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IMPULSE TESTING OF SOIL SAMPLES FOR LIGHTNING EARTHING DESIGN

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Abstract – In case of a direct lightning striking on a structure or on a lightning rod, a current impulse is injected in the earthing system at the point of strike. This will lead to overvoltages, sharing of energy amongst various path and earth electrodes and current injection in services via SPD or sparkover. In case of the earthing system be a dedicated lightning earthing system, this current injection in services will be reduced and the overvoltages created at the injection point will be minimized. It is the aim of this paper to investigate the performance of various soil samples when they experience impulse current and voltage impulses in a laboratory environment. The initial aim is to explain the laboratory set up and to outline the worrying issues, when dealing with lightning earthing systems, which are currently neglected.

1 INTRODUCTION

In the event of lightning strike on a lightning protection system, the air termination system should intercept between the structure and the lightning stroke by driving the lightning current through the down system to the earth termination system. But what happen when the lightning current impulse flows to a remote earth? In the vicinity of the electrode of the remote earth it appears a high voltage which may lead to sparking over between the earth electrodes and other part such as water pipe or alike.

In order to better assess these effects, a testing experiment has been developed at the ELEMKO high voltage testing laboratory. Various samples of soil have been tested with two mains tests. The first test is using a high voltage generator in order to establish the withstand voltage of the sample under test allowing to compare some soils in different configuration and also to determine the impedance of the earth electrode. The second test is a current injection using impulse current generators. Purpose of this second test is to measure both the response of the earthing system to current injection and the change in earth impedance with respect to the soil.

The test object is a barrel of the type used for oil storing. It has a cylindrical shape and is connected to the earthing point of the generator. The earth electrode under test is a short copper coated steel rod located in the middle of the barrel. This is the injection point for the current generator and the high voltage spot for the high voltage generator.

Various soils are tested (sand, mixture of sand with carvel and sand with soil improver compounds) with various content of water. First the samples are supposed to be homogeneous and a portable concrete mixer is used to achieve this stage as best as we can. Then, the soil will be degraded by mixing sand to garden soil and clay and at a later stage by integrating small rocks.

This experiment will be on the long term. This paper is presenting the experiment itself and preliminary results.

2 SPECIMENS USED FOR THE TESTS

For the purpose of these tests three soil samples were used, the soil samples were installed in a PVC barrel with the dimensions as shown in figure 1. Initially a metallic barrel was used but the sparkover inside the barrel was occurring between the anode rod electrode and any part of the barrel since it was all metallic (side and bottom). By using the PVC barrel with metallic parts only the anode and the bottom of the barrel it was possible to have a constant path for the sparkover inside the soil sample and therefore possible to compare different samples. However since it is impossible to predict the precise path of the sparkover through the soil sample the results should be taken into consideration for comparison purposes between the three soils samples that were tested

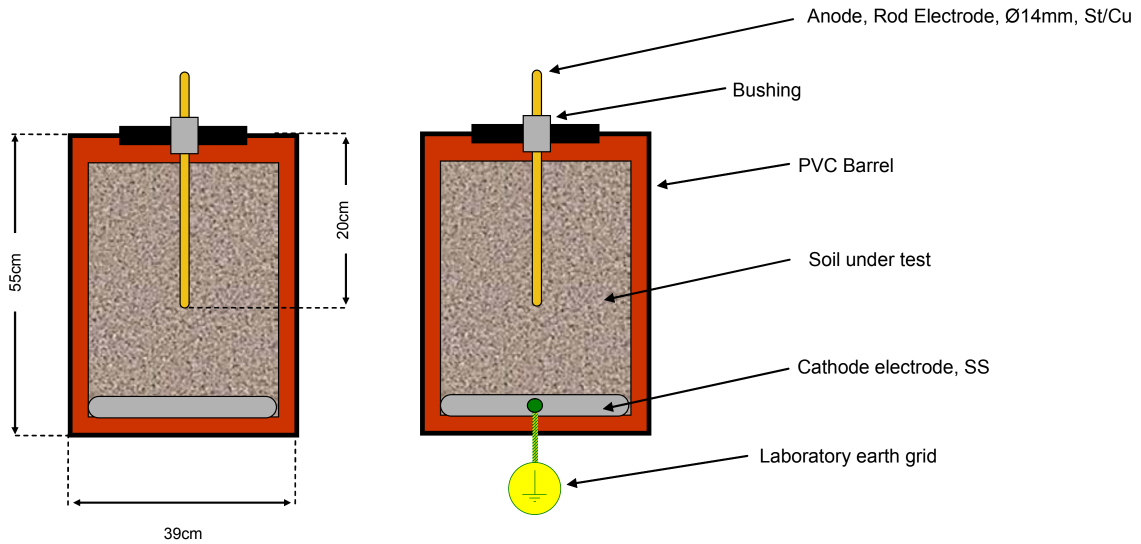

Fig. 1 –Dimensions of barrel and samples used under test

In figure 2 the three soil samples that were tested are described. Soil sample 1 was simulating a homogenous soil made out of sand, which was mixed by using a portable concrete mixture so as to get even distribution of the water contamination (humidity) as even as possible. Soil Sample 2 was simulating also a homogenous soil but with higher resistivity, this was achieved by mixing 75% sand and 25% gravel (approximate diameter of gravel rock was 1cm). Soil sample 2 was also mixed in the concrete mixture so as to achieve the best possible distribution of sand and gravel as well as water contamination. Soil sample 3 was simulating a non homogenous soil, this was achieved by using sand and the surrounding of the anode rod electrode with a diameter of 10cm was filled with soil improver having as main ingredient betonite.

