Scientific Journal of Riga Technical University
Power and Electrical Engineering
DOI: 10.2478/v10144-010-0027-x *2010*
Volume 27

Correlation Analysis between Grounding Resistance and Diurnal Variations of Upper Soil Resistivity during March 2010 in Balozhi, Latvia

Marina Kizhlo, *Riga Technical University*, Arvids Kanbergs, *Riga Technical University*,
Mihails Kizhlo, *Riga Technical University*

***Abstract.* The accurate measurement of soil resistivity and grounding system resistance is fundamental to electrical safety. However, geological and meteorological factors can have a considerable effect on the accuracy of conventional measurements and the validity of the measurement methods. This paper examines some aspects of grounding measurements and grounding system performance in the context of both geological and meteorological effects.**

We are reporting the results of grounding measurements using the 3-point method with ground resistivity tester type M416. The measurements were conducted during selected period from 2010 March 1 to March 31 in Balozhi, Latvia. We also noted that the resistivity of the upper layer significantly varied from a point to another, reflecting difference in water content in the upper soil layer due to local topography and other parameters.

***Keywords*: correlation analysis, diurnal variations, electrical properties of soils, grounding resistance, measurements, soil resistivity**

I. INTRODUCTION

Grounding of electrical installations is primarily concerned with safety; in particular, the prevention of electrical shock risks to life. As such, grounding system must be designed, tested and maintained to satisfy this primary aim.

In Latvia, grounding systems are installed in widely differing soil types and geological context, and are subject to a range of climatic conditions. As a result of the wide variation in soil conditions across the Latvia, it is important to obtain an accurate measurement of the soil resistivity.

The measurement should be made local to the electrical installation under consideration and the resistivity down to a depth up to hundred meters should be determined. Normally, soil resistivity will be measured at the site at the planning stage.

There are different methods for obtaining these measurements. Due to variations in electrodes and soil, a number of measurements should be taken and evaluated for a consistency.

A typical safety assessment for a fault in a power plant, a substation or another grounded object consists of soil resistivity measurement and interpretation, fault current distribution computations, and grounding system analysis. Typical results from the safety assessment includes GPR (Ground Potential Rise) and ground resistance, for example, of the substation grounding grid, touch and step voltages in the grounded object area, and body currents when a person is subjected to a touch or step voltage under fault conditions. From these results, conclusions can be reached regarding the safety in the substation area during a fault. It is known that grounding system performance and safety are closely related to soil characteristics.

If the soil was homogeneous and its resistivity unaffected by seasonal variations it would be expected that measured and computed ground resistance values would compare closely. Subject to the maintained integrity of the grounding system, its resistance value would not change. Unfortunately, in practice, the ground exhibits are far from uniform structure. Often, the structure will have horizontal layers related to the physical layers of topsoil, sub-soil, and country rock. There may also be vertical divisions. Accordingly, the assumption of a homogenous resistivity or uniform horizontally layered soil structure is rarely valid in practice. Clearly these layers or divisions in soil structure will have a considerable impact on both soil resistivity and ground resistance measurements of installed grounding systems [1-3].

One of the more practical geophysical techniques involves measuring the ground’s ability to conduct electrical current. Evidence concerning a subsurface soil type, its moisture content, or whether it is frozen or unfrozen can, in certain situations, be revealed from surface resistivity measurements [4]. The climatic effects on the electrical properties of soil are mainly restricted to the upper part of the soil.

II. ELECTRICAL PROPERTIES OF SOILS

The electrical resistivity of a substance, such as soil, is the measure of its ability to resist the flow of electrical current through it. Most soils and rocks are highly resistive (i.e., have low conductivities) and are classified as electrical insulators.

Soil solid components are generally electrical insulators, the conduction of electrical current only lies on two phenomenon occurring in water: volume conduction controlled by the electrolyte concentration in water and the geometrical characteristics of macro voids network; surface conduction controlled by the double diffuse layer that depends on the solid-liquid interactions, the specific surface of clay minerals and the geometry of particles contacts. For the water contained in macro voids the pre-eminent phenomenon seems to be volume conduction while for the water contained in micro voids, it seems to be surface conduction.

The conductivity of a soil is primarily determined by: the number, shape and size of the soil particles; moisture content; concentration of dissolved electrolytes; temperature and phase state of the moisture; and amount and composition of colloids present.

Minerals such as magnetite, graphite and various sulphides may occur naturally in sufficient quantities to increase the grounds overall conductivity. However, most current flow in "standard" soils is electrolytic in nature and takes place through and around the moisture-filled pores and minute cracks within the soil matrix [4].

