Optical investigations of pulsed sparks in soil near electrode

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Abstract. Experimental results of laboratory investigation of nonlinear processes in moist soil near electrode simulating grounding of electric power facilities are presented. A method of optical recording of spark formation in the soil is developed. Investigations were carried out at voltage of 20–50 kV and current pulse duration of tens of microseconds. The critical electric field and delay of sparks beginning in soil in depending on the electrode construction, moisture and impulse duration are obtained. The images of sparks in soil are obtained for the first time.

1. Introduction

Soil is typically composed of several different substances including, for example, water, pockets of air, gravel, sand, clay, dissolved gases, mineral salts and organic material [1]. The properties of these substances affect the electrical properties of the soil. Although the electrical breakdown properties of the constituent solid, liquid and gaseous dielectrics are individually well understood, a comprehensive physical model for soil has not yet been developed [2]. In the generally accepted, that electric field generated by high current can result in spark channels formation in the water and gas within the soil surrounding the electrode. Since the resistivity of the plasma in the discharge channels is lower than that of the surrounding soil there is an apparent decrease in the resistance to earth of the electrode [3]. This effect is usually referred to as soil ionization. Processes associated with the sparking in the soil are nonlinear and depend on the current density [4, 5]. There are images of spark channels above the ground, however, has not yet been obtained direct evidence of the sparking formation and plasma channels in soil at excess of the critical current density. The aim of this work was to develop a method of recording of sparks in the soil and investigation of sparks formation at various conditions.

2. Experimental setup

Scheme of experimental setup for investigation of high-voltage impulse processes in the moist soil is shown in figure 1. Scheme of current and voltage measurements on electrode buried in the

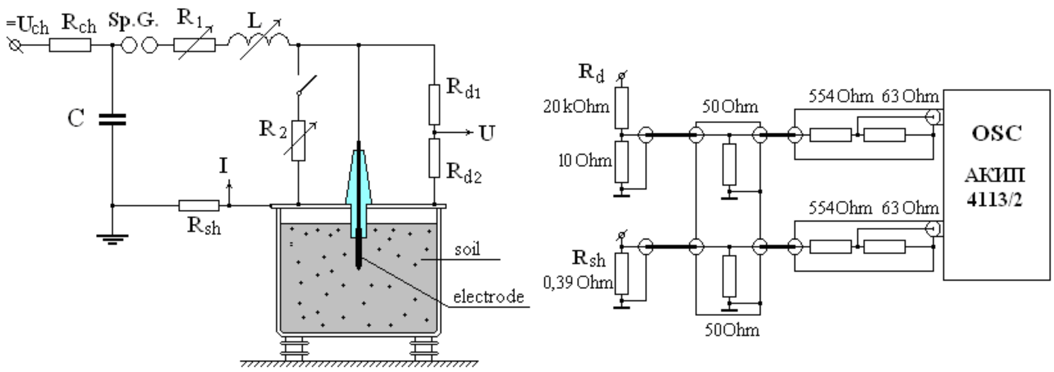

Figure 1. High-voltage pulse setup and measurement scheme for investigations in moist soils. U_{ch}—high voltage of DC current, R_{ch}—charging resistance, C—charge capacity, $Sp.G.$—high-voltage arrester, R_1—ballast resistance, L—inductance, R_{sh}—shunt resistance, R_2—resistance forming a rise time pulse, R_{d1}, R_{d2}—resistances of the voltage divider, OSC—oscilloscope.

