10.2478/v10144-009-0009-z

The Causes of the Parameters Changes of Soil Resistivity

Marina Kižlo[1], Arvīds Kanbergs[2]
[1] Riga Technical University (Riga, Latvia), [2] Riga Technical University (Riga, Latvia)
marina.kizlo@rtu.lv, arvids.kanbergs@rtu.lv

Abstract – **The grounding of electrical installations is primarily concerned with safety; in particular, the prevention of electrical shock risks of human life. As such, a grounding system must be designed, tested and maintained to satisfy this primary aim. This scientific paper presents a survey of soil resistivity and how its value varies from geological and meteorological factors. Soil resistivity is not only a useful measurable that reflects subsurface structure, but also a basic parameter to the design of effective grounding and lightening prevention / protection system. The most significant variations occur from such parameters of soil resistivity as moisture content, chemical composition, porosity, conductivity, temperature, vertical thickness and divisions, etc. Knowledge of soil resistivity at the intended site provides a valuable insight into how the desired ground resistance value can be achieved and maintained over the life of the installation with the minimum cost and effort.**

I. INTRODUCTION

The electrical characteristics of the ground have an effect on the resistance of the whole grounding system, and therefore to the electrical safety of the personnel, which operates and uses electrical devices [1].

Soil resistivity is a basic parameter necessary for the design of effective grounding and lightning prevention / protection systems. In addition, resistivity profiling can yield information on characteristics (including depth) of different layers in the subsurface. The resistivity of rocks or soils is in general a complicated function of their porosity, permeability, ionic content of pore fluids and mineralization. In most rock materials, the porosity and the ionic content of the pore fluid are more important in governing resistivity than the conductivity of the constituent mineral grains. In situations where the porous rocks lie well above the water table and the fraction of the pores filled with fluid is negligibly small, mineralization starts to contribute. Igneous rocks tend to have higher resistivity than sediments [2].

The most significant variations occur from such parameters of soil resistivity as moisture content, chemical composition, mineralization, porosity, permeability, ionic content of pore fluids, conductivity, temperature, vertical thickness, depth and divisions, etc.

The conductivity of surface layer substantially influences the value of the touch voltage and step voltage. The resistivity of the ground changes in the very wide range depending on the geological structure of the ground. By changing the spacing of the grounding electrodes, it is possible to develop a profile of soil resistivity at various depths, which can be used to identify the most appropriate ground electrode design. However, even on the area, selected for the construction of the grounding system, the ground vary most frequently in terms of significant heterogeneity in the vertical and horizontal sectional views; therefore soil resistivity, which satisfies the high accuracy of calculation, can be obtained only by direct measurements. In cases when the high accuracy of calculation is not required, it is possible to use tabular values of soil resistivity of the ground.

Typical results from the safety assessment includes GPR (Ground Potential Rise) and ground resistance of the substation grounding grid, touch and step voltages in the substation area, and body currents when a person is subjected to a touch or step voltage under fault conditions [3]. 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. A widespread conventional thinking is that the highest soil resistivity results in the worst condition concerning safety.

Two similar terms have distinct meanings and must not be confused or transposed: resistance and resistivity. The former, as it applies to grounding, indicates a relationship between a grounding electrode and its environment in the soil. Resistivity, on the other hand, is a natural property of soil itself, largely independent of human activity. It can be deliberately influenced such as by the introduction of chemicals, as will be discussed.

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

II. SOIL RESISTIVITY

The property of resistivity can be defined for any material. As applied to soil, resistivity is an indication of a given soil's ability to carry electric current. The flow of electricity in the soil is largely electrolytic, determined by the transport of ions dissolved in moisture (see Table I) [4].

Soil resistivity is the resistance measured between two opposing surfaces of a 1 cubic metre of homogeneous soil material, usually measured in the ohm metre (Ω·m). Soil resistivity has a direct effect on the resistance of the grounding system.

Pure water has an almost infinite resistivity and is, in fact, utilized as an insulator in specialized adaptations. This property of water frequently leads to confusion and frustration in practical grounding when wet soil turns out to provide a very poor ground in the face of optimistic expectations to the contrary.

TABLE I
EFFECT OF MOISTURE CONTENT ON SOIL RESISTIVITY

Moisture content by weight, %	Resistivity, Ω·m		
	Top soil	Sandy loam	Silica based sand
0	10000000	10000000	-
2.5	2500	1500	3000000
5	1650	430	50000
10	530	185	2100
15	210	105	630
20	120	63	290
30	100	42	-

This phenomenon occurs in soils having poor retentive capabilities because of molecular structure, so that saturation leaches away the necessary ions. Dissolved salts from a large number of familiar prevalent compounds like sodium chloride, copper sulfate, and sodium carbonate provide the necessary charge to carry current (see Table II) [4].

