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Electrical properties of dry soil under high impulse currents

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Abstract

To date, no publication has been made on dry soil characteristics under high impulse current conditions. This is because, no conduction current was detected in the dry soil, which may be due to high bulk resistance in the dry soil, limitations in the impulse generator and in the transducers adopted during the tests. In this study, however, for the first time, conduction current in dry soil was observed, despite the high resistivity of the dry soil and the large equivalent resistance of the test cell. It would be expected that the ionization process occurred mainly in the dry soil, since there is no water path in dry soil, and the voids are filled mainly with air. The goal of this paper is to contribute a better understanding of the ionization and thermal phenomena that occur in dry soil.

Keywords: Dry soil; Ionization process; Impulse conditions; Earthing systems

1. Introduction

Overvoltage protective devices such as surge arresters and protective gaps are used to divert high lightning surges from line to earth through an earth electrode. An effective design of earthing systems is therefore important to dissipate fault current to earth effectively regardless of the type of fault. However, the characteristics of earthing systems under high impulse conditions are not well understood. This paper is to contribute to a better understanding of the earthing systems under fast transients.

It has been well published in previous work [1–5] that under high impulse currents, a non-linear soil behavior is observed. This non-linear behavior is thought to be due to the effects of two conduction processes: (a) thermal and (b) soil ionization. In the thermal process, two types of conduction processes can occur, depending on the energy absorbed