

LIGHTNING EARTHING SYSTEM : A PRACTICAL GUIDE

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ABSTRACT

To make a lightning earth may be very costly. It is probably the more complex earthing system to design. The selection of a good lightning earth is a balance between the cost of achieving it and the benefits: namely weaker SPDs and in some case even less SPDs. Standards describe how to make a good lightning earth. To improve the earthing value, there are many ways that may be combined (more electrodes, earth enhancement compounds etc.). If it is not possible, then a provisional action may be to use stronger SPDs.

1. Introduction

To make a lightning earth may be very costly. It is probably the more complex earthing system to design. As a matter of fact, the electrical installation earthing can cope with bad earthing provided that safety of people is guaranteed and this can be obtained for example by a RCD for TT systems.

Safety earthing where sparks need to be avoided can be obtained with deep driven rods (up to 50 m in sandy places) but this only work for low frequency as lightning will never reach the extremity of these deep driven rods and thus only a short part of the rods (not exceeding 20 m) will be used in practice.

Regarding lightning earthing, the lightning current is a current generator that will impose its current through various circuits including the earthing circuit thus leading to high voltage at the earthing terminal. This high voltage can create dangerous sparks (with possible fire, explosion or human hazards) and in case SPD Type 1 are used to provide equipotential bonding between electrical systems entering the building and this lightning earth, will create additional stress to this SPDs.

The selection of a good lightning earth is a balance between the cost of achieving it and the

benefits: namely weaker SPDs and in some case even less SPDs.

It is known how to make a good lightning earth. Each down-conductor should be connected to at least 2 earthing electrodes and these electrodes should be smaller than 20 m. If, with such an arrangement, the earthing resistance is less than 10 ohms, there is nothing to do provided that every entering line (both power and signal) is protected by a Type 1 SPD (or equivalent, tested with a 10/350 waveshape). But if there is a will to protect only a few lines with Type 1 SPDs or if the value is more than 10 ohms then something need to be done to either improve the earthing or take provisional actions.

To improve the earthing value, there are many ways that may be combined:

- Add more electrodes in parallel
- Use earth enhancing compounds around electrodes (soil environment friendly and decreasing both resistance and impedance)
- Make a high frequency earthing measurement to check if the impedance at high frequency is good in spite of resistance being bad

If it is not possible, then a provisional action may be to use stronger SPDs. According to IEC 62305-1 [1] the sharing of current between the lightning earth and the other circuit is at best 50%/50% and could be much less in earthing (and thus much more, up to 80%, in circuits). There is a formula to be used to calculate this sharing based on soil resistivity and earth impedance (and not resistance). The later may be obtained with a high frequency earthing meter.

2. High frequency measurement ; principles

We used the «Tellurohm-meter» AES 1002 which allow measurement in an automatic process, by means of an integrated processor on a range of

frequencies from 79 Hz to 1 MHz [2]. It applies a sinusoidal voltage at a varying frequency between the earthing system and a current injection rod, and allows the measurement of the current received by an auxiliary rod. It does this using a standard three points measurement configuration with an injection electrode (z) and a measuring electrode (y) aligned and with the measuring electrode located at 66% of the distance between the injection electrode and the earth electrode under test (x). The difference between this tester and other 3-point fall of potential testers is that coaxial cables are used to connect the electrodes to the test instrument to take care of the high frequencies used and that the test is conducted at 20 different frequencies. The coaxial cables currently limit the length of the z cable and y cable to 15 m and 10 m, respectively. The resistance, the reactance and impedance measured are displayed and recorded. This allows a computer analysis and print out. This equipment has been developed in cooperation with France Telecom and has been extensively tested in field. Of course, such a device does not inject high currents in the soil and this does not fully represent the behavior of the earthing system under high lightning currents conditions and for example flashovers in the soil are ignored. However, injecting such a high current is not really practical for an industrial purpose and may create some risk for both people and process.

The device directly includes criteria, presented in various international publications [3], and gives an immediate result regarding quality of the earthing system regarding lightning current dissipation. This is classified in “very good”, “good”, “acceptable” or “bad”.

The software developed for that measuring device draw curves that are allowing a more in depth analysis of the earthing characteristic enabling the user to decide what to do to improve the earthing impedance, if this is justified. The figure represents the resistance (R), the reactance (X) and the impedance (Z, given by the formula $Z = R + jX$) in Ω versus frequency in Hz. In the example below, the impedance Z is represented as a plain line, the reactance X as a dotted line and the resistance R as a broken line. This example given in Figure 1 represents the impedance of a crow foot buried in a soil with a high resistivity, situated on top of a rocky hill.

