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The Role of the Grounding System in Electronics Lightning Protection

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***Abstract* - 'Grounding is the most sophisticated and unknown part of electronics' – this statement was written about 40 years ago and valid up today! A reason to support this situation for such a long time is that we use think about voltage and make a static reference for it – the "ground". It is true voltage is the Queen but things happen just when current comes into play. And then we should think a reference not as a static "ground" anymore but as a dynamic circuitry, the grounding system, which includes the protective measures against disturbances. This study illustrates the role of the grounding system in electronics lightning protection' under the EMC scenario, where different procedures are characterized.**

Keywords— grounding; earthing, EMC, SPD, LPS, Lightning, protection

I. The Grounding System

The primary purpose of the grounding system (also called earthing system depending if we use American English or not) is to provide safety for people both for lightning frequencies and for network faults conditions. But grounding is also crucial for reduction of risk situations regarding occurrence of interference problems and/or damage of equipment. This should be consolidated both in the design and installation as well as in the maintenance phases in order to guarantee the proper operation of the electronics.

This proper operation electronics is directly related to the integrity of the equipment, 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.

To reach such an EMC configuration, the control of electromagnetic interference and/or damage is achieved 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 by electromagnetic disturbances in the environment);
- and completing the EMC needs for that particular facility, through a proper design of protective measures for its installation.

The design of such protective measures is based on:

- Noise control, where it should considered a compromise between different sources of electromagnetic disturbance so that the total noise coupled into the circuit doesn't cause interference or damage;
- Earth electrodes, where it should address a topology able to "dissolve" the electromagnetic disturbances (as, for example, the currents caused by lightning) without the creation of high differences in potential;
- Electromagnetic fields, where the radiation properties of the circuit are to be considered when the dimensions of the circuit can no longer be considered small compared to the wavelength;
- Common mode currents, which are responsible for most of interference problems (this aspect is often referred in the literature as 'ground loop´s', what doesn´t seen an adequate name as it leads to the wrong idea that "loop´s in the ground is a bad thing").

However, the various protective measures that will be implemented for a facility are indeed related to the grounding system within a whole, and must be addressed in this context, what means that the protective measures to be implemented (surge protective devices, isolation transformer, cable shielding, filtering, etc.) are part of the only single grounding system.

The grounding system must then answer the needs of a specific project developed for a particular installation, including all the protective measures installed, and constitutes a single circuit, which goes from the earth electrode subsystem to the components in printed circuit boards.

The consequence is that the grounding system so considered is directly related to the power system, to the Lightning Protection System and to the transmission of signals, under different approaches, what makes it necessary to integrate all these different aspects in just one circuitry, this integration compounding the scenario for EMC – Electromagnetic Compatibility:

- Regarding the power system, where the electrical potential of the power conductors relative to the earth's conductive surface is committed by its earthing system, whose value of 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 critical for safety and for the design of Surge Protective Devices but it is not important for EMC - the way how the "Protective Earth Conductor" is distributed in the facility is the main factor to guarantee the correct performance of the electronics.
- Regarding the transmission of signals through the facility, 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 and the information is preserved although the signal may not be.
- Regarding LPS, some aspects are illustrated in this study aiming at dissipating the lightning current safely for people and equipment and also to decrease the stress on Type 1 SPDs

II. Lightning current parameters

The Lightning Protection System should comply with international standard IEC 62305 series [1]: Protection against lightning, which includes in its part 2, 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, lightning flash to ground density, topography, etc.) and correlated parameters that may exist as explosive ATEX zoning. Technical study 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 and is described in part 3 and part 4 when part 1 present lightning parameters.

The four main sources of damages due to lightning are:

S1 = Flashes to the structure,

S2 = Flashes near to the structure,

S3 = Flashes to a service,

S4 = Flashes near to a service,

The different types of damages caused by these sources are:

D1 = injuries of living beings due to touch and step voltages,

D2 = physical damages (fire, explosion, chemical release, mechanical destruction ..,) due to the lightning current effects, including sparking,

D3 = failure of internal systems due to Lightning Electromagnetic Impulse (LEMP)

The occurrence of such damages depends, on one hand, on the sensibility of the affected part, and, on the other hand, on the characteristics of the lightning current.