TABLE II
EFFECT OF SALT CONTENT ON SOIL RESISTIVITY

For sandy loam, 15.0% moisture	
Salt content	Resistivity, Ω·m
No salt added	107
1.0% salt added	4.6
20.0% salt added	1

Is soil, then, a "good" conductor, insulator, or what? To gain a more comprehensive understanding of this issue, it is helpful to make a comparison to other materials. A pure substance, for example copper, has a resistivity of a fixed value, and this value is commonly included in the description of the material. Indeed, the degree of deviation is an inverse indication of purity. By contrast, soil resistivity numbers vary with such enormity that resistivity measurements might appear to the neophyte to be useless [4].

Table III to Table V show how typical values alter with changes in soil, moisture and temperature [6].

The resistivity values for several types of soils and are shown in Table III. These changes are caused by the influence of admixtures and by different structure of the mineral grains, on which the measurements were conducted.

Microscopic cracks and oxidations of surface within the limits of individual grains produce significant changes in the values of the measured resistances. The values of the resistivity of the ground water are given in Table IV.

The resistivity of rocks depends also on temperature. For the water-containing rocks the temperature effect on the resistance of rocks is the same as the temperature effect on the electrical resistance of the located in the rocks water and the temperature range between the points of its freezing and boiling [6].

Table V demonstrates evidently a sharp increase of the resistivity of the rocks with the freezing of pore moisture. The resistivity of soil varies with changes in temperature and the rate of its increase as temperature declines. The moisture content of the soil in Table 5 is 15% of its total weight. The resistivity of the soil at -15°C is 45.9 times higher than the resistivity of the same soil at +20°C [6].

Soil resistivity is, in fact, influenced by many factors and it fluctuates constantly.

Because of this enormous range of values, local soils can vary equally widely in their ability to provide a ground. It is in the determination of where a given site falls on this spectrum that the measurement of soil resistivity finds its practical use.

TABLE III
EFFECT OF SOIL TYPES ON SOIL RESISTIVITY

Types of soil	Resistivity, Ω·m
Chalcopyrite, bornite, pyrite, galena, magnetite, etc.	0.000001 ~ 0.01
Schists, slates, shale, etc.	10 ~ 100
Paddy of clay and swamps	10 ~ 150
Farmland of clay	10 ~ 200
Peat, loam and mud	5 ~ 250
Clay and sand mixtures	4 ~ 300
Seaside sandy soil	50 ~ 100
Decomposed granites, gneisses, etc.	50 ~ 500
Zinc blendes, hematite	10 ~ 10000
Paddy or farmland with gravel stratum	100 ~ 1000
Mountains	200 ~ 2000
Granites, gneisses, basalts, etc.	1000
Pebble seashore, parched river bed, gravel	1000 ~ 5000
Rocky mountains	2000 ~ 5000
Moraine gravel	40 ~ 10000
Ridge gravel	3000 ~ 30000
Solid granite	10000 ~ 50000
Sandstone or rocky zone	100000 ~ 100000000

To measure it, the standard method that enjoys overwhelming acceptance is the Wenner method. This is named for Dr. Frank Wenner of the U.S. Bureau of Standards, now known as the National Institute of Standards and Technology (NIST), who developed it in 1915.

III. EFFECTS OF CLIMATE

Probably the most significant short-term changes to soil resistivity are caused by recent weather. It is established that up to saturation, increased water content of any soil or rock will increase its conductivity. Also, the conductivity of soils generally increases with temperature, except in the case of highly metalliferous rocks or soils.

The climatic effects on the electrical properties of soil are mainly restricted to the upper part of the soil.

TABLE IV
EFFECT OF MOISTURE CONTENT ON SOIL RESISTIVITY

Type of water	Resistivity, Ω·m
Pure water	200000
Distilled water	50000
Lake and brook water	100 ~ 400
Rain water	200
Tap water	70
Spring water	10 ~ 150
Well water	20 ~ 70
Mixture of river and sea water	2
Sea water (inshore)	0.3
Sea water (ocean 3%)	0.2 ~ 0.25
Sea water (ocean 5%)	0.15

TABLE V
EFFECT OF TEMPERATURE ON SOIL RESISTIVITY

Temperature, °C	Resistivity, Ω·m	Rate
20	72	1.0
10	99	1.4
0 (water)	130	1.8
0 (ice)	300	4.2
-5	790	11.0
-15	3300	45.9

IV. EFFECTS OF WATER CONTENT

It is the moisture content of soils that will have 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). There will be a contribution due to local effects such as agricultural chemicals, local industrial pollution and salt drift inland from coasts. Salt wind drift can have an effect in excess of 10 km inland, even more in the case of particularly exposed coasts. However, the bulk water content in soil is probably dominates in affecting resistivity. Most rainfall wets soil from the top down.

