related issues that may exist, such as explosive atmosphere (ATEX) zoning. Technical studies to implement what has been specified by the risk assessment, the installation and its initial inspection, and further periodic inspections complete the protection of structures against lightning.

Here again the value of the earth resistance is not critical - it is far more important a proper topology of the grounding system to spread the lightning currents into the soil through the earth electrode system without creating high differences in potential, than a low value of the earth resistance, although a low value is addressed and should be the basic goal whenever possible.

For the protection of electronics and services against lightning (which is also covered by the international standard IEC 62305 – Protection against Lightning), a better understanding of the nature of the problem and the importance of grounding system is achieved by considering lightning protection within the scope of EMC, taking into account that lightning and its effects are indeed electromagnetic disturbances too.

Within the context of EMC, the protective measures to eliminate electromagnetic interference are defined upon the initial identification of the *source* of electromagnetic disturbance (what is generating the electromagnetic disturbances, which can be internal or external to the system), the *coupling* *mechanism* (how those generated electromagnetic disturbances are coupled to the circuit) and the *receiver* (the circuit that is being affected). Then it is possible to solve the problem by working on one or more of these components to reduce the coupled noise and hence the EMI.

Regarding the protection of automation and control systems against lightning we may consider that it is not convenient, nor even possible, to work on the *receiver* (the equipments are already defined by manufacturers) and neither on the *source* of electromagnetic disturbance (lightning). We can only then work on the *coupling mechanism*!

Returning to the context of EMC, electromagnetic disturbances are coupled into electronic circuits through three main basic mechanisms: capacitive coupling (electric fields), inductive coupling (magnetic fields) and common impedance coupling (ground).

Most of the techniques that can be applied to reduce these coupling mechanisms are directly related to the design of the grounding system. For example:

- the performance of a filter depends on how it is installed, that is, how it is grounded;
- a non magnetic shield can be used to reduce magnetic field coupling into signal cable where its use is oriented for the reduction of the "loop" area defined by the noise current flow, that is, how the shield is "grounded";
- and the same grounding situation is important for many other EMC techniques, too.

The grounding system is indeed the main factor to attenuate the noise coupling mechanisms within an EMC context and, in this same way, the grounding system assumes the leading role in protecting installations of automation and control systems against lightning and its effects, from which some guidelines can be derived.

For the protection of the instrumentation against EM fields generated by lightning currents (indirect lightning), all signal cables within an area (LPZ – Lightning Protection Zone) should run close to individual elements of the meshed grounding system to avoid the creation of large current "loop" areas. A metal tray that forms part of the mesh-grounding structure, and/or a grounded cable (PEC - Parallel Earth Conductor) run together with the cables fulfills this need, which should be expanded throughout the area of the protected zone, with the metal tray providing better control of higher frequencies than a wire PEC.

The protection against high voltage/current surges on instrumentation cables interconnecting instruments located in buildings or areas far apart each other in the event of a lightning strike in one of the buildings or areas is another important situation to be addressed. Although each building or area can have its own earth electrode system, if they are interconnected through long cables (and they should be connected), it will not be possible to “equalize” them to higher frequencies in order to avoid such surges. The situation can be circumvented by the use of non-metallic media for galvanic isolation, which may include fiber optic or radio for signal transmission or, alternatively, if not using galvanic isolation, then it will be necessary to use Surge Protection Devices (**SPDs**).

The use of SPDs for the protection against surges due to indirect (EM Field coupling) or direct lightning stroke requires a specific study regarding the grounding system, in addition to the SPDs own characteristics. The discharge current diverted by SPDs always goes somewhere in the circuit – it doesn´t disappear! The grounding system is the destination of these currents. A misunderstanding comes from the fact that a convenient name for most of this type of device (SPD) should be better TGD - Transient Grounding Device, because this is its function, while SPD - Surge Protection Device, is the purpose for which it is used, leaving a margin to imagine that the fact of using a SPD is enough in itself, what is not true. The currents diverted by SPD´s should flow to the very same (ground) reference of the protected circuit (not necessarily to the electrode earth system) and the discharge path must be as short and direct as possible to reduce its series inductance, to help insure that the transient voltages in the circuitry or the transient noises induced in nearby circuits are not too high.

