WHAT IS A SUITABLE LIGHTNING EARTH ?

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ABSTRACT :

The recent spread of lightning protection systems (LPS) has emphasized the fact that a safety electrical earth is not, in most of the cases, a suitable lightning earth. Lightning is a high frequency phenomenon with frequency content up to 1 MHz. In such a case, a 10 m cable may lead to a 100 kV voltage drop meaning that what is supposed to be connected to earth (roughly assumed to be a 0 volt reference point) is in fact at a very high voltage. This may explain failures encountered in building without LPS or with LPS badly installed.

INTRODUCTION :

There is 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. The lightning earth must be interconnected with the other earthing systems and especially the electrical safety earth. But 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 and 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 part is badly understood and lead sometimes to false assumptions and poor results.

ELECTRICAL MODEL :

An easy model to understand the phenomenon is the one of a buried conductor in an homogeneous soil. The model used is described in [1] . The parameters per unit (for example per meter) are the resistance r, the conductance g, the inductance l and the capacity c as shown in the following formula : $Z = \frac{\sqrt{r + j\omega l}}{\sqrt{g + j\omega c}}$.

To have a low impedance we need to minimize r and l and to maximise g and c.

The resistance per unit r is not what we call the earth resistance in standards. It is the resistance of the conductor (generally copper) used as earth electrode which is low by definition and then of small importance for our study. However it must noted that at high frequency, skin effect play a big role and that only a part of the conductor (the rim) is used to let flow the current. This means that with the same surface a flat conductor will have a better behaviour at high frequency than a round one.

The conductance g is linked to what is called the earth resistance and measured with usual low frequency ohm-meters. It depends on soil resistivity as well as on good contact between soil and earth electrode. The only thing which can be done to improve that parameter is to increase the number of conductors in the ground or to add some chemical additives to increase contact between soil and earth conductors.

To improve the capacity c we can increase the surface of the electrodes (for example a plate or a grid will behave better than a single conductor) and also improve the contact between soil and the conductors by using some additives as mentioned above.

To decrease the inductance, we can use multi conductors in parallel instead of a single one of equivalent total length. For example 3 tape conductors of 3 m each will have a significantly better inductance than a single one of 9 m. At the same time, the resistance of both earthing systems will be somewhat equivalent, if the 3 conductors are laid out in such a way that they not interfere too much between each other.

STANDARDS :

Usually standards does not deal with high frequency impedance. In general standards recommend a maximum value for earth resistance (as discussed above 10 Ω 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 [3], it is 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".

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. The main part of the energy content of the lightning wave is in fact delivered at lower frequency (some tens of kHz, see [1]) 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. Hopefully, some 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. 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.

HIGH FREQUENCY MEASUREMENT

Different experimental earthing systems have been built on five sites with different soil resistivities ranging from 110 Ω/m to 2700 Ω/m.

The figures described below represent the resistance (R), the reactance (X) and the impedance (Z, given by the simple formula $Z = R + jX$) in Ω 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.

Figure 1 for example represents a vertical rod in a soil with a resistivity of 300 Ω/m. In spite of the reactance X increasing from 800 Hz, the earth impedance decreases on the whole range of frequency. This is mainly explained by the fact that the rod is short and so its inductance small and its effect negligible. But as the rod is short the resistance is high.

Equivalent behaviour was found for a horizontal grid in the same 300 Ω/m soil and with a cylindrical vertical grid in a 200 Ω/m soil. However the impedances were significantly lower in these later cases. This shows that grids have good high frequency behaviour and that larger grids would give better results.

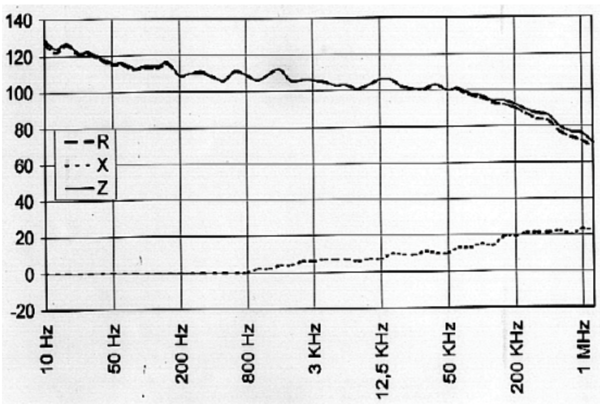

Figure. 1 : behaviour of a vertical rod

To allow comparisons we have measured two cylindrical vertical grids in a 450 Ω/m soil, one being bare and the second embedded in a chemical compound in order to reduce the local resistivity and to improve the contact between electrodes and soil. The impedance value at 10 Hz was 230 Ω for the bare system and 75 Ω for the embedded one. At 1 Mhz the impedance were respectively 70 Ω and 35 Ω. So, such compounds seem to improve not only the earth resistance but also the earth impedance, mainly by improving the capacitive coupling with the soil.

