Practical high frequency measurement of a lightning earthing system

A. Rousseau, Pierre Gruet

Practical high frequency measurement of a lightning earthing system

A. Rousseau[1], P. Gruet[2]

1: APS, 10 Rue Gabriel Péri, 94230 Cachan, France - alainrousseau@worldonline.fr
2: INERIS, Parc Technologique Alata BP N°2, 60550 Verneuil-en-Halatte, France - pierre.gruet@ineris.fr

Abstract: The authors have used a high frequency earthing meter worldwide to qualify lightning earthing systems and got some feedback. Purpose of this paper is to present some of these practical results and to start discussion on how to use these results. Some indication will be given. In particular, the equivalent high frequency resistance R_{HF} is defined and limits based on experience are proposed.

Keywords: Earthing, high frequency, measurement

1. Introduction

Many papers [1] have already presented various ways to characterize and measure the high frequency behaviour of a lightning earthing system. There is still some confusion today regarding what is a good lightning earthing system. The standards, either international or national, are giving some engineering rules. A resistance value of less than 10 Ω is often requested and this is often misleading contractors. The lightning earth must be interconnected with the other earthing systems and especially the electrical earth. The dedicated lightning earthing system need to be checked when built and also after some year in a maintenance program. So measurement means are needed. So far all standards refer to "usual" ohm-meters which are working at low frequencies. However lightning is a phenomenon which has a broad frequency spectrum from low frequency up to 1 MHz. Experience has shown that the high frequency behaviour is badly understood and lead sometimes to false assumptions and poor results. This paper will summarize standards point of view. A device, presented in previous publications, to measure the earthing impedance up to 1 Mhz has been used extensively in field to gain experience. Some typical results are presented. It appears to the authors that it may be sometimes difficult to decide what to do with the results as experience of the engineers making the measurement may not convince a site manager or in the worse case a court. A simple parameter has been introduced and is presented to start a fruitful discussion.

2. Standards

Usually standards does not deal with high frequency impedance. In general standards recommend a maximum value for earth resistance (as discussed above 10 fi is a value found in many standards as for example in British Standard BS 6651 [2]). But engineering rules are added to try limiting the impedance. In the European pre-standard ENV 61024-1 it was wisely mentioned "shape and dimensions of the earth-termination system are more important than a specific value of the resistance of the earth electrode. However, in general a low earth resistance is recommended".

3. Lightning earth impedance

There are many bad experiences which prove that an earth impedance is different from an earth resistance. Numerous cases are known where the earthing system is built for practical reasons in a good soil area far away from the building. It is the case for example in mountains where making an earthing system is quite a challenge. This "good" local earth becomes very bad at high frequency due to the conductor which is making the liaison between it and the building and which behave as an inductance There are other cases where the equipotentiality is bad at high frequency and the lightning current is then flowing elsewhere than expected. The main problem comes from the front of the lightning wave (where the frequency is the highest) and is related to possible flashovers in the installation due to overvoltages and bad equipotentiality. The main part of the energy content of the lightning wave is in fact delivered at lower frequency (some tens of kHz, see [3]) and size of conductors given in standards allow to withstand that stress.

Even if you follow strictly the engineering rules given in standards you cannot check the high frequency behaviour satisfactorily with a regular ohm-meter. A few measuring devices exist to allow high frequency earth impedance measurement and to identify the potential problems. For example, we used the «Tellurohm-meter» from the AES 100x series which allow measurement in an automatic process, by means of an integrated processor on a range of frequencies from 10 Hz to 1 MHz. It applies a sinusoidal voltage at a varying frequency between the earthing system and a current injection rod, and allow the measurement of the current received by an auxiliary rod. The resistance, the reactance and impedance measured are displayed and recorded and then transferred to a computer. This allows an analysis and print out. This equipment has been extensively tested in field. Of course, such a device do not inject high currents in the soil and this does not fully represent the behaviour of the earthing system under high lightning currents conditions and for example flashover 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.

4. Field high frequency measurement

In previous papers [4] we have already presented the testing which were made to prove the device efficiency. We will now concentrate on field experience obtained with this device. The figures given below represent the resistance (R), the reactance (X) and the impedance (Z, given by the simple formula Z = R + jX) in *Ci* versus frequency in Hz. The impedance Z is represented as a plain line, the reactance X as a dotted line and the resistance R as a broken line.

Measurement made in actual conditions (factories, chemical sites, commercial sites ...) are beneficial, especially because in such cases the earthing system is already built and it is not possible to check if the engineering rules have been followed or even if the system has changed after some time.

A lot of measurements have been recorded in various places. Sometimes, it is difficult to define limits for a good impedance simply by reading the curve. Six field measurements are presented and a method is proposed to assess the quality of the earthing system.

