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The influence of seasonal soil moisture on the behavior of soil resistivity and power distribution grounding systems

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ABSTRACT

This paper discusses the influence of the moisture content on the seasonal behavior of both soil resistivity and ground resistance typical of power distribution grounding systems. Although field surveys indicate a wide variation in the moisture content only for the topmost soil layer, laboratory tests show that the resistivities of several types of soil are greatly affected. As a consequence, the ground resistance of systems with small dimensions may vary significantly and compromise the lightning performance of protection systems. The strong correlation, identified from measurements in this work, between soil moisture and, thus, soil resistivity, and monthly rainfall allows extrapolating resistivity measurements for the most critical conditions providing data that can be used to improve the design and performance of grounding systems.

1. Introduction

In a typical electric power system, the number of distribution lines surpasses dozens of times (or even a hundred) the number of transmission lines. Thus, differently from transmission line projects, which are developed on a case by case basis, the design of distribution lines uses pre-established standards. In this sense, utilities have standards for materials, equipment, structures, etc. which were designed to be applied to typical distribution systems. Distribution grounding systems are characterized by small dimensions due both to the lack of space for installation and high cost resulting from the large number of grounding structures. In order not to impair the performance of the overcurrent protection system, high values of ground resistances observed in critical, high resistivity soil conditions, are compensated through an increase in the number of grounding points [1]. However, this approach is not enough to prevent flashovers caused by lightning overvoltages. Due to the inherent high frequency content of the lightning surges, the performance of distribution systems is strongly affected by the ground resistance locally [1–5], and, in this case, high values cannot be compensated by increasing the number of grounding points.

Thus, to achieve a proper protection, it is essential to implement technical procedures to ensure not only that the ground resistance values measured during the implementation of the grounding system are within the limits set by the standards, but also that they will remain within these limits in all seasons of the year. In this regard, the Brazilian standard ABNT NBR 7117 [6] instructs that soil resistivity measurements are made in a dry period after at least 7 days without rain. However, in some regions professionals may have to wait months to get this condition, which hinders the applicability of the recommendation. IEEE Std. 81 [7] points out the significant influence of moisture content, temperature, and soil compaction on the resistivity, but it does not suggest measurement procedures to minimize the problem. In the case of substations, IEEE Std. 80 [8] recommends performing periodic measurements for the verification of maximum values of the ground resistance. In distribution systems this procedure is not economically feasible considering the thousands of existing grounding points.

Aiming at finding solutions to this problem, this paper presents the results of an investigation on the influence of seasonal moisture on soil resistivity and its effect on distribution grounding systems.

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From these measurements, an extrapolation procedure is proposed to determine the critical values for resistivity and ground resistance of small grounding structures. The results were obtained from the study of the most representative soils of the southern region of Brazil. Section 2 presents the methodology and results, which are analyzed in Section 3. The conclusions are stated in Section 4.

2. Methodology and results

The methodology consisted of an investigation regarding (i) the main soil characteristics that affect the values of resistivity; (ii) the study of the behavior of the main types of soils in different moisture conditions and (iii) the study of the resistivity/depth behavior as a function of rainfall on soils with different characteristics. From the obtained results, the seasonal behavior of the resistances of typical grounding topologies used in distribution systems was also analyzed.

2.1. Definition and characteristics of soil

There is no single and accurate definition for soil. Depending on the field of science, soil can be defined in different ways [9,10]. In civil engineering, soil could be defined as a granular material formed by decomposed rock, water, air, and organic matter, which can be excavated manually. Rock is an aggregate of minerals which, according to [10] can be defined as a material which cannot be manually excavated, requiring explosive to disassemble. Thus, the earth's crust is composed of various types of elements that interlock and form minerals which can be aggregated as rocks or soil. In this paper we have followed the definitions traditionally used in pedology [9], according to which the classes of soil depths are qualified as shallow (less than 0.5 m), little deep (between 0.5 m and 1 m), deep (between 1 m and 2 m), and very deep (more than 2 m).

Due to the strong bonds between minerals, rocks are compact, whereas soils, being decomposition products, show higher porosity [10]. In geology, porosity is a physical property of a soil associated with the volume of void, or open space, in a soil sample. The spaces between soil grains, namely, the pores, can be filled with water, when the soil is saturated, with air, when the soil is completely dry, or both, which is the most common form found in nature [11].