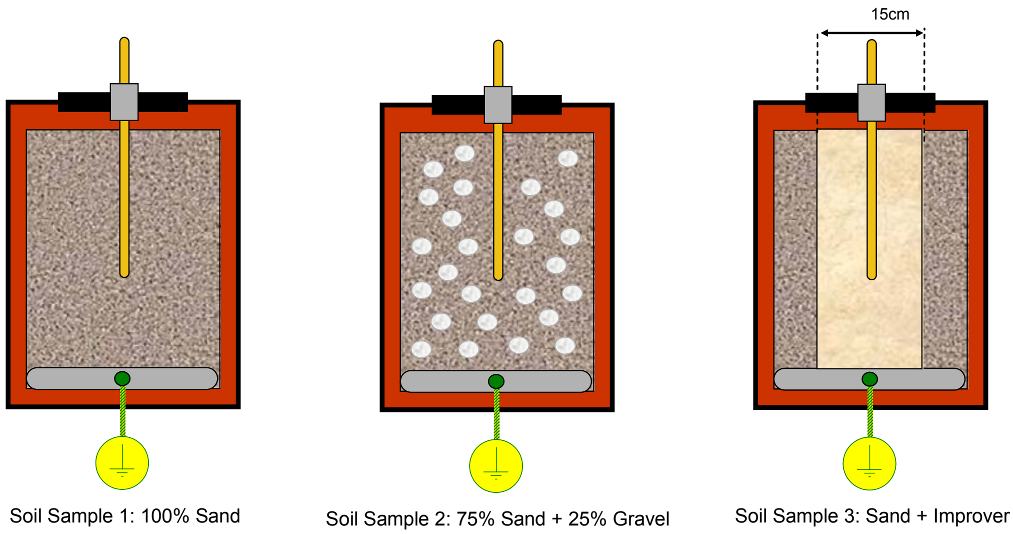

Fig. 2 – The three soil samples used for the preliminary tests

3 EXPERIMENTAL SET UP AND PRELIMINARY RESULTS

For the purpose of these preliminary tests two experimental set ups were used, one with a combination wave generator with 2Ω internal impedance (12kV, 6kA) and one with the impulse voltage generator (Marx type 500kV). Both set ups with the preliminary results of each test are explained below. In both test the same soil samples were used.

A. Testing by using the Combination Wave Generator, 12kV

The purpose of this test was to investigate the performance of the soil sample when subjected to discharge an impulse voltage by injecting a voltage pulse through the input electrode A and to measure the potential difference between electrode A and reference electrode B (see Figure 3). This experiment aims to simulate what may happen to a metallic surface which is in the vicinity of an earth electrode, which is discharging an impulse voltage but there is not any direct equipotential bonding between the two, supposing that since they are both in the soil it is assumed that the potential difference will not be at a dangerous level. The spacing between input electrode A and voltage reference electrode B was always constant at 8.5cm.