The lightning current flow, and its consequences including voltages and the effects of magnetic field so generated, depends on the amplitude and frequency content (for example, a 30 m long 53mm² conductor has an impedance in the order of 0.01 ohms at DC, of 0.02 ohms at 50 Hz, and of 330 ohms at 1 MHz).

The IEC 62305-4: Electrical and electronic systems within structures, presents a very precise set of parameters for the lightning current characterization as referred in Table I.

The primary electromagnetic sources of harm to the electronic system are the lightning current I_0 and the magnetic field H_o. Partial lightning currents flow through the incoming services. These currents as well as the magnetic fields have approximately the same waveshape. The lightning current to be considered here consists of a first positive stroke I_F (typically with a long tail 10/350 µs waveshape) and first negative stroke I_{FN} (1/200 µs waveshape) and subsequent strokes I_S (0,25/100 µs waveshape). The current of the first positive stroke I_F generates the magnetic field H_F, the current of the first negative stroke I_{FN} generate the magnetic field H_{FN}, and the currents of the subsequent strokes IS generate the magnetic fields H_S. The magnetic induction effects are mainly caused by the rising front of the magnetic field. The rising front of H_F can be characterized by a damped oscillating field of 25 kHz with maximum value $H_{F/MAX}$ and time to maximum value $T_{P/F}$ of 10 µs. In the same way, the rising front of H_S can be characterized by a damped oscillating field of 1 MHz with maximum value $H_{S/MAX}$ and time to maximum value $T_{P/S}$ of 0.25 µs. Similarly the rising front of H_{FN} can be characterized by a damped oscillating field of 250 kHz with maximum value $H_{FN/MAX}$ and time to maximum value $T_{P/FN}$ of 1 µs.

It follows that the magnetic field of the first positive stroke can be characterized by a typical frequency of 25 kHz, the magnetic field of the first negative stroke by a typical frequency of 250 kHz, and the magnetic field of the subsequent strokes by a typical frequency of 1 MHz. Damped oscillating magnetic fields of these frequencies are defined for test purposes in IEC 61000-4-9 and IEC 61000-4-10.

III. Safety for people and protection for electronics

In order to protect person in the building from injury or death, and structures from fire or mechanical destruction, the Lightning Protection System (LPS) is compounded by:

- external lightning protection system - the air-termination system, the down conductor system and the earth-termination system;

- internal lightning protection system - separation distances and lightning equipotential bonding including the surge protective devices.

TABLE I. VARIOUS STRESSES ACCORDING TO DIFFERENT STANDARDS

1	Relevant standard	**Primary source of harm LEMP**				
		As defined from parameters in accordance with lightning protection levels I to IV				
	IEC 62305-1		Impulse	Amplitude for LPL	Steepness for	Relevant effects:
				I – II – III – IV	LPL I – II – III – IV	
			µs	kA	kA/µs	
		I_0	10/350	200 – 150 – 100 – 100	20 – 15 – 10 – 10	Partial lightning current
			1/200	100 – 75 – 50 – 50	100 – 75 – 50 – 50	Induction
			0,25/100	50 – 37,5 – 25 – 25	200 – 150 – 100 – 100	Induction
		H_0	Derived from the corresponding I_0			
2	**Rated impulse voltage level of power installation**					
	As defined for over voltage category I to IV for nominal voltages 230/400 V and 277/480 V					
	IEC 60664-1	U_W	*Overvoltage category I to IV*	6 kV – 4 kV – 2,5 kV – 1,5 kV		
3	**Withstand level of telecommunication equipment**					
	ITU Recommendation K.20, K.21 and K.45					
4	**Tests for equipment without suitable product standards**					
	Withstand level of equipment as defined for conducted (U,I) lightning effects					
	IEC 61000-4-5	U_{OC}	*impulse 1,2/50 µs*	*4 kV – 2 kV – 1 kV – 0, 5 kV*		
		I_{SC}	*impulse 8/20 µs*	*2 kVA – 1 kVA – 0,5 kVA – 0,25 kA*		
5	**Tests for equipment not complying with relevant EMC product standards**					
	Withstand level of equipment as defined for radiated (H) lightning effects:					
	IEC 61000-4-9	H	*Impulse 8/20 µs,*	1 000 A/m – 300 A/m – 100 A/m		
			(damped oscillation 25 kHz, TP = 10 ms)			
	IEC 61000-4-10	H	Damped oscillation 1 MHz,	100 A/m – 30 A/m – 10 A/m		
			(impulse 0,2/0,5 ms, T_p = 0,25 ms)			