The soil resistivity is the most important parameter for purposes of electrical grounding. It varies not only with the soil chemical composition, but also with its moisture content and temperature. As pointed out by Kizhlo and Kanbergs [12], freezing inhibits the ionic migration and may cause a substantial increase in the soil resistivity. For positive temperatures the influence is less pronounced, but a resistivity obtained in the temperature range of 5–45 °C can be referred to that corresponding to 25 °C by using, e.g., the equation proposed by Ma et al. [13]. In order to evaluate the soil resistivity as a function of humidity, both laboratory and field measurements were performed. In the former case the ambient temperature varied between 23 °C and 26 °C, while in the latter the range was from 13 °C to 29 °C. No significant correlation was observed between temperature and resistivity. While the determination coefficients between moisture and resistivity were around 0.80 (for the layers below 1 m), those between resistivity and temperature were always below 0.30. Actually the application of the correction factor for temperature proposed in [13] leads to a decrease in the determination coefficient. In this paper, possible variations of resistivity with temperature were assumed to be incorporated in the errors inherent to the measuring process and, therefore, no correction factor was applied to the measured values.

As for the humidity, the resistivity varies significantly between the extremes dry and saturated soil conditions, since the soil electrical conduction is electrolytic [8]. In turn, the amount of moisture in the soil depends on the soil porosity and environmental conditions.

Table 1
Major soil types in southern Brazil.

Item	Description	Acronym
1	Dystric Cambissol	CMdy
2	Rhodic Ferralsol	FRro
3	Humic Ferralsol	FRhu
4	Dystric Leptosol	LPdy
5	Humic and Xanthic Ferralsol	FRhu-xa
6	Humic and Ferralic Cambisol	CMhu-fl
7	Eutric Cambissol	CMeu
8	Eutric Leptosol	LPeu
9	Haplic Alisol	ALha
10	Rhodic Nitisol	NTro
11	Dystric Gleysol	GLdy
12	Haplic Acrisol	ACha

2.2. Soil resistivity behavior as a function of moisture content

This section presents the results of laboratory tests on soil samples to determine the behavior of the resistivity as a function of moisture conditions. Two geographical regions were studied. The first, with 96,000 km^2, covering the state of Santa Catarina and the second, with 91,000 km^2, covering the northwest of Rio Grande do Sul state, both located in the southern region of Brazil. The test set comprised 12 different samples, which are representative of the most common soil types of these two regions [1,14].

Table 1 lists the tested soils, classified according to the World Reference Base for Soil Resources (WRB) [15]. The Recognition Soil Map of the State of Santa Catarina [16] and the Exploratory Soil Map of the State of Rio Grande do Sul [17] were used to find the spots for soil collection. At least two samples of each type of soil were collected at different locations distant from each other and at a depth of 0.6 m. The humidity and resistivity characteristic curves were obtained according to the methodology presented in [14,18]. The maximum operating frequency of the test equipment was 1 kHz.

The test results concerning the characteristic curves are shown in Fig. 1. The curves present the mean values of at least two soil samples and clearly show the strong influence of moisture on the soil resistivity.

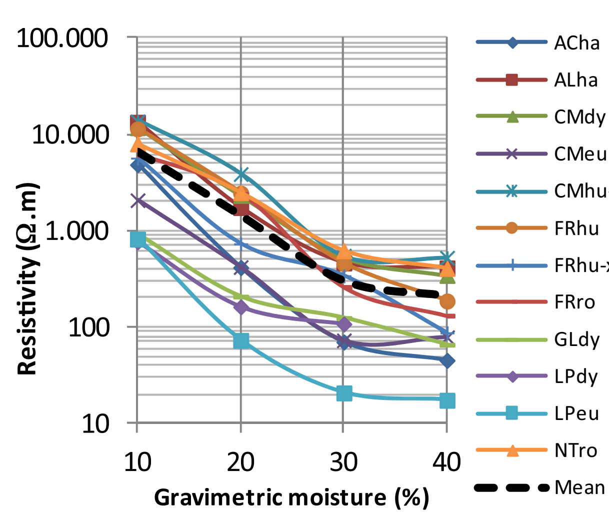

Fig. 1. Resistivity vs. gravimetric moisture behavior of the soil samples.