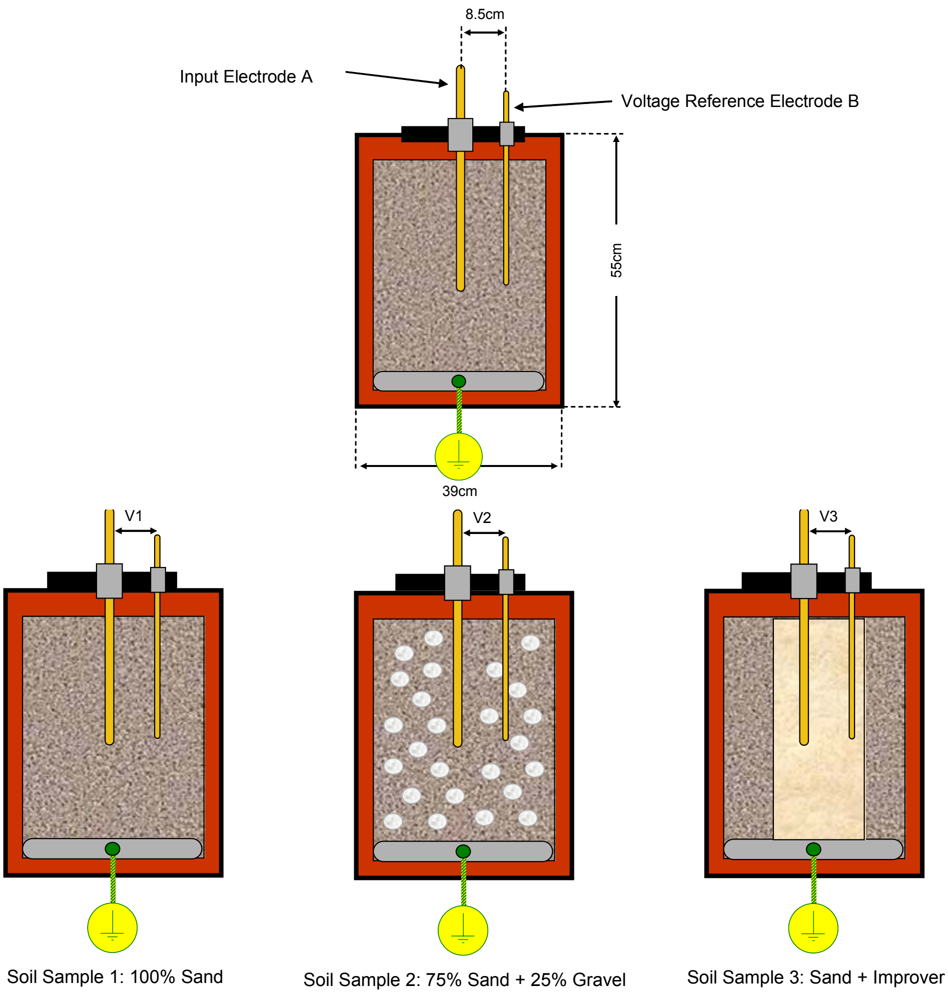

Fig. 3 – Investigation on the voltage pick up at a remote earth electrode

The HV output of the combination wave generator was connected to the input electrode A (see figure 3) and the potential difference between the two electrodes was measured by using two voltage dividers with a division ratio 1:1000 and recorded with a 300MHz TDS 3032 digital phosphor oscilloscope (see Figure 4 and 5). The generator was able to produce an open circuit voltage pulse of 12kV (O/C), which leading to a short circuit was able to deliver up to 6kA (S/C) depending on the specimen impedance, however these 12kV could not cause any breakdown of the soil samples, therefore the test was carried out by injecting a pure impulse voltage of 12kV. All three soil samples were tested in a same way as described above and the potential difference between electrode A and B was recorded.

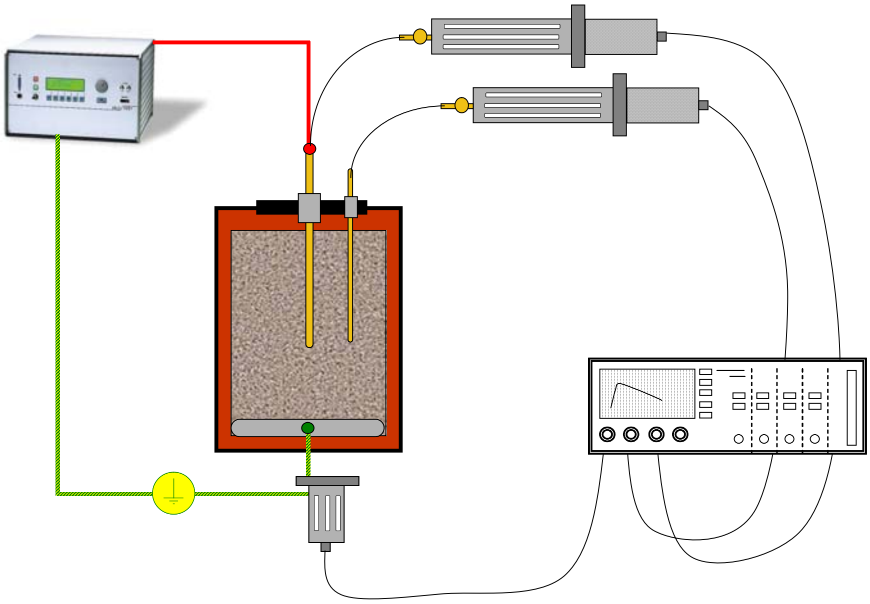

Fig. 4 – Experimental layout of voltage pick up test

Fig. 5 – Photograph of experimental set up of voltage pick up test

The results of the soil sample testing by injecting 12kV on electrode A are summarized in Table 1

Table 1: Summary results of soil samples tested with 12kV impulse

	Voltage at Electrode A	Voltage at Electrode B	Potential difference between electrode A and B	Reference figure
Soil Sample 1 (100% Sand)	12kV	5.8kV	6.2kV	6
Soil Sample 2 (75% Sand + 25% Gravel)	12kV	5.9kV	6.1kV	7
Soil Sample 3 (Sand + Improver)	11.5kV	10.8kV	0.7kV	8