Figure 2 represents the impedance of a crow foot (configuration d) buried in a soil with a high resistivity, situated on top of a rocky hill. The impedance increases from 12,5 kHz and its value at 1 MHz is around 5 times bigger than the value at 10 Hz. In spite of this increase, the value of the impedance is still quite reasonable especially when one consider the difficult soil conditions. With lower resistivity conditions (200 Ω/m) the variation of impedance of the crow foot from 10 Hz to 1 MHz was not really noticeable. In addition, the value obtained at 1 MHz even in a bad soil, is significantly lower than what was obtained with the earthing systems described previously, showing that a crowfoot is a satisfactory system for making a lightning earth.

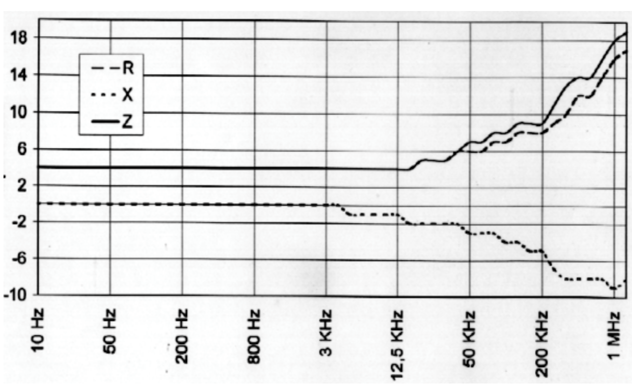

Figure. 2 : behaviour of a crow foot

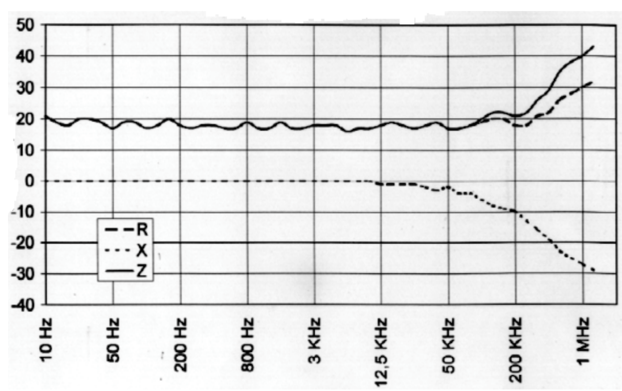

Figure. 3 : behaviour of an horizontal tape

Figure 3 shows the impedance of a 25 m horizontal tape in a 110 Ω/m soil. The impedance increases quickly above 50 kHz to reach at 1 MHz a value about twice the one at 10 Hz. A horizontal tape 50 m long demonstrates an impedance increase even higher at 1 MHz. This clearly shows that a longer length of copper tape which is beneficial to decrease the earthing resistance is not improving the high frequency behaviour. Same phenomenon occurs with deep drilling (20 m and 50 m depth in a 200 Ω/m soil) where impedance was significantly higher at 1MHz than at low frequency (for example for the 50 m deep drilling, the impedance was less than 10 Ω at low frequency and was about 70 Ω at 1 MHz.).

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.

Figure 4, is for example showing a case of an extended earthing system. 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 1 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 downconductor while the other buildings are protected by a mesh system.

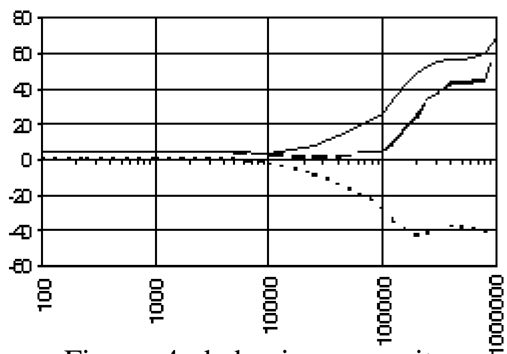

Figure. 4 : behaviour on a site

The result of the earthing impedance measurement at this location, presented in figure 4, 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 value than 4 Ω. 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.

CONCLUSIONS :

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. Compounds used to decrease the earthing resistance in case of bad soil resistivity seem also to be efficient under high frequency conditions. 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.

REFERENCES

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[3] "Protection of structures against lightning, part 1 General principles", ENV 61024-1, 1995