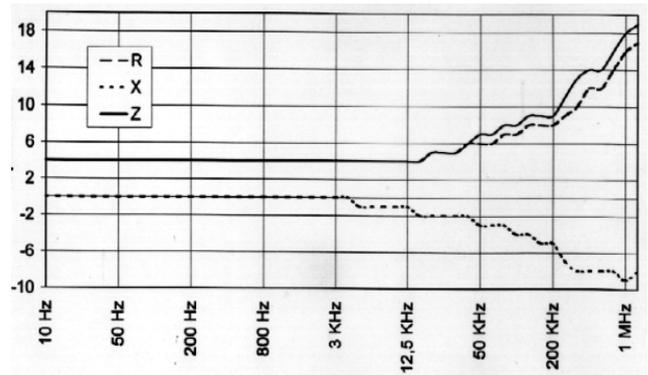


Figure 1 - behavior of a crow foot

According to standards, the conventional earthing impedance is "the ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously". The average impedance between 63 kHz and 1 MHz given by the device is similar to the "conventional earthing impedance" that standards define and use for example for current sharing between various earthing electrodes in IEC standards [1].

3. High frequency measurements validation regarding sharing of current in real lightning conditions

There are only few instances where there has been an opportunity to compare measured grounding system impedance with data recorded during actual lightning events. Much of the initial information used to confirm the results obtained from high frequency earthing impedance testers is based on comparison of measured data from specifically designed earthing systems (typically for telecom applications) with simulations of the expected response of the grounding system. More recently, a device using the injection of surge current was compared with one of the devices measuring selected frequencies of up to 1 MHz [4]. It was found that these devices yielded similar results.

However, comparisons with real lightning data were still missing so an attempt was made in 2009 to make impedance measurements at Camp Blanding in Florida to take advantage of the vast amount of lightning results registered at the research facility [5]. The measuring device used for these measurements is of latest generation. This device provides a current source. After each of the twenty frequencies used to draw the impedance .vs. frequency curve, the device goes to the next frequency whatever the result obtained at previous frequency was usable or not. For earthing systems

that have a dominant capacitive behavior, it can be that impedance at highest frequencies are well below than impedance at low frequency and then at least a part of the curve can be used.

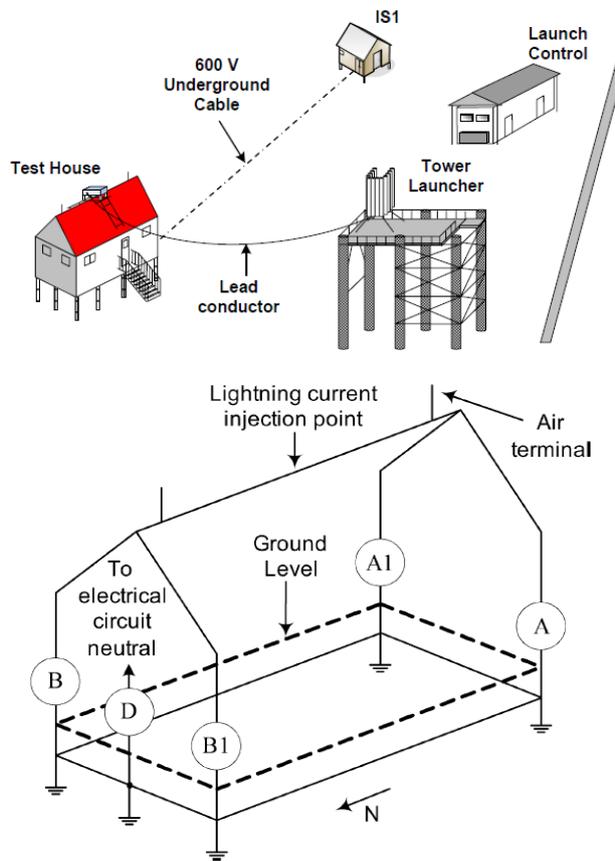


Figure 2. Camp Blanding facility and zoom on the test house.

The purpose of this experiment was to make measurements at various locations in the Camp Blanding facility (see Fig.2), especially around the test house, in order to use the network of measured impedances to predict the sharing of current between the various earthing points (test house, earthing at the remote end of the power cable, etc.) using the IEC 62305-1 method.