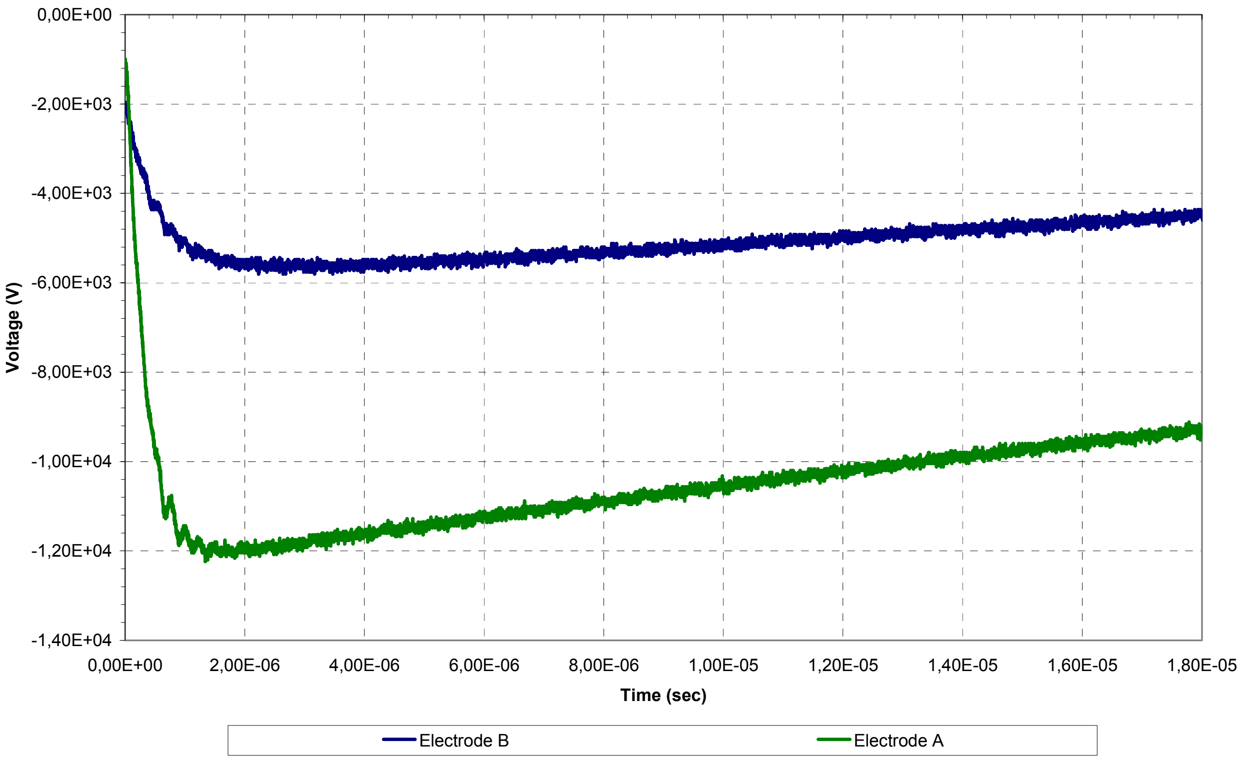

Fig. 6 – Potential difference between electrode A and electrode B by injecting 12kV impulse at electrode A in homogenous soil of 100% sand (soil sample 1)