Figure 1 (Case A), is for example showing a case of an extended earthing system for a group of office buildings near to Lyon (France). The soil was rather bad and its structure is made of a rocky base above which is a layer of high resistivity soil covered by a thin layer of low resistivity soil.

The thickness of the two layers was at some places around I m only. Also to obtain a good earthing system, many copper tape conductors have been embedded around the different buildings and interconnected. The result was pretty good as the value measured at low frequency, measured in many location, was 4 Ω only. However, the highest building is protected by a lightning rod connected to the earthing system by one down-conductor while the other buildings are protected by a mesh system.

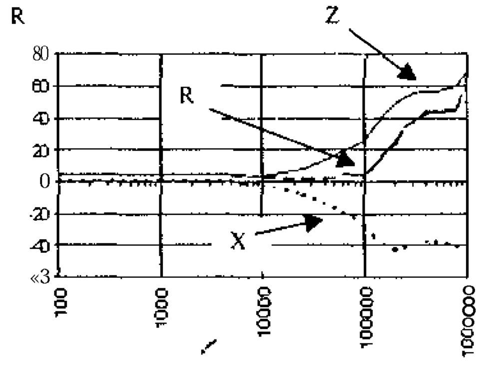

Figure 1: Case A - behaviour on an extended site

The result of the earthing impedance measurement at this location, presented in figure 1, shows that at 1 MHz the impedance is 70 Ω, more than 17 times the value at low frequency. So, we can have some doubts on the behaviour of this earthing system when a lightning current will be injected from the lightning rod. For a 10 kA current, the voltage with be 700 kV instead of the expected 40 kV at the earthing system terminal. This means that flashover can occur or that, if SPD are used in the installation, they will be more stressed than expected. The result will not be as favourable as expected originally with a so low resistance value. In that particular case, measures which could have been used to improve the earthing system have not been applied due to the misleading feeling that the earthing system was already adequate.

Another case (Case B) is the one of factory in Burgundy which intend to expand its site. For that purpose, they have created another earthing system and they wanted to qualify it before creating the new building. What happens is that the soil is of very bad quality made mainly of rocks. There is only a thin layer of rich soil on the top of it. The result is given in figure 2 when figure 3 is a picture of the site.

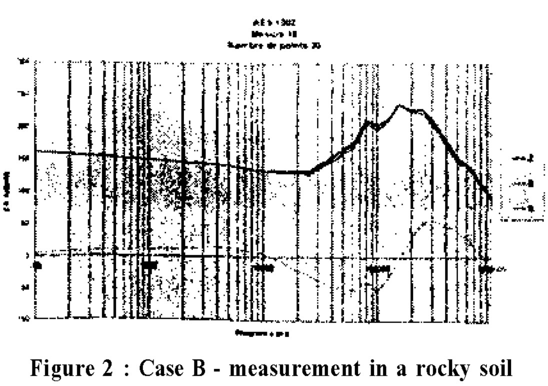

Figure 2 : Case B - measurement in a rocky soil

We can *sec* that the value of the earthing system is quite bad (150 Ω) but due to the effective shape the impedance is not so degraded with frequency. However, in such a case, it will be necessary to create a good equipotentiality of the building including services to ensure that a direct lightning strikes is not creating flashovers.

Figure 3 : Case B - view of the earthing system termination and of the existing building

Another measurement (Case C) is made on a little silo (3 m diameter). All faces are metallic but the area in contact with the soil is small.

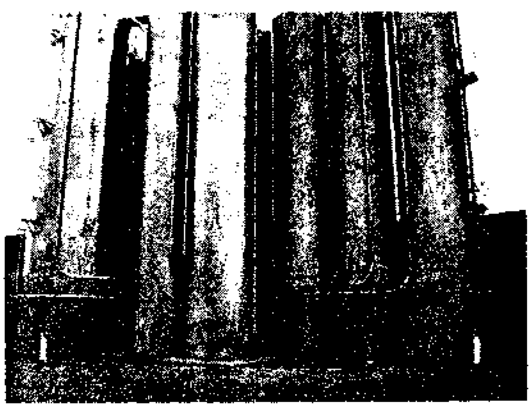

Figure 4 : Case C - measurement of earthing system of the silo

Figure 5 shows that the resistance value is small for low frequencies and increases for high frequencies. This earthing system is not very good but probably acceptable.

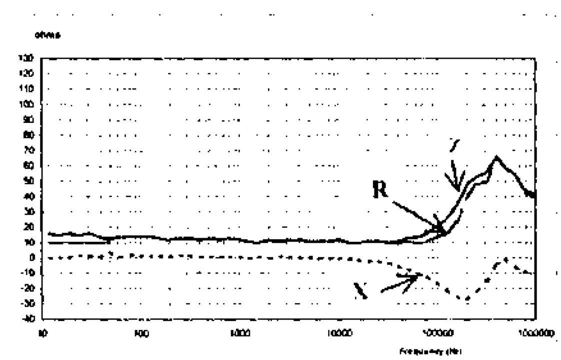

Figure *5* : Case C - little silo

Case D is a large shed built with a metallic frame. The resistance value at low frequency is very low and the impedance increases weakly then the frequency increases.