However, there are some soils that "reverse wet". A particular example of this is clay. This soil often develops permanent fissures to a depth of several meters. Surface water can drain into these fissures, hardly wetting the surface layer. At depth, the rainwater diffuses sideways and upwards eventually affecting the water content of the uppermost layer. Reverse wetting is a somewhat similar process to the rise in a perched water table.

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.

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 earth resistance measurements.

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 earth 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.

In addition to natural changes in moisture and water table, the effects of human activities can also be significant. Examples of this which affect the water table level are: adjacent commercial gravel abstraction, which involves significant water pumping and lowers the local water table; water abstraction from perched aquifer by a distant pumping station.

V. EFFECTS OF TEMPERATURE

Temperature affects both electronic and ionic conductivity. Apart from areas where the geothermal energy is significant, ground temperature is affected by air temperature and more significantly by insolation. Whilst topography will affect thermal coupling, being highest on wind ward 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 interesting to note that freezing inhibits ionic migration; therefore frozen ground will measure with an anomalously high resistivity. Measurements under these conditions are best avoided.

VI. EFFECTS OF GEOLOGY

There is acknowledgement of the non-homogeneous nature of soils and a number of methods are available to produce multi-layer soil models from an analysis of a set of Wenner soundings. However, when resistivity data is interpreted, it may not yield a unique solution [7] to the dimensions and resistivities of the various layers.

Unfortunately, a model based on horizontal layering, which assumes correspondence with actual horizontal strata will often be erroneous. In practice, many sites will also experience lateral inconsistencies. These may include vertical discontinuities (faults or dykes), vertical divisions (fault-bounded blocks) as well as dipping strata. If the measurement transect crosses a fault, resistivities may be different on each side. Or, a fault may introduce a band of high resistivity as would be the case for an intruded dyke. Lateral variations may also include local anomalies on a small enough scale to affect individual electrodes.

It is important to recognize that anisotropic properties of soils may also have a significant effect in respect of electrical resistivity. Such effects can exist on both a small-scale (e.g. with clays) and on a large-scale with formations (e.g. with bedding within one rock unit) [7]. Small-scale effects may affect individual electrodes differently, while large-scale effects may affect the overall measurement depending upon the relative alignment of the transaction to the formation.

VII. CONCLUSIONS

In this brief review, it has been demonstrated that the effects of geological and seasonal variations in soils have a considerable impact on the electrical characteristics and therefore can affect grounding system performance. It has also been demonstrated that a multi-disciplinary approach to grounding should benefit the subject.

Certainly here are aspects of geophysics and geology that would usefully complement the traditional purely electrical engineering approach. What is somewhat disappointing is that effects of weather and geology have for so long been ignored. Perhaps it can be shown that under all combinations of such conditions the effects on measurements and performance are negligible. If this is indeed the case, well and good, it will maintain the resent simplicity of approach.

However, in order to be able to confidently disregard such effects, their magnitudes must first be properly quantified and so far this does not appear to have been adequately done.

REFERENCES

[1] Marina Kizhlo Arvids Kanbergs. The research of causes and consequences of parameters changes of grounding electrical installations // Proceedings of the 4th International Conference on Electrical and Control Technologies ECT-2009, May 7-8, 2009, Kaunas, Lithuania. Kaunas: Technologija, 2009, pp. 261-265.

[2] Telford, W. M., Geldart, L. P., & Sheriff, R. E. "Applied geophysics" 2nd ed. Cambridge: Cambridge University Press, 1990.

[3] J. Ma, F. P. Dawalibi, R. D. Southey, "On the equivalence of uniform and two-layer soils to multilayer soils in the analysis of grounding systems," IEEE Proceedings - Generation, Transmission and Distribution, Vol. 143, No. 1, January 1996, pp. 49-55.

[4] Wenner, F., "A Method of Measuring Earth Resistivity," Report No. 258, Bulletin of Bureau of Standards, Vol. 12, No. 3, October 11, 1915.

[5] Laver, J. A., Griffiths, H. "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.

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

[7] Dawalibi, F., Mukhedkar,D., "Ground electrode resistance measurements in non-uniform soils'', IEEE Trans. PAS, Vol.93, No.1, 1974.