As the grounding system should be only one for the facility, it must also support the Lightning Protection System (besides power and signal transmission) whose function is to intercept the lightning strike and safely conduct it to the earth-termination system to spread the lightning currents into the soil

The grounding design should start with a field campaign for measuring of ground resistivity, what may include the following set of electro-resistivity soundings:

- by the Wenner arrangement, with up to 64 m spacing;
- by Schlumberger arrangement, with higher spacing at selected alignments.

These soundings should be complemented by the geotechnical survey of the area, with the evaluation of the local lithology and geological structure.

The study of the earth-termination system shall include two types of simulations or measurements to avoid injuries of living beings due to touch and step voltages:

- phase-to-ground faults in the medium and high-voltage systems (50/60 Hz); and
- injection of high frequency current (up to 1 MHz) in order to simulate lightning [2].

To avoid dangerous sparking within the structure, there should be an appropriate equipotential bonding or sufficient electrical insulation distance between different metallic parts, the equipotential bonding been implemented for high frequencies what requires low inductance.

The low inductance equipotential bonding network required is achieved by means of interconnections between all metal components aided by equipotential bonding conductors inside the LPZ of the building or structure through a three-dimensional meshed network interconnecting all that is "at hand": all metal installations (e.g. pipes, boilers), reinforcements in the concrete (in floors, walls and ceilings), gratings (e.g. intermediate floors), metal staircases, metal doors, metal frames, cable ducts, ventilation ducts, lift rails, metal floors, supply lines.

Besides, a lattice structure of the equipotential bonding network around 5 m x 5 m reduce the electromagnetic lightning field inside an LPZ by a factor of 2 (6 dB).

For the protection of electronics (and services) against lightning, a complementary approach for the understanding of the nature of the problem and the importance of grounding system is achieved by considering lightning protection within the scope of EMC since lightning and its effects are indeed electromagnetic disturbances too.

Within EMC context, 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 electromagnetic disturbances so generated are coupled to the circuit) and the receiver (the circuit that is being affected). Then it is possible to solve the problem working in one or more of these components to reduce the coupled noise [3].

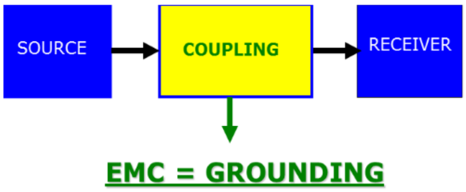

Fig. 1. Coupling mechanism

Regarding the protection of electronic systems against lightning we may consider that it is not convenient, nor even possible, to work on the receiver (the equipment 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 EMC context, 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). Practically all techniques that apply to reduce these coupling mechanisms are directly related to the grounding system.

For example, to reduce magnetic field coupling into signal cable, the basic technique is the reduction of the "loop" area defined by the current flow - a shield can be used for this purpose but its use is oriented for the reduction of the "loop" area, that is, how the shield is "grounded".

The grounding system is then the key factor for the reduction of the noise coupling mechanism within EMC context and assumes this very same way as the leading role in protecting electronics against lightning and its effects, as considered in the following examples.

If a lightning strikes a telecommunication tower then the tower potential will rise up according to the current of the lightning discharge and the impedance of the earthing system and of the tower, what results the equipment to be stressed by the difference in potentials between its ports, leading it to be damaged (in a very rough calculation if I= 100kA and R= 10ohms then we have 400kV between equipment terminals, making its isolation to be disrupted and the equipment to be burned).

The protection is achieved not by reducing the earth resistance, although it may help a little, but by providing a high frequency grounding system reference to accommodate tower and equipment and by using a non-metallic connection to the far end earth terminal or by the use of Surge Protection Devices - SPD.

