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Experimental investigation on breakdown characteristics of sand, bentonite and their mixes

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ABSTRACT

Experimental work conducted on the impact of soil and bentonite on transient performance of grounding systems has been reported. Three soil samples were tested after classifying them under their texture and grain size. Resistivity and permittivity were found to decrease with frequency, in all samples. The resistivity of sand-bentonite mixed at 1:1 ratio by volume, was decreased by 86% compared to that of sand whereas the breakdown voltage was decreased by 20.5% for positive and 30% for negative impulses, compared with the same parameters of sand. Air-voids may be playing an important role in the breakdown process.

1. Introduction

In electrical power systems, grounding network is used as a sink permitting fault and lightning currents to be dissipated securely and reliably into the mother earth [1]. Measurements of grounding impedance of electrode systems are usually performed at low frequencies as the systems are most often designed to handle currents at nominal power frequency (50/60 Hz) and also due to the practical constraints in measuring grounding impedance at high frequencies. Under power frequency conditions, grounding impedance is represented mainly by resistance of the electrode system, that of the masses of soil and the contact resistance between the electrode and the soil [2]. For fast transients, namely those associated with lightning, the electrical and magnetic properties of the soil are described by three parameters: Electrical conductivity or resistivity, dielectric permittivity and magnetic permeability. In most cases, the magnetic permeability of soil has a value similar to the permeability of air, thus it remains rather constant with frequency. However, based on experimental results, it has been known for a long time that the soil resistivity and permittivity are strongly dependent on field frequency [3]. Soil has quite a complex composition and a large number of variables influence its behaviour under electromagnetic fields. These variable parameters are grain size, particle shape, lattice arrangement, moisture, salt content, and temperature [4,5].

A direct correlation exists between the arc impedance and the soil grain size. Typically, the arc impedance in small soil particles is higher than that in those with large soil particles [6]. On the other hand, for the soil, when an impulse voltage is applied, the soil gap will be penetrated after a certain time delay depending to soil type and density [7]. In addition, these electrical parameters are also influenced by the frequency of the injected current. The higher the frequency, the lower the conductivity and permittivity of soil [8]. The Soil breakdown around the conductor will occur when the electric-field strength surrounding the grounding conductor exceeds its critical electrical field value (E_c). There is a wide range of E_c values and Oettle [9] proposed an E_c value of 1000 kV/m. Mousa's estimation of the critical soil ionization gradient is equal to 300 kV/m and which is proposed to be used for the critical electric field of typical soil [10]. CIGRE utilizes the value of 400 kV/m without any explanation [11]. An IEEE working group specified a value but only indicates the 1000 kV/m value proposed in Ref. [12]. In order to improve the design of grounding systems and to obtain more accurate results when taking impulse behaviour into account, the decrease in the grounding resistance, which results from soil ionization processes under high-voltage conditions, has to be taken into account [13]. Thus, the critical electric field of soil plays quite a vital role in the studies of impulse behaviour of grounding systems.

Now, in many countries, it is common to use many natural and man-made substances as a ground enhancement material (GEM) for grounding systems which should be compatible with IEC 62561–7:2001 [14]. Among these GEMs bentonite plays an important role as it

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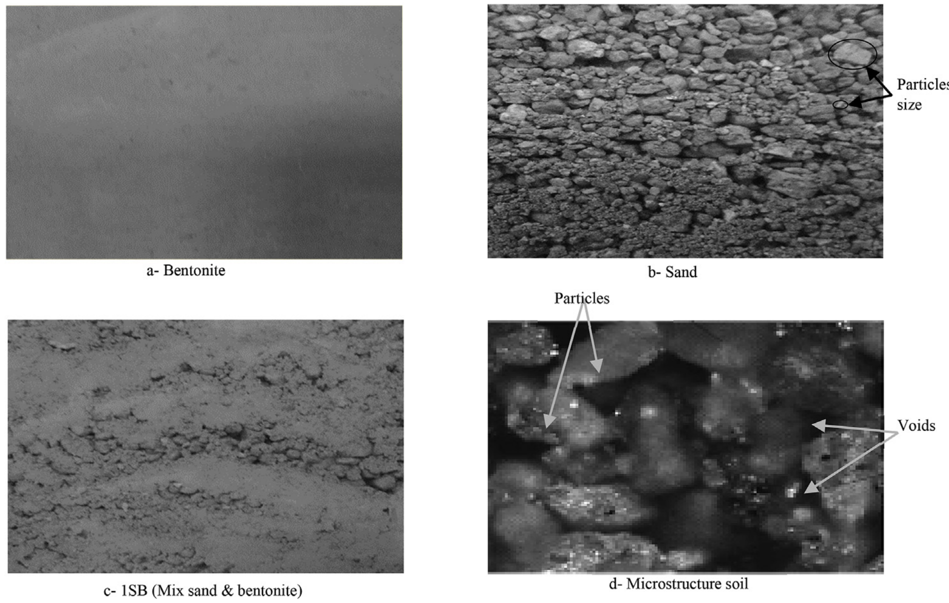