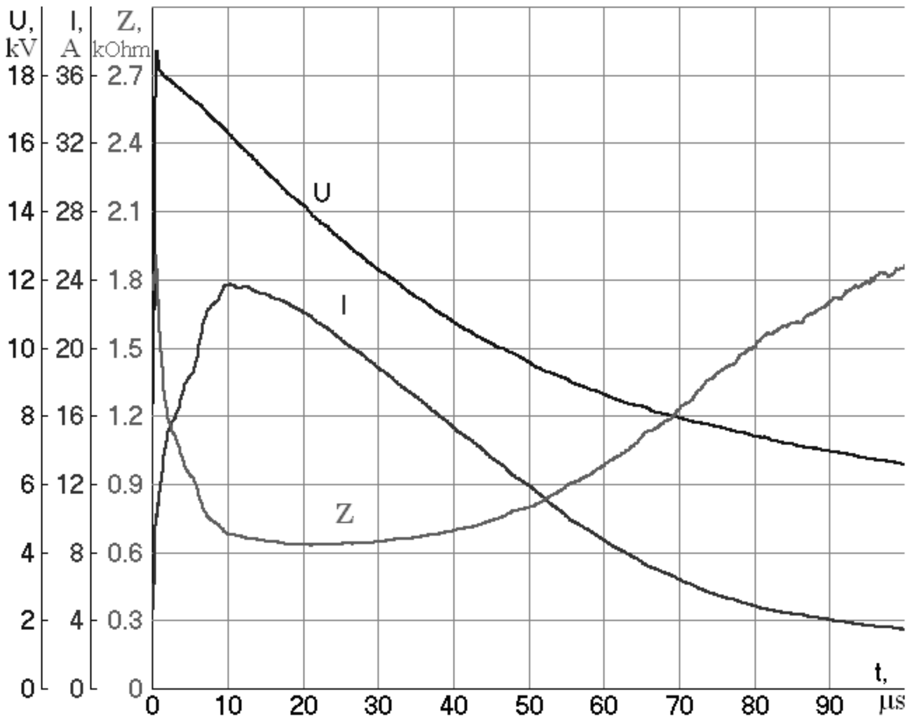

Figure 2. Oscillograms of the pulse current, voltage and dynamic resistance.

soil is also shown in figure 1. Figure 2 shows obtained oscillograms of the pulse current, voltage and dynamic resistance $Z = U/I$.

The dynamic resistance is usually determined as the ratio of the maximal voltage on the grounding electrode to the maximal current through it $Z = U/I$. In general, these maximums do not coincide in time, due to the influence of the reactive parameters, of ground electrode. The real time delay might be very large in the microsecond scale typical for thunderstorm overvoltages. In this case the initial time lag is approximately equal to 0.5 μs.

Design of the optical observation setup is shown in figure 3. Sparks in the soil were recorded by a digital camera through the glass window in the vessel with moist sand. High-voltage

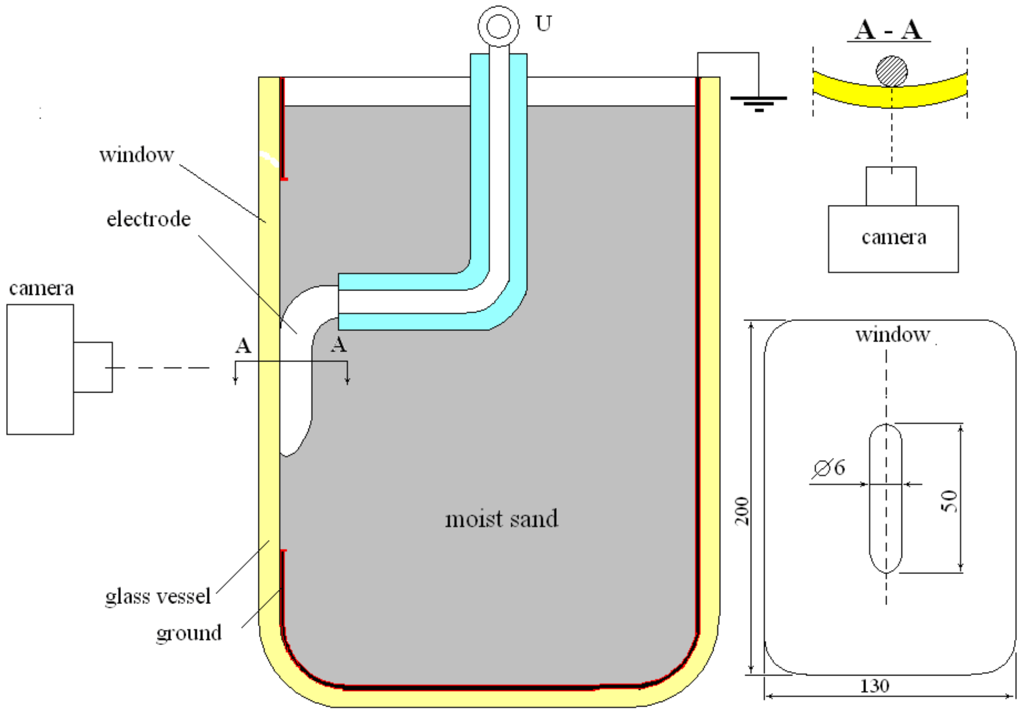

Figure 3. Optical recording of sparks in the soil.

electrode in the soil was pressed against the glass in the window, which was surrounded by a grounded electrode.