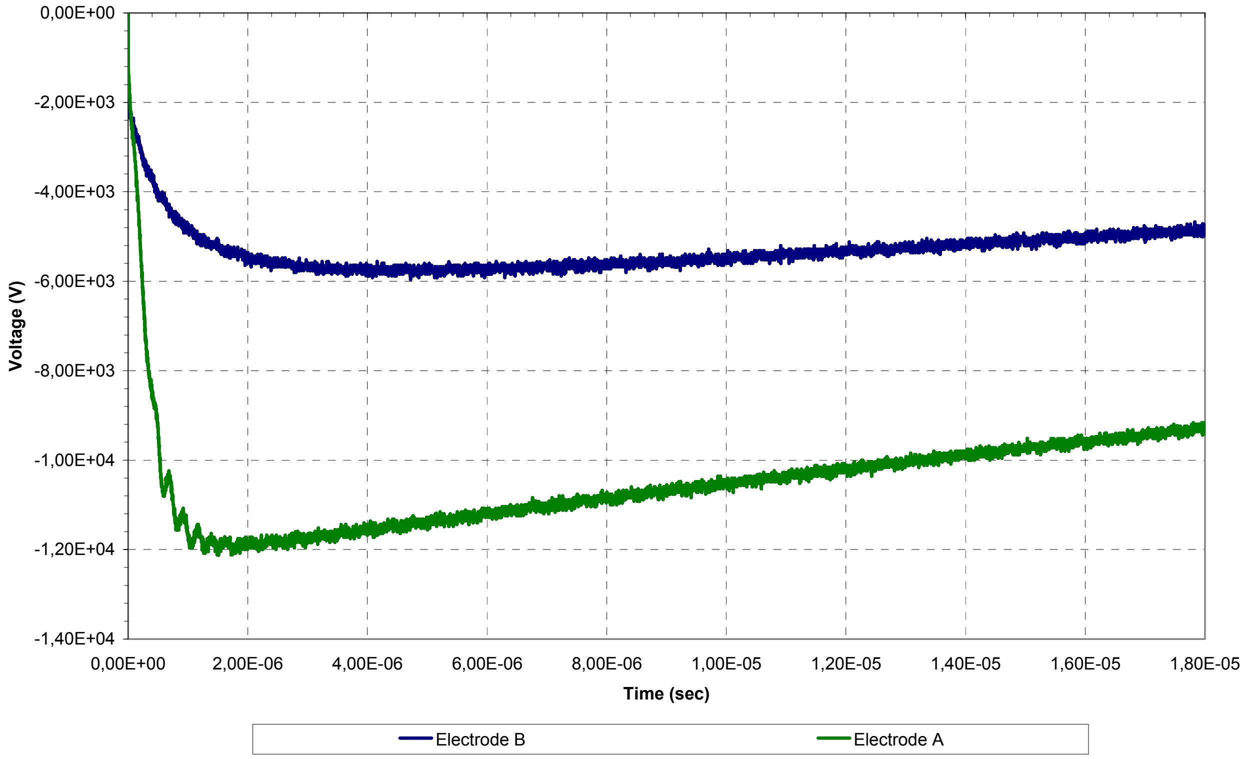

Fig. 7 – Potential difference between electrode A and electrode B by injecting 12kV impulse at electrode A in homogenous soil of 75% sand and 25% gravel (soil sample 2)

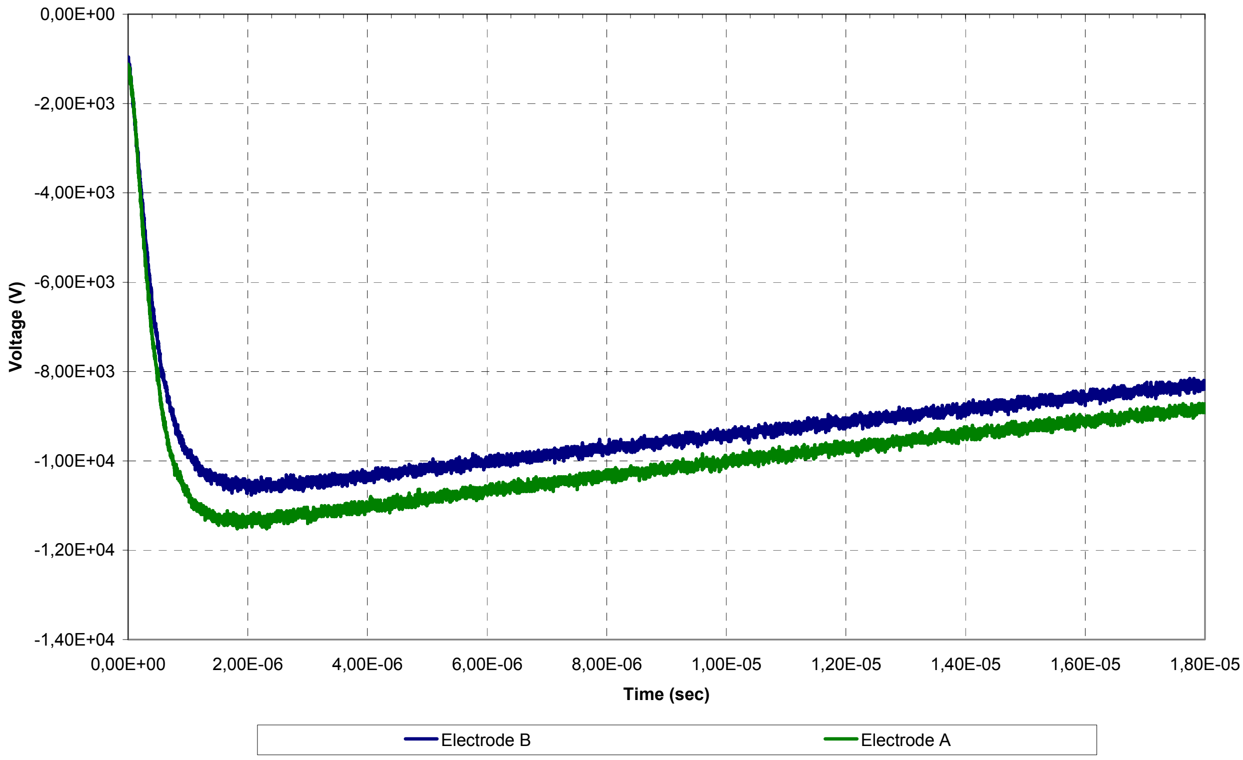

Fig. 8 – Potential difference between electrode A and electrode B by injecting 12kV impulse at electrode A in non homogenous soil of sand and earth resistivity improver (soil sample 3)

B. Testing by using the Marx impulse voltage generator, 500kV

The purpose of this test was two prime targets. Initially is to investigate impedance variation of a specific earth electrode inside thee soil samples when subjected to discharge an impulse current followed by an investigation on the potential difference that may be generated between the earth electrode when discharging impulse currents and metallic surfaces situated in the vicinity. Both targets are still under development, in this paper only the experimental set up and the preliminary results are presented.