The general classification of soils is by grain size. Sand is coarser than silts which are coarser than clays. Sands and silts are generally excellent insulators, as is completely dry clay [8]. However, the introduction of moisture to clay changes its electrical characteristics substantially. The fine-grained nature of clay results in an immense surface area per unit volume of material which, with the addition of water, permits considerable ion mobility.

As a general rule, resistivity increases with increasing soil particle size, decreasing colloidal fraction, and decreasing moisture content.

The resistivity of an electrolyte is inversely proportional to the number of ions available in solution and the mobility of these ions within the solution. In distilled water, there are few ions so its resistivity is correspondingly high [4].

The concentration of dissolved salts in ground moisture can strongly influence the bulk resistivity of a soil. For example, the contamination of an area by sea water can easily mask variations in geological subsurface features; this possibility should be considered in making resistivity surveys near coastal areas.

The resistivity of an electrolyte varies almost inversely with temperature over normally encountered ranges. Temperature variations with season and depth must be considered because of this effect.

As pore water freezes, its resistivity abruptly increases. The use of resistivity measurements for detecting ice masses or ice-rich soils relies upon this contrast.

III. EFFECTS OF CLIMATE

The electrical resistivity of a substance, such as soil, is the measure of its ability to resist the flow of electrical current through it. Most soils and rocks are highly resistive (i.e., have low conductivities) and are classified as electrical insulators.

Temperature affects both electronic and ionic conductivity. Apart from areas where the geotherm is significant, ground temperature is affected by air temperature and more significantly by insolation. Whilst topography will affect thermal coupling, being highest on windward slopes, it affects insolation even more. South facing slopes, especially with a dark and or rough texture and of sparse vegetative cover, will be subject to most solar heating. Depending upon the type of soil, temperature affects resistivity to a greater or lesser extent [5]. This will be evident on a seasonal timescale but short-term, short-range effects produced by shading might also be significant.

It is the moisture content of soils that will have the greatest effect on resistivity, especially in the case of porous and permeable soils and rocks. The electrical conductivity of pore water is also significant. Some of the conducting ions in the water are natural to the soil/rock (unless leached out), and some will depend on the conductivity of precipitation (all rainwater is naturally somewhat acid). However, the bulk water content in soil is probably dominates in affecting resistivity [6].

There are a number of factors that determine how much of the precipitation actually enters the soil. Of the rain that falls onto an area, some will pond, and some will run off into local surface drainage streams. Some water will temporarily enter the topsoil but will be rapidly lost to the atmosphere again due to transpiration and evaporation. Some will also rapidly drain down to natural or artificial drainage. It is only the remainder that will linger long enough to significantly affect the electrical resistivity of the soil [6].

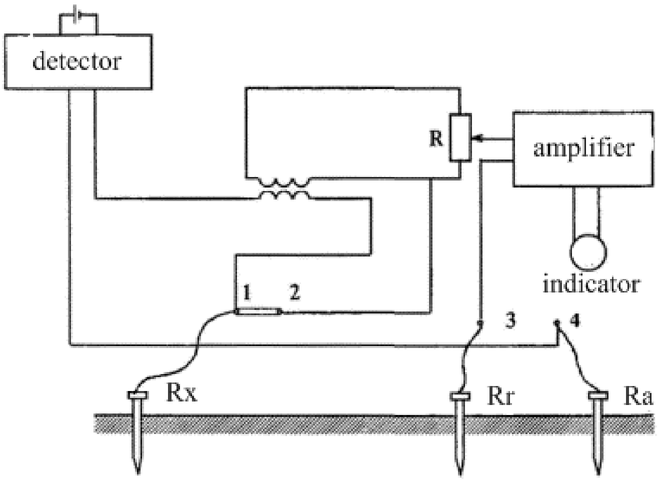

Fig. 1. Block diagram of Ground Resistivity Tester M416.

Naturally, recent weather conditions will also affect the 'Water Acceptance Potential' of a soil. If a soil is already saturated, any further rain will either pond or run off. If the soil has been baked during a long, hot period, it may take a long time for the pores to reopen and allow normal water acceptance processes to re-establish. Long term weather, i.e. climate, will also affect the level of the water table in many places. Most ground surfaces are uneven and will therefore wet unevenly. This will result in small-scale changes in resistivity which can affect both soil resistivity and ground resistance measurements [6].

If a soil has a good rainfall acceptance potential, an episode of rain will produce a "slug" of water which drains down and diffuses through the various layers of the soil. As this water soaks down through the ground layers, it will affect the resistivity of the different layers in a complex way. It complicates the apparent layering of the soil model which may be difficult to establish from surface measurements alone.