Table 1 presents the calculated current sharing based on average impedances measured in 2009. The percentage of current flowing through each of the measured location is inversely proportional to its average impedance.

This table also contains average currents measured on down conductors during the 8 strokes recorded in 2005 (0510-1, 0512-1, 0512-2, 0514-1, 0517-1, 0517-2, 0520-1, and 0521-1) as given in 0.

Table 1: Comparison between the 2005 experiment and earthing measurement made in 2009.

Electrode location	Current based on average impedance in % of injected current	Measuring point (see Fig.2)	Observed average current in % of injected current
EA	18,7%	Down conductor A	19,7%
EA1	17,1%	Down conductor A1	24,0%
EB	17,9%	Down conductor B	35,9%
EB1	17,1%	Down conductor B1	20,5%
Utility rod at test house	12,8%		
IS1	16,3%	Cable neutral connection at IS1	17,1%
Total	100,0%		

The 2005 (direct lightning experiment) and 2009 results (high frequency measurements) match quite well except for electrode EB. The reason there is much more current measured in down conductor B than in others could be that a previous test house and its earthing system are not far from the electrode at measuring point B, allowing some current to be dispersed by this additional earth electrode. It should be remembered that due to poor soil conditions, the current flows more at the surface as it should do in better soils. It is then easier for lightning current to attach to any ground electrode or embedded metal part in the vicinity where lower impedance to ground exists.

After this preliminary comparison we used IEC 62305-1 [1] to try to estimate the current sharing between the local earthing at the test house and what is injected in the utility cable and IS1. Annex E of that standard allows such a calculation, based on local earth impedance and the earthing impedance of the cable given as a function of the soil resistivity. The earthing impedance of the cable is suggested in that document to be 35Ω , due to high soil resistivity. The local earth impedance is calculated based on 2009 measurements, taking into account all the measured locations in parallel (at EA, EB, EA1, EB1 and at the utility rod). This leads to a sharing of current of 28% in local earth and 72% in the cable. Data from the 2005 experiments give a value of 60% measured in D, so the earthing system existing in 2005 at the test house was more efficient to disperse high frequency currents locally than what has been measured in 2009.

It appears that in spite of some difficulties due to high soil resistivity (sand, low moisture content, etc.) the measurements have been successfully performed. Sharing of current among various electrodes based on the measured earth impedances matches quite well with data recorded in 2005 during triggered lightning experiments. Of course, some results are in need of further in-depth analysis. The high-frequency earthing measurements appear to be a good tool to evaluate earthing behavior under lightning conditions.

4. High frequency measurements : validity in good soil and known environment

Due to rather difficult conditions obtained at Camp Blanding regarding earthing measurement leading to only partial curves impedance vs. frequency, one can question the ability of the used device to measure satisfactorily earthing impedance as well as giving consistent results with other low frequency earthing meters. Tests have been performed [7] with the same device in a much better soil (in terms of resistivity as well as water content) 2 months after measurements have been completed at Camp Blanding. These tests were performed on known earthing electrodes embedded specifically for the purpose of the test, namely horizontal stainless steel tape conductors 10 m long and on 1m long copper coated steel earth rods with different surrounding materials. Results obtained are presented in Table 2.

Table 2 data obtained in 2009 according to [7]

Electrode	10 m galvanized steel tape	1 m copper coated steel	1 m copper coated steel surrounded by concrete and isolated by bitumen
DC value (Ω)	29,2	692	Not measurable
High frequency device - Impedance (Ω)			
79 Hz	31	707	????
63 kHz	22	558	944
1 MHz	60	362	267
Average value of Z (63 kHz-1MHz)	42	437	640
Criterion	Bad	Bad	Bad

As can be seen from the table, none of the electrode was considered good according to the high frequency criterion given by the device. The 10 m long electrode was presenting an inductive

behavior that explain the relatively bad performance at high frequency. The 1 m long rods were presenting mainly a capacitive behavior but the length was too short to provide a good value especially due to the soil conditions. It is interesting to note that the rod surrounded by concreted and isolated by bitumen, was not measurable with the 3 points measuring method using a low frequency meter. It was the same for the lowest part of the frequency range with the high frequency meter but as soon as frequency reached 63 kHz a result was obtained.

Figure 3 show the obtained curves for the tape (multiplied by 10 for reading sake) impedance and the two rod impedance. For the second rod the reading starts at 63 kHz as explained.