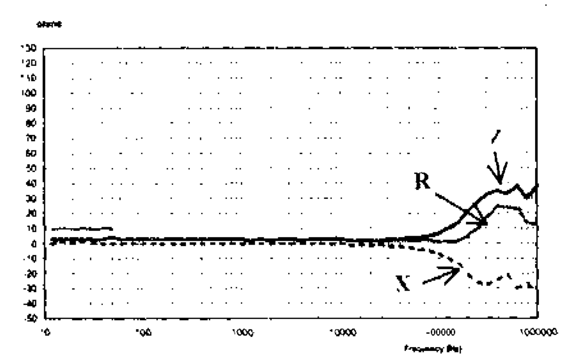

Figure 6 : Case **D** - **Impedance measurement on a metallic frame**

Interpretation of the curves for the case C and D is easy. The resistance at low frequency is low and the impedance increases with the frequency showing a dominant inductive effect. The earthing system seems good for the case D and acceptable for the case C.

Case E represents the measurement of a group of stainless chimneys. An earthing has been made on each chimney and all of them are connected together to a single earthing system by a long length of copper tape.
The resistance is low, but the impedance increases quickly with the frequency. The earthing system seems bad, but what is the acceptable maximum value of impedance for a suitable earthing system ? We need a criterion to help making a decision.

Figure 7 : Case E - measurement of earthing system of a group of stainless chimneys

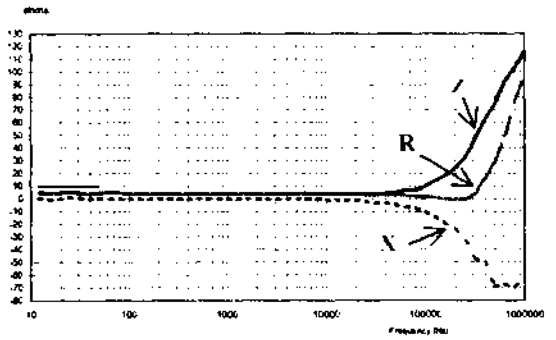

Figure 8 : Case E - Impedance measurement on a group of stainless chimneys

The case F is the measurement of a tank (diameter 6 m) near the sea. The concrete base is immersed in a mixture of sand and water.

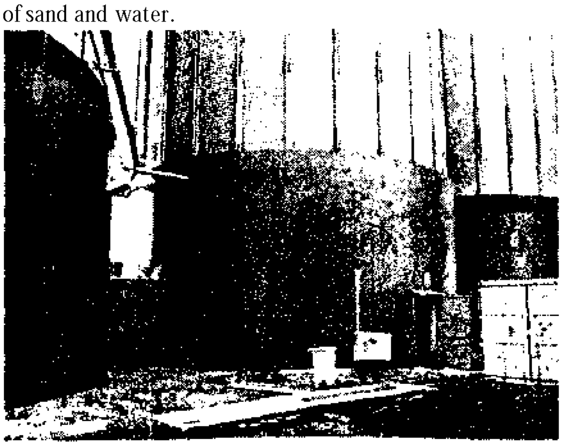

Figure 9 : Case F - measurement of earthing system of a metallic tank

No dedicated earthing is made for the lightning protection. Figure 10 shows that the impedance is quite good.

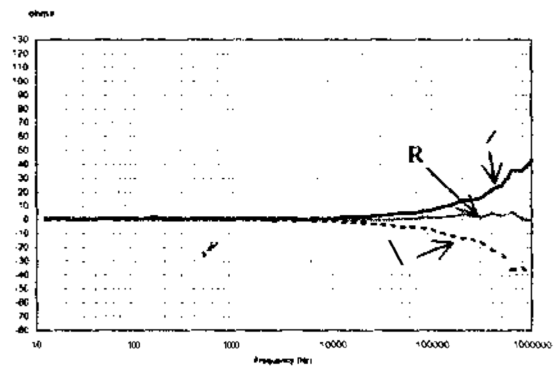

Figure 10 : Case F - Impedance measurement on a metallic tank

According to the low frequency value, cases B is clearly not acceptable according to the standard (value higher than 10 ohms at low frequency). The other cases give a low value of resistance (lower or just a little higher than 10 ohms) but we cannot conclude on the high frequency values of impedance as there is no recommendation in the standards.

The worst case in this respect is for the group of stainless chimney (figure 7 - case E) where the impedance increases quickly after 100 kHz. Its value is so high that it is clear that the earthing system is not adequate for lightning purpose.