IV. MEASUREMENTS AND ANALYSIS

The measurements were conducted during selected period from 2010 March 1 to March 31 in Balozhi, Latvia with ground resistivity tester type M416.

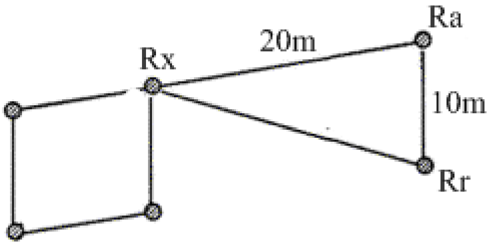

Fig. 2. The arrangement of the electrode under test (Rx), a reference probe (Rr), and an auxiliary probe (Ra).

The principle of ground resistivity tester type M416 is based on a compensatory method of measurement. Block diagram of the device shown on Fig. 1.

Alternating current from the transformer through the primary winding of the transformer, the current terminals 1 and 4, the device enters the external circuit. The secondary circuit of the device is connected to resistor R, whereby compensation is the voltage on the measured resistance. Under this scheme the inclusion on the measuring device (amplifier, detector and indicator) is applied voltage difference across the resistor R and the measured resistance [7].

The measurement technique uses the electrode under test (Rx), a reference probe (Rr), and an auxiliary probe (Ra). An arrangement of electrodes is shown in Fig. 2 [9].

Three points of contact are made with the soil. Ground resistivity tester acts as a current source, and the current probe establishes a circuit through the soil via the electrode under test. The potential probe then senses the voltage gradient established by the test current against the local soil resistance.

V. RESULTS AND DISCUSSION

In order to be sure that a good grounding system is in place, it is necessary to maintain a low resistance to remote ground of all the electrodes, and a low resistivity of the local soil.

TABLE I

RESULTS OF MEASUREMENTS DURING MARCH 2010 IN BALOZHI, LATVIA

Date [dd.mm.yyyy]	Temperature, (°C) [10]	Resistance, (Ω)	Humidity, (%) [10]	Pressure, (mm Hg) [10]
01.03.2010	+3.6	79	55	741
02.03.2010	-2.5	111	78	-
03.03.2010	-3.5	126	78	755
04.03.2010	-2.6	82	95	756
05.03.2010	-5.8	124	86	762
06.03.2010	-6.8	**142**	90	768
07.03.2010	-2.6	102	75	773
08.03.2010	-3.2	88	62	769
09.03.2010	-3.3	77	82	769
10.03.2010	+1	**74**	67	768
11.03.2010	-0.6	80	66	759
12.03.2010	-1.3	86	89	753
13.03.2010	-1.2	84	92	751
14.03.2010	-3.3	116	69	750
15.03.2010	-6.2	122	94	755
16.03.2010	-2.1	114	82	758
17.03.2010	-2.1	110	74	761
18.03.2010	+1.9	86	82	761
19.03.2010	+6	**74**	74	756
20.03.2010	+4.8	78	91	751
21.03.2010	+5.2	86	95	748
22.03.2010	+0.2	132	69	764
23.03.2010	+2.7	136	94	756
24.03.2010	+1	100	97	767
25.03.2010	+2.7	86	84	767
26.03.2010	+7.6	80	82	756
27.03.2010	+8.3	**74**	85	747
28.03.2010	+4.8	78	93	753
29.03.2010	+8.3	121	68	754
30.03.2010	+11.5	120	56	757
31.03.2010	+17.5	126	51	753

Of several parameters that control soil resistivity — e.g., porosity, permeability, and mineralization of soils, and fraction, ionic content, and temperature of pore fluids — only water content and temperature of soils may vary in measurable timescales (Fig. 3).

Results of measurements are summarized in Table 1.

Even a fact, that the precipitation in March was richest in the last 86 years in Latvia - the average rainfall of about 126%, or more than twice the usual norm of March [10] the measured grounding resistance was significant high.

The highest grounding resistance 142Ω measured on March 6, and the lowest 74Ω – on March 10, 19, 27 (Fig. 3).