The impulse current was produced by operating a five stage impulse voltage generator in a short circuit. This experiment aims to simulate the response of the lightning earth impedance of an earth rod when the applied impulse voltage is high enough so as to cause a sparkover between the anode electrode and the cathode electrode (see figure 9). Then the voltage at the anode is recorded and the current passing through the cathode electrode is also recoding making possible the calculation of the earth impedance and its response when discharging impulse currents. All three soil samples were tested in a same way as described above and the potential difference between electrode A and B was recorded.

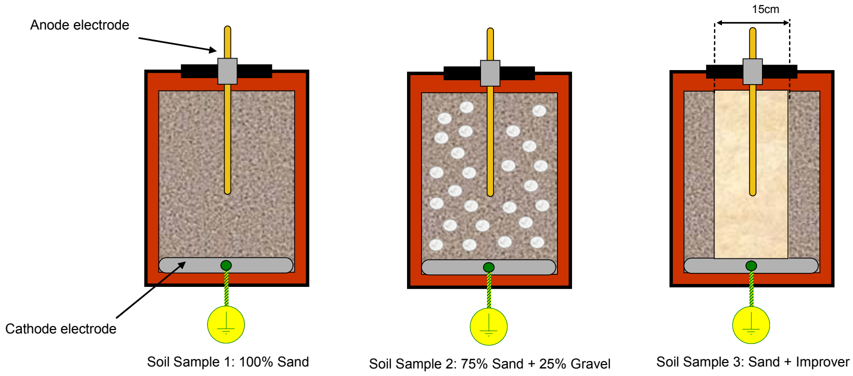

Fig. 9 – Investigation on the impedance response of a lightning earth

The test set-up consisted of a Marx design five-stage impulse generator, with a maximum charging voltage per stage of 100kV, arranged to produce a 1.2/50μs wave-shape at its output. The output voltage was measured with a 1:7000 damped-capacitive voltage divider and the current was measured with a coaxial shunt of 1mΩ. Both voltage and current impulses were recorded with a 300MHz TDS 3032 digital phosphor oscilloscope. The generator was able to produce a voltage pulse of 500kV (O/C), which leading to a short circuit was able to deliver up to 5kA depending on the specimen impedance (see figure 10 and 11).

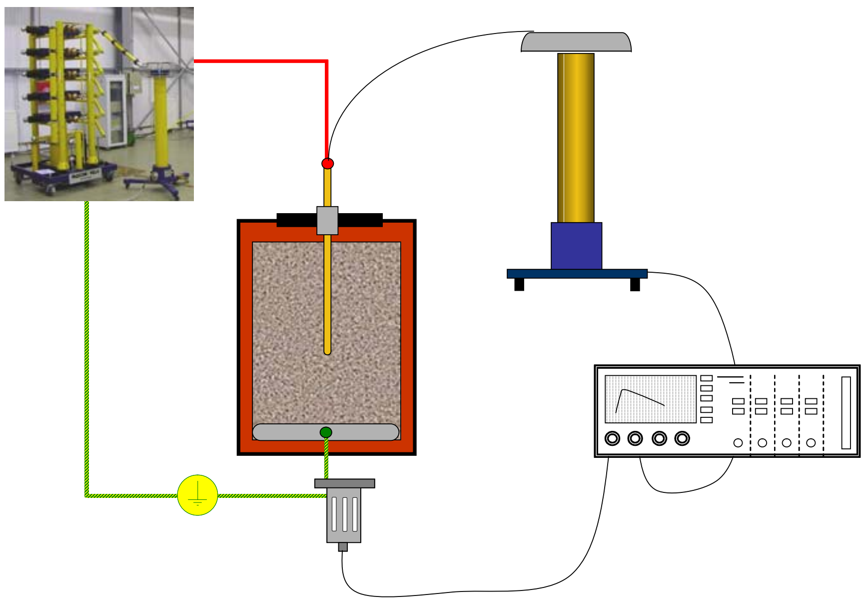

Fig. 10 – Experimental layout of earth impedance response testing

Fig. 11 – Photo of experimental set up of earth impedance response testing

The results of the soil samples testing when investigating the impedance response are shown in Table 2.

Table 2: Summary results of soil samples impedance response

	Conducting voltage	Voltage between anode electrode at peak current	Current through cathode electrode path	Derived peak impedance of anode electrode	Reference figure for V and I
Soil Sample 1 (100% Sand)	73,5kV	33kV	266A	124Ω	12
Soil Sample 2 (75% Sand + 25% Gravel)	72,8kV	35kV	212A	166Ω	13
Soil Sample 3 (Sand + Improver)	17,4kV	17.4kV	460A	37Ω	14

From the results it is possible to observe the variation of the anode electrode impedance with respect to the soil sample which is installed. When applying impulse voltages lower that the ones summarized in table 2 – named conducting voltage - sample 1 and 2 were not conducting at all. However when applying conducting voltage (73.5kV for sample 1 and 72.8kV for sample 2) and looking at figure 12 and 13 it can be observed that the first soil sample 1 and soil sample 2 they can initially withstand the applied impulse voltage but during the tail of the applied impulse voltage a sparkover between the anode electrode and the cathode electrode occurs leading to a short circuit current. This is mainly due to the high resistivity of the soil samples, which withstands a high voltage before conducting. During the conduction the voltage at the anode electrode and the current through it is recorded. The ratio between the voltage and the current gives an indication of the impedance variation of the electrode. For soil sample 3 (with the improver) a sparkover does not occur since the resistivity of the sample is low enough so as to allow it to conduct even at a very low voltage. Similarly the ratio between the voltage and the current gives an indication of the impedance variation of the electrode inside sample 3.