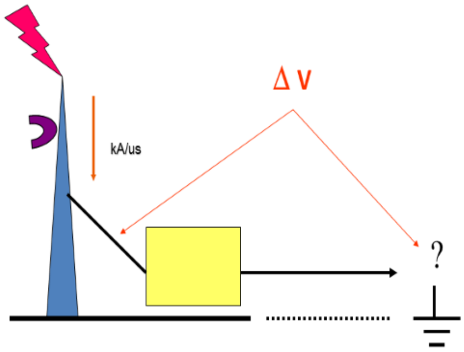

Fig. 2. Example : a telecom tower

The use of Surge Protection Devices for the protection against surges due to indirect (EM Field coupling) or direct lightning stroke requires a specific study regarding the grounding system besides its own characteristics.

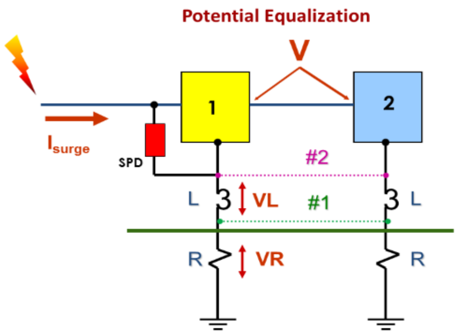

Fig. 3. Application of SPDs

The Surge Current diverted by the SPD to the earth system makes the potential of equipment #1 to rise of VR (surge current x earth impedance) plus VL (caused by the inductance of the wire, which can easily reach some kV´s due to the high frequency content of surge current) and this voltage rise is seen by equipment #2.

It is interesting to note that it is not the performance of the SPD which leads the protection of equipment #2 – the equipment may be damaged because the problem is not in the SPD but in the grounding system.

The discharge current diverted by SPD´s always go somewhere in the circuit - the grounding system is the destination of these currents. A misunderstanding comes from the fact that using a SPD is enough in itself, what is not true. A SPD should be properly installed to be efficient.

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 in order to avoid creating voltages in the circuitry or inducing noise in nearby circuits.

The protection against high voltage/current surges on electronics cables interconnecting equipment 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 the lightning 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 by the use of Surge Protection Devices (SPD).

Another situation is the coupling of electromagnetic disturbances due to magnetic fields, which is a function of the magnetic flux density, the frequency content of the magnetic field, the area of the circuit so disturbed and the orientation of this circuit relative to the magnetic field.

That is why it is so important to have the lightning current parameters (intensity, frequency) quite well characterized as they are in IEC 62305-1 and -4 [4].

For the protection of the electronics against EM fields generated by lightning currents (indirect lightning), we can work on the magnetic flux density, where spatial shielding of the building can be used to reduce the magnetic field, and/or the orientation of the circuit in respect to lightning current flow.

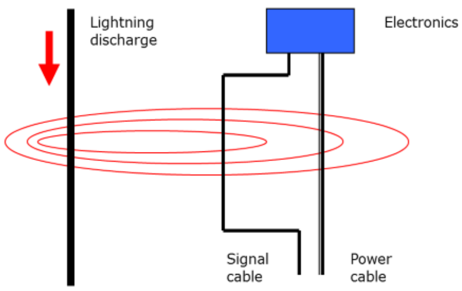

Fig. 4. LEMP : lightning electromagnetic pulse

However, the basic principle is to avoid large signal loop areas, what can be implemented by making all signal cables within an area (LPZ – Lightning Protection Zone) to run close to the grounding system to avoid the creation of such large current "loop" areas. A grounded metal tray for the cables run and/or a grounded cable (PEC - Parallel Earth Conductor) running together with the signal cables fulfill this need, which should be expanded throughout the area of the protection zone.

The use of shielded cables can also be used where the focus is mostly in the reduction of the area and not in the magnetic shielding properties.

IV. CONCLUSIONS

All different electrical-electronic technologies existing in electrical installations (facilities) necessarily converge into the grounding system and it is therefore where the noise coupling problems occur and thus it is where they must to be solved.

The grounding system should be low impedance to take care of lightning injected current for both protection of people in vicinity of the structure and for the proper design of the Type 1 SPDs.

For all these reasons the grounding system is essential to the people, to the Lightning Protection System design and to the electronics lightning protection scheme.

The grounding system is then related, under different approaches, to the power system, to the lightning protection system and to the transmission of signals, what makes it necessary to integrate all these different aspects in just one circuitry, this integration compounding the scenario for EMC – Electromagnetic Compatibility.

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