Another method for registration of sparking in soil is shown in figure 4. Photographic paper was placed in the moist sand and the electrode was installed on this paper. The size of the electrode was the same as in the previous experiment. After the voltage pulse the photographic paper was removed and then treated to take the photo for visualization of the spark discharge channels in the sand.

3. Experimental results

Figure 5 shows the images of spark channels in the soil around rod electrode recorded by optical method and with photographic paper. The amplitude of voltage pulse was 20 kV.

Figure 6 shows images of the spark channels in the soil around a flat disk electrode with 25 mm diameter.

All the processes at the beginning of sparking in the soil are nonlinear, especially in non-uniform electric field. The nonlinearity can be seen from dynamic current-voltage characteristics (figure 7), obtained from oscillograms (figure 2). Figure 7 shows experimental results for half-buried spherical electrode. Amplitudes of voltage pulses were in the range of 25-50 kV. The voltage pulses rise time was 0.1 μs, time-to-half value was 120-270 μs. For low voltages, dynamic resistance is linear and equivalent to stationary one. The current-voltage characteristic at high voltage pulses has hysteresis shape, associated with non-linear properties of the soil. It is seen from the figure 7 that when current density at the electrode surface exceeds critical value, the dynamic resistance starts to decrease due to soil ionization.

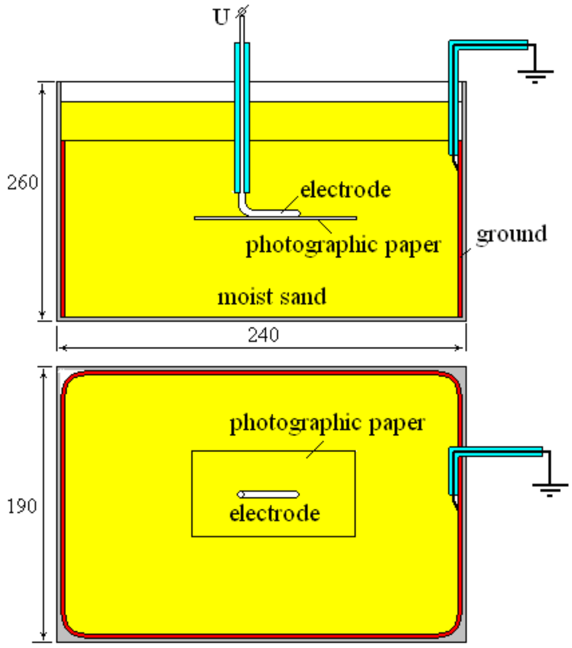

Figure 4. Recording of spark channel in the soil with the photographic paper.

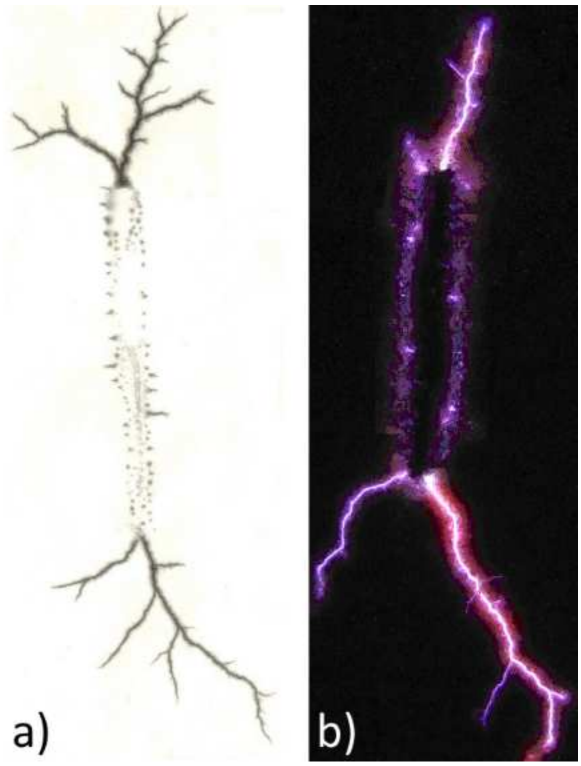

Figure 5. Images of sparks in soil recorded with photographic paper (a) and through the glass window (b).