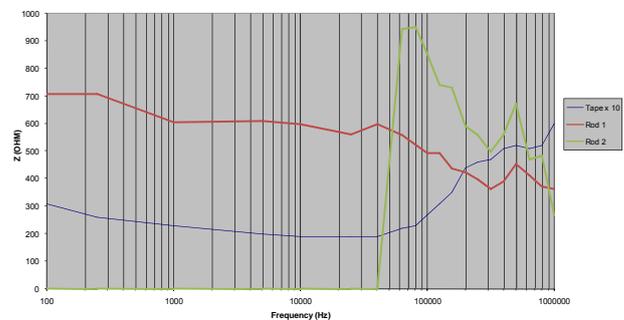


Figure 3. Measurement on known electrodes.

The measurements with a regular earth resistance meter are consistent with those obtained with the high frequency device. The curve pattern obtained on known electrodes can be used to analyze what is really embedded in the soil when measurements are made on unknown earthing systems.

5. How to make a good lightning earthing system

It is clear in standards that to make a good earthing system shape is more important than resistance value. This is why the 10 ohm value is no more mandatory. IEC 62305-3 [8] indicates: “When dealing with the dispersion of the lightning current (high frequency behavior) into the ground, whilst minimizing any potentially dangerous overvoltages, the shape and dimensions of the earth-termination system are the important criteria. In general, a low earthing resistance (if possible lower than 10 Ω when measured at low frequency) is recommended”

At least two electrodes are needed for each down conductors. This will decrease the impedance. If it is possible to provide more paths to ground it will be better as it will further reduce the impedance. Each of the electrodes should not be longer than 20

m as the efficiency will decrease after that length. Better two electrodes of 10 m with enough separation to avoid coupling, than a single 20 m long electrode. This is why the “crow foot” type earthing system is popular and why it is efficient.

IEC 62305-3 also indicates: “*High frequency measurement is possible at the installation stage as well as for the maintenance of the earthing system to check adequacy between the designed earthing system and the need*”.

What are the benefits of high frequency measurements?

- Allow incorporation of an existing earthing system in a lightning earthing system or even use of natural earthing system for that purpose (e.g. an embedded tank)
- Determine if a part of earthing system is still able to disperse lightning current properly: this can apply to parts of earthing system that has been corroded or mechanically damaged. This is particularly true for type B earthing system (ring) where a degraded earthing system may be undiscovered with low frequency measuring technique if the ring is large but may be critical if lightning strikes where the earthing system is degraded.
- Allow a better definition of the earthing system. For example, for a ring electrode (type B according to IEC 62305-3), it is very likely that the global resistance will be low if the electrode is long enough. But this will not mean that where lightning will strike, the local impedance will be low. This really depends on soil homogeneity and local value of soil resistivity. As the current sharing between then down-conductors will be uneven, this may lead to high overvoltages if the striking point is near the location where the local impedance is high.

So what are the steps to make a good lightning earthing system?

- Provide at least two electrodes for each of the down conductor: Type A electrode for local earthing system and Type B electrode for ring electrode. A mix a Type A and Type B can be used and is very efficient as it provides at the same time a better equipotentiality between the down conductors and also low impedance locally. These electrodes should fulfill the IEC 62305-3 requirements and be of low resistance or of a minimum given length. If

this is not the case, or if there is any doubt on quality of earthing system, the earth impedance should be measured to show that the earthing system will behave well in lightning conditions.

- In a few cases it is possible to reduce the number of electrodes and even to reduce it to one by measuring the earth impedance with a high frequency earthing measuring device. This is particularly useful when you decide to connect a down conductor to an existing earthing system and for example a natural earthing system.
- If the standard earthing system is not providing a satisfactory earth impedance (either obtained by following standard requirements or by high frequency measurement) there are two possibilities :
 - o Improve the earth impedance: this can be done by adding more parallel paths or by using earth enhancing compounds as it has been shown that they reduce both resistance and impedance. Another way to reduce impedance is to use a mesh system or even a ground plate as they are providing also good impedance (high frequency earth measurements have shown that the curve Z .vs. frequency is rather flat on range 79 Hz- 1 MHz).
 - o Improve equipotentiality by using IEC 62305-1 formulas, it is possible, based on the impedance measured with a high frequency tester to determine the percentage of current that will flow through the lightning earthing system and how much will flow through metal pipes and through Type 1 equipotential bonding SPDs. Also by using SPDs with higher I_{imp} values, it may not be necessary to improve the earthing system.

6. References

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