For all the other cases we don't know what to conclude.

What is the worst : an intermediate value of impedance on a large range of frequency or a very high value near 1 MHz? We will try to answer to this question in the following chapter.

5. Proposed criteria

The value of the impedance is not enough to characterize the earthing system. Both component R and X have to be taken into account.

As the measuring device gives for each testing the values of R and X for 20 frequencies we decided to use these values to calculate what is the result of injection of a lightning current in such earthing systems. We will concentrate on a steeper wave than the usual 10/350. This last one is convenient regarding the energy sharing between various earthing systems but in our case we will concentrate on the front of the wave where highest overvoltages occur even if energy content is low. For simplicity sake we used a 1/20 wave supposed to represent the overvoltages created by a secondary impulse. A 10 kA 1/20 was injected in the earthing system represented by couples (R,X) function of the frequency as given by the measuring device. The crest value of U given by a simulation using the earthing model is then divided by 10 kA in order to calculate the equivalent lightning resistance (R_{HF}). Assuming that 1 m of conductor is represented by a 1 µH inductance, we will give also the equivalent length of the earthing system in m.

Results are as follows :

	Z Impedance value (Ω)					
Frequency (kHz)	Case A	Case B	Case C	Case D	Case E	Case F
63	19	178	14	4	7	5
80	22	212	16	5	7	6
100	26	204	21	7	10	7
125	35	214	26	10	14	9
156	42	237	34	14	18	9
199	49	227	48	22	24	11
250	53	230	53	28	33	14
316	55	208	52	33	47	14
398	57	180	66	35	52	16
500	57	152	59	33	75	25
633	59	142	54	38	84	36
797	61	114	44	30	104	35
1000	69	93	41	38	116	43
RHF (Ω)	47	203	35	22	47	16
Mean Z (Ω)	46,7	184	40,7	22,9	45,5	17,9
eq. length (m)	24	102	18	11	24	8

Table 1 - mean value of impedance, calculated high frequency resistance and equivalent length

If R_{HF} is high, this means that equipotentiality in the system needs to be very good to avoid sparkovers due to expected high overvoltages. In the same way, if the equivalent length is long, this means that the earthing system behaves as a single long conductor having a high inductance and thus a high impedance potentially generating high overvoltages.

It possible to have a good assessment of quality of the earthing system with a simple and quick calculation. It consists in calculating the mean value of the impedance measured at high frequencies (between 63 kHZ and 1 Mhz). As can be seen from the above table (and validated on many other field results) the result of such a a mean value is close to the one of the lightning resistance (U/I). In all our field experiences the error was less than 20% between R_{HF} and the mean Z. Such a quick calculation can be made directly in field.

Based on our experience with the device we propose the following split in order to start discussion :

- R_{HF} (≈ mean value of Z) < 10 Ω : the earthing is very good
- 10 Ω < R_{HF} ≤ 30 O : the earthing is good
- 30 Ω < RHF < 40 Ω : the earthing is acceptable
- R_{HF} > 40 Ω : the earthing is bad.

It appears clearly that earthing systems A, B and E are considered as bad earthing systems when case C is acceptable and cases D and F are good earthing systems.

Note : the last value (40 fi) is a little below the one we proposed previously [4] due to increased field experience and also due to the fact as we now use the value directly given by the measuring device (logarithmic scale instead of linear scale used previously)

5. Conclusion

To make a lightning earth, specific engineering rules must be followed. However it may be sometimes useful to really measure the earth impedance when the earthing systems is finalised. An equipment allowing such a measure has been used to make extensive measurements in various sites. Main conclusions are that a long or deep earthing system doesn't always make a good lightning earth. More specific shapes give a better result in order to decrease the impedance. Of course, the behaviour in case of a lightning strike will add other parameters such as soil ionisation and sparking due to the high magnitude of the lightning current but the measurement equipment gives useful indications to build and check a lightning earthing system. Some examples are given of measurements in field to illustrate the behaviour of various earthing systems and a method is proposed to try qualifying an earthing system. The purpose of this method is to avoid conflict in future in using such measuring devices. It is presented here in order to start fruitful discussion.

6. Acknowledgment

Many thanks to François Buret (Cegely) for his support.

7. References

[1] S. Wojtas, "Efficiency evaluation methods of earthing systems for lightning protection purposes, ICLP 2002

[2] "Protection of structures against lightning", BS 6651, 1999.

[3] P. Auriol, A. Rakotomalala, A. Rousseau, "Lightning distribution through earthing systems", Lightning Protection Workshop Hobart 12-13 November (published also in IEEE EMC proceedings in 1994 under same title), 1992.

[4] A. Rousseau, P. Gruet, "Measurement of a lightning earthing system", SIPDA 2004