4 - The Grounding System and its relationship with the transmission of signals

For the distribution of signals through the plant, what is sought is a compromise between different sources of electromagnetic disturbance so that the total noise coupled into the circuitry does not cause interference, that is, the information is preserved although the signal may be distorted. To attain this proper configuration the pertinent techniques should be applied to control radiated or conducted noise coupling on each signal path but always preserving safety requirements regarding power distribution and lightning protection.

The control of common mode currents, generically called “ground loops”, is the most critical aspect for the grounding system regarding the instrumentation distributed in the plant. When considering the two conductors in a circuit (source, load, and the two conductors), we must distinguish between two forms of current circulation: *differential mode*, the desired signal, meaning that the current flows from the source to the load by one conductor and returns through the other; and *common mode*, the usually unexpected and unwanted signal (noise), meaning that the noise current flows in the same direction on both conductors of the circuit, returning by a third conductor, usually a "Ground Reference" (hence the term "ground loop").

The common mode current circulating circuit may have a "material existence", as in the case where both the signal source and the load are directly connected to a reference ("Ground") at different points (note that the concept of “potential equalization” does not apply for practical purposes at frequencies higher than a few kHz, because at these frequencies inductive reactance dominates the impedance of the ground structure, not resistance). In this case, the source of common mode current can be an electrical potential difference between these two reference points ("Ground"), which forces the current flow in both conductors in the same direction.

Under this scenario it would be quite convenient to implement the signal circuits in a single point topology for the grounding system, that is, just the signal source or the load is grounded at one end of the circuit, thereby avoiding the circulation of currents in the common mode. The instrumentation circuits for the transmission of signals from sensors, which are mostly floating low frequency devices, have been using the single point topology for many years. As the voltages and currents in power frequency (50/60 Hz) in the plant were the main noise threat, the use of shielded (to avoid electric field coupling, the shield grounded at one end only, normally at the equipment room where the circuit is grounded) twisted (to avoid the coupling of magnetic fields, by reducing the area of current loop) pair cables is largely used.

However, this traditional approach is increasingly ineffective due to the many high frequency devices which are increasingly used in Industrial Plants, such as microprocessors, digital/wireless data communications, switch-mode power conversion, etc.. When higher frequencies are considered, the circuit where the common mode currents flows may not have a "material" connection to close their circulation "loop", which is usually to a reference (such as Ground). This can be understood by considering that, for high frequencies, stray capacitances at that ungrounded end of the circuit have a sufficiently low impedance to close the current loop. The high frequency CM current quite happily creates ground loops by flowing through the air at one or more points along its route, defeating the purpose of the single-point grounding topology.

As a consequence, sensors will almost always suffer from high frequency common mode noise from digital processing, digital/radio communications, switch-mode power converters (off-line as well as DC/DC), and the sampling circuits in their A/D converters. Where equipment does not comply with an appropriate EMC specification, these high frequency noises can be very significant and will need to be controlled by (grounding related!) mitigation techniques such as breaking the high-frequency CM loop (e.g. by the use of high-frequency isolating transformers, fiber optics, CM chokes, etc.); using shielded cables (properly grounded at both ends for radio frequencies), or using circuits more tolerant to common mode currents (e.g. balanced circuits), and others, which generally require a grounding system that is effective up to such high frequencies, that is, an “EMC grounding” as referred before in this article and better considered in the IEC 61000-5-2 and other references listed at the end of this article.

Instrumentation systems with floating power supply are sometimes used for signal transmission because they can help solve common mode current problems by adding high impedance in series with the common mode current loop, notably at low frequencies. However, there is some controversy in using this technique due to maintenance problems (an accidental short to ground can be difficult to identify, because the system remains operative whilst its EMI problems might increase) and voltages induced in the signal conductors which can take high values and make them unsafe.