Note: The initial peak of the current pulse (0-4µs) show in figure 12 and figure 13 occur due to ionization and should be neglected for the purpose of these tests.

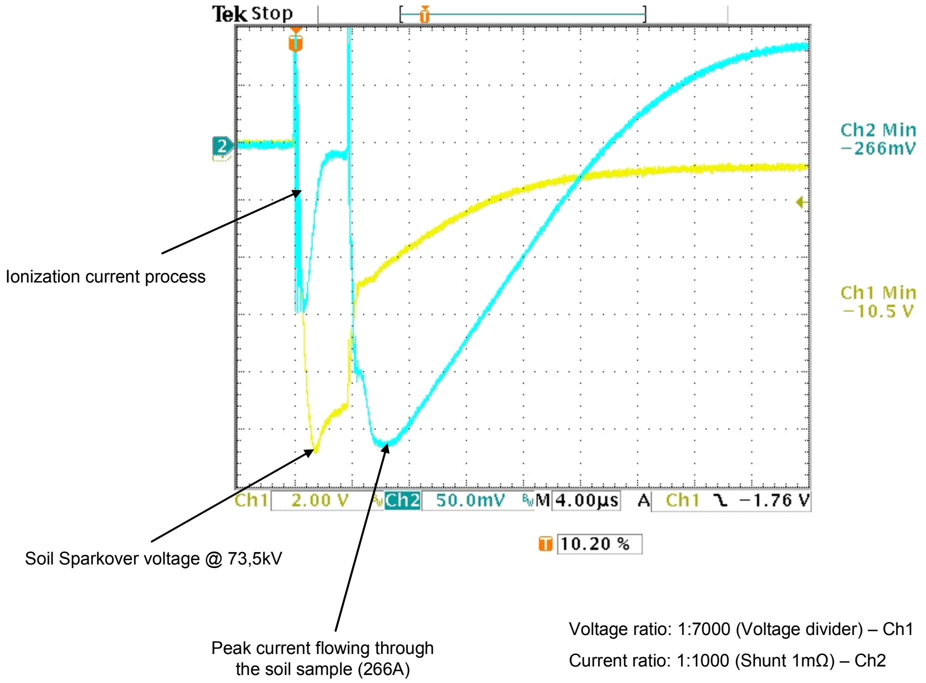

Fig. 12 – Oscilloscope capture for voltage and current pulses when testing soil sample 1 (100% Sand)

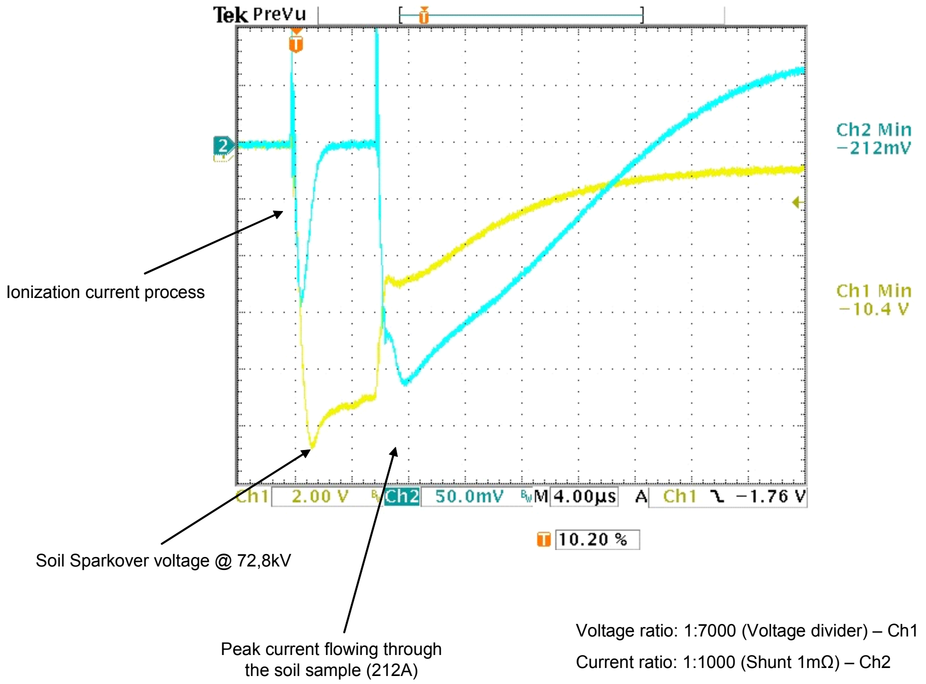

Fig. 13 – Oscilloscope capture for voltage and current pulses when testing soil sample 2 (75% Sand+25%Gravel)