Fig. 1. Samples under test, a- Bentonite, b- Sand (Sandy loam), c-1SB Mix bentonite with sand (ratio = 1:1), d-Photo showing the microstructure of soil adopted from Ref. [24].

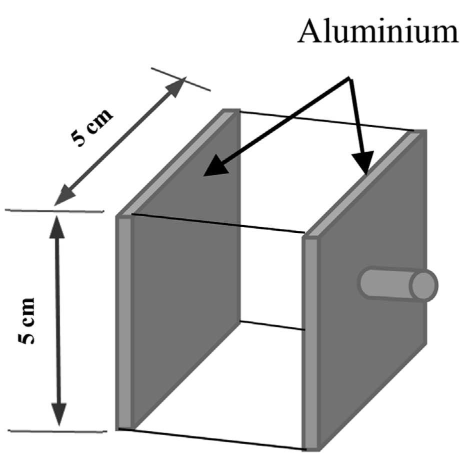

Fig. 2. Cubical box.

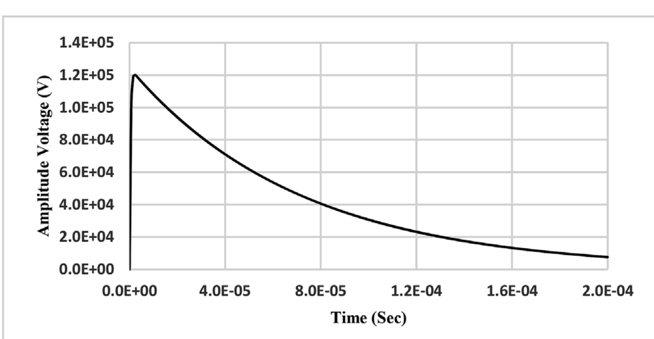

Fig. 3. Lightning voltage impulse (1.2/50 µs) applied to the sample.

provides significant reduction in ground resistance of electrodes and also due to its abundance and availability at a low cost [15,16],. Bentonite is a high water absorbent aluminium phyllosilicate clay composed mainly of montmorillonite ($(Na,Ca)(Al,Mg)_6(Si_4O_{10})_3(OH)_6$-$nH_2O$). Bentonite possesses positive properties that qualify it as a practical GEM: such as low and stable resistivity, low cost, high water absorptivity, slow releasing of retained water into the surrounding, chemically neutral behaviour in soil, etc [17].

Electrical grounding systems under transient conditions have been widely studied [18,19], however, despite GEM have been successfully used to reduce ground resistance for a long time, very few studies have been conducted so far to investigate their behaviour under transient voltage/current conditions [20]. This is a major obstacle in recommending such materials for grounding systems that are designed for lightning protection systems. The objective of this work is to study the variation of electrical parameters of soil-bentonite mixes (including individual materials) under a range of frequencies and also to find their breakdown characteristics under lightning voltage impulses (1.2/50 µs).

The outcomes will not only provide useful information to determine whether the GEMs are capable of dissipating charge brought by lightning currents but also regarding their applicability in preventing arcs between high potential points in the ground (under transient conditions) and nearby underground conducting systems such as oil pipelines.

2. Methodology

This experiment is conducted in three parts.

2.1. Material texture

In the first part, the selected materials and their mixes were checked for the grain structure, which generally consists of solid particles and air voids between them. Soil texture is defined as the relative proportion of sand, silt and clay. The United State Department of Agricultural (USDA) classification of soil texture is based on the proportion of sand 2.0–0.05 mm, 0.05–0.002 mm and clay < 0.002 mm particles [21]. The sieve analysis was performed on the three soil samples to evaluate the particle size distribution in the soil. The physical composition of the soil has significant effect on the discharge characteristics under lightning impulse voltages [22,23],thus, experiments were conducted to find the texture of the materials tested. Fig. 1 to illustrate the samples that have been tested.