Temperature measurements systems require a special attention due to their noise susceptibility. For thermocouple circuits it is advisable to use signal conditioning (e.g. 4 to 20 mA or 0 to 10 Vdc) for the signal transmission from the sensor to the control room, placing the signal conditioning circuit (often called a temperature transmitter) as close as possible to the sensor. The cable to connect the sensor to the conditioner should be a shielded twisted pair, its length as short as possible, the shield grounded only at the transmitter (ungrounded sensor) or at the sensor (grounded sensor), or at both ends. Sensors with grounded connections to the cable’s shield can be more vulnerable to noise than ungrounded ones. If the environment has a high potential for electromagnetic interference, the use of resistance temperature detectors (RTD) or even better infrared thermometers provides a better immunity to noise than thermocouples.

However, care should always be put on considering EMC under a compromise of different parts and not restricted to a single unique element – if you have a sensor with built-in electronics to connect to a digital bus system (e.g. Profibus) it probably makes little difference whether it is a T/C or RTD sensing element. That is why grounding, interconnecting the whole system, is the key factor to EMC.

5 - The Grounding System and its relationship with Engineering Procedures

The primary purposes of the grounding system are to ensure electrical safety and, then to reduce the occurrence of interference problems, and these two issues should be fully taken into account both in the design and installation phases, plus in the maintenance phase in order to help ensure the correct and reliable operation of automation and control systems.

5.1 - Design and Installation: Interference Control Plan

Each facility has its own particularities, regarding the specific electromagnetic environment and the characteristics of the automation and control systems, which makes it difficult to use such a simple low-cost “standard design" or “*rules of thumb*” for the grounding system to cope with all possible EMI scenarios.

The planning of EMC activities is the best cost-effective methodology to answer for both the inherent complexity of such systems and the sophisticated nature of electromagnetic interference problems and their solutions.

The “Interference Control Plan” aims to answer all situations for the occurrence of interference problems:

a. By requiring each item of equipment to comply with EMC standards, which cover both the aspect of emission (the equipment constituting a source of electromagnetic disturbance) as immunity (the equipment not being affected to an unacceptable degree by electromagnetic disturbances in the environment). The EMC standard IEC 61326-1 Ed. 2.0 :2012 – “Electrical equipment for measurement, control and laboratory use - EMC requirements” defines the necessary EMC qualification in order to guarantee that units of equipment are suitable to operate correctly in a wide range of installations.

b. By completing the EMC needs for that particular installation through a proper design of the grounding system. This work is carried out through an EMC Analysis where a matrix for the EMI risk situations relating the various sources of EM disturbances (internal and external to the system) and the susceptible circuits is developed and then all the would be EMI situations are mitigated supported by EMC recommended practices and guidelines as published by IEEE and IEC, or others.

5.2 - Maintenance: EMC Procedures

Every Industrial Plant with a few years of existence undergoes changes in its initial design installation: data acquisition systems are modified, new equipment and its controls are changeable, new technologies come into place, accidental and/or broken connections or loose contact happens to occur, to mention some usual facts.

As a consequence there must be specific “EMC Maintenance Procedures” to guarantee the performance of the automation and control systems against the constant changes in their electromagnetic environment and, quite important, the Maintenance personnel are to complete and adapt these electromagnetic interference control procedures according to the new technologies come in use during the operational lifetimes.

The “EMC Maintenance Procedures” should include:

a. *EMC Records* – addressing the set of measurements to be made throughout the year such as power quality, electromagnetic fields intensity, electrical continuities, surges, etc., and also detailed description of eventual occurrences in the Plant due to lightning, equipment failure, etc.

b. *EMC Guidelines* – addressing the methodologies, requirements and technologies related to EMC to be applied in the Plant over the time.

Acknowledgements

May I express my deepest gratitude to Mrs Belinda Stas and Mr Keith Armstrong for reviewing and adding quite valuable contributions to make the initial document much more interesting and comprehensive.

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