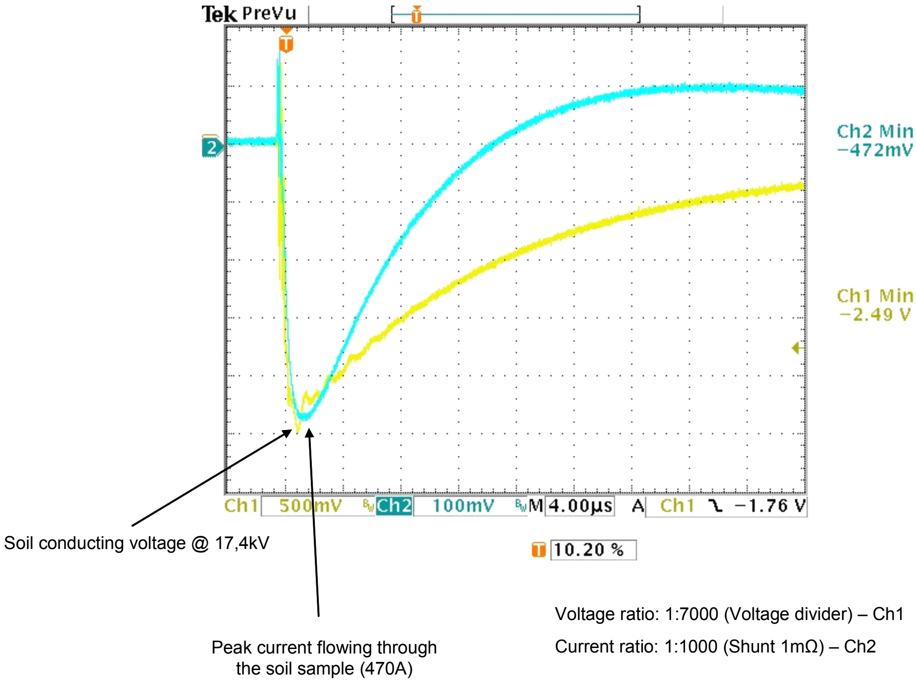

Fig. 14 – Oscilloscope capture for voltage and current pulses when testing soil sample 3 (Sand + Improver)

4 DISCUSSIONS, SUMMARY AND FUTURE WORK

The main aim of this paper is to show that metallic installations such as pipelines, cable sheaths etc, which are situated in the vicinity of an earth electrode, will not have potential equalization between them just due to the fact that they are inside the ground at a close vicinity. This was primary shown by injecting an impulse voltage at an earth electrode and the voltage pick up was measured at a reference electrode in the vicinity of the first one. The initial results have shown that indeed a high potential difference between the two can be generated and their equipotential depends on the soil medium. In conductive soils the potential difference between the two can be reduced however a solid bonding will be the best practice. On the other hand if separation is required then a safe separation distance should be reconsidered for metallic surfaces buried in soil by IEC and EN standards in a similar way with the metallic surfaces above ground.

The second part of this paper has shown preliminary results on the response of earth electrode impedance when discharging an impulse current. This part of the experiment will be further investigated since the main aim is also to show the potential difference that may occur between the earth electrode and metallic surfaces in the vicinity of it when the earth electrode is discharging impulse currents. Various waveshapes will also be used as long as the critical sparkover voltage of the soil sample is achieved so as to allow the current to flow through the soil. In this paper the experimental set up was shown in conjunction with preliminary results, which have shown that indeed issues regarding potential equalization inside the ground between the earthing system conductors and metallic surceases should be taken into consideration.

5 REFERENCES

[1] IEC 62305 – 3:2006, Protection against lightning Part 3: Physical damage to structures and life hazard
[2] EN 62305 – 3:2006, Protection against lightning Part 3: Physical damage to structures and life hazard
[3] A. Rousseau, How to get a suitable earth? 26th ICLP Cracow 2002
[4] Gonos I.F., Stathopulos I.A.: Soil Ionization under Lightning Impulse Voltages, IEE Proceedings Science, Measurement and Technology, Sept. 2004.
[5] Gonos I.F., Topalis F.V, Stathopulos I.A.: Transient Impedance of Grounding Rods, Proceedings of the 11th International Symposium on High-Voltage Engineering (ISH 99), Lightning, protection against strikes, earthing earthing, London, UK, 1999,.
[6] Gonos I.F., Antoniou M.K., Topalis F.V., Stathopulos I.A.: Behaviour of a Grounding System Under Impulse Lightning Current, Proceedings of the 6th International Conference and Exhibition on Optimisation of Electrical and Electronic Equipment's (OPTIM '98), Brasov, Romania, 1998