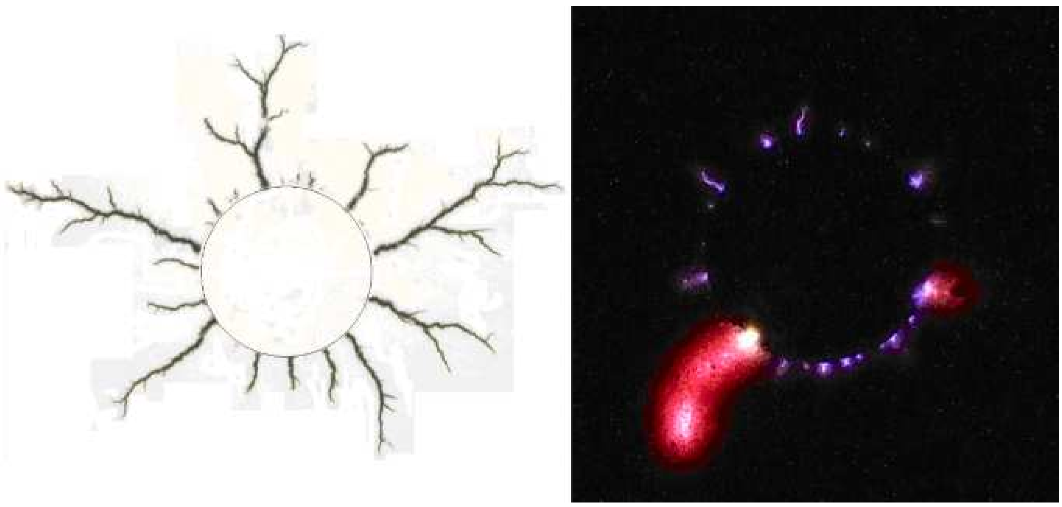

Figure 6. Sparks in soil around the disk electrode.

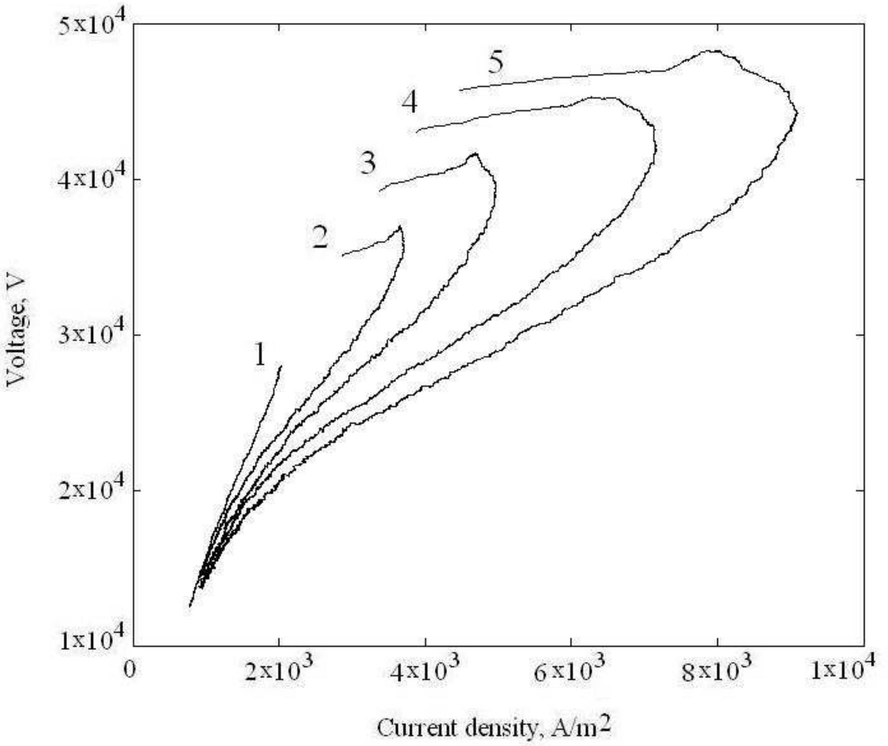

Figure 7. Dynamic current-voltage characteristics for moist soil. Moisture 10%. 1—U = 28 kV, 2—U = 37 kV, 3—U = 42 kV, 4—U = 45 kV, 5—U = 48 kV.

4. Conclusion

Diagnostics of the forming of sparks in the soil with use of the digital camera recording through a glass window is created. Another established method of diagnosis uses photographic paper, placed in the soil around the electrode. It was first shown, that in excess of the critical current density, flowing from the electrode into the soil, the plasma channels are beginning to grow from electrode. As a result, dynamic resistance of electrode becomes non-linear and it is accompanied by hysteresis phenomena, confirmed by the current-voltage characteristics. Experiments with photo paper clearly show that in symmetric electrode systems with non-uniform field, instability of plasma processes arise with voltage growth.

Acknowledgments

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