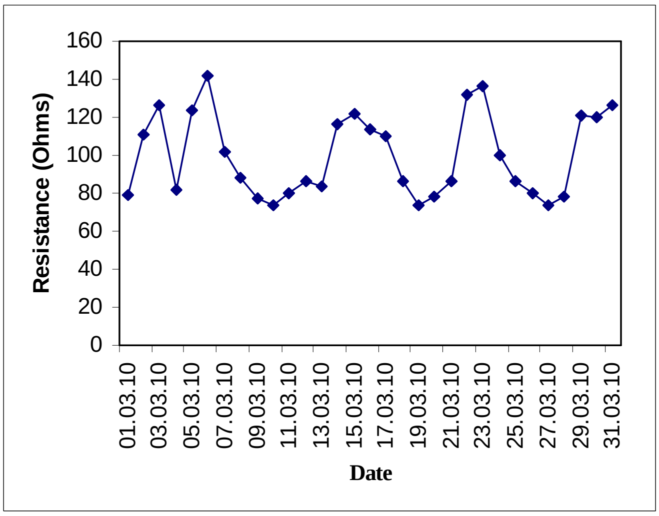

Fig. 3. Grounding resistance during selected period from 2010 March 1 to March 31.

Difficulties in establishing good electrical contact with highly resistive soils prevented the use of older techniques in some soil types. The expense involved in acquiring data often led to an insufficient number of measured values to establish a reasonable background against which anomalous readings could be delineated.

VI. CONCLUSIONS

This paper has shown that both spatial and temporal changes could occur during measurements on scales that may significantly affect results. Further, in order to be able to use retest results for the condition assessment of grounding system, repeatability needs to be good. This is somewhat doubtful and field experience bears this out.

Perhaps LVS standards for grounding systems and their testing need to be revised in order to take into account both weather and geology.

It has also shown that the performance of an existing grounding system may be adversely affected by climate, and that this is likely to be geology dependent. It may even be beneficial for site geology, etc, to be taken into account in any initial design.

ACKNOWLEDGMENT

This work has been supported by the European Social Fund within the project “Support for the implementation of doctoral studies at Riga Technical University”.

REFERENCES

[1] R. G. van Nostrand and K. L. Cook, “Interpretation of Resistivity Data”, Geological Survey Professional Paper 499, US Government printing office, 1966.

[2] G. F. Tagg, ‘‘Measurement of Earth-Electrode Resistance with Particular Reference to Earth-Electrode Systems Covering a Large Area’’, Proc. IEE, Vol.111, No.12, 1964.

[3] F. Dawalibi and D. Mukhedkar, ‘‘Ground Electrode Resistance Measurements in Non-Uniform Soils’’, IEEE Trans. PAS, Vol.93, No.1, 1974.

[4] R. Jurick, R. McHattie, “Mapping Soil Resistivity”, The Northern Engineer, Vol. 14, No 4.

[5] G. V. Keller and F. C. Frischknecht, ‘‘Electrical Methods in Geophysical Prospecting’’, Pergamon, 1966.

[6] J. A. Laver and H. Griffiths, “The variability of soils in earthing measurements and earthing system performance”, Rev. Energ. Ren.: Power Engineering, School of Electrical Engineering, Cardiff University, UK, 2001, pp. 57-61.

[7] Маньков В.Д., Заграничный С. Ф. «Защитное заземление и зануление электроустановок» Л.: ПИ, 2005.г.

[8] J. Wityn, „Die Sande and die Sandböden in Lettland”, Herausgegeben von dem Forst-Departement des Landwirtschaftsministeriums, Lettland, 1924.

[9] R. E. Sverko, “Ground measuring techniques: electrode resistance to remote earth and soil resistivity”, ERICO, Inc. Facility Electrical Protection, U.S.A, 1999.

[10] State Limited Liability Company "Latvian Environment, Geology and Meteorology Centre" data. [Online]. Available: http://www.meteo.lv/public/27557.html

Marina Kizhlo was born in 1984. She received her Bachelor’s degree and Master’s degree at Riga Technical University, Faculty of Power and Electrical Engineering with distinction and awards from the public limited company Latvenergo AS in 2006 and 2008, respectively. She is a PhD student at Riga Technical University, Institute of Power Engineering, Department of Electrical Machines and Apparatus since 2008 and licensed/registered professional electrical engineer since 2009. Her main activities include design of power supply and the main research interest is grounding of electrical installations.

Arvids Kanbergs was born in 1934. He is graduated University of Latvia Faculty of Mechanics in 1957, the Candidate of Technical Sciences in 1986, the Doctor of Science in Engineering 1992. Since 1990 has been associate professor at Riga Technical University, Institute of Power Engineering, Department of Electrical Machines and Apparatus. He has 50 years of teaching experience.
His area of interests is electrical machines and apparatus.

Mihails Kizhlo was born in 1984. He received his Bachelor’s degree and Master’s degree at Riga Technical University, Faculty of Power and Electrical Engineering in 2006 and 2008, respectively. He works as electrical engineer since 2002. His main activities include design and construction of power supply and the main research interest is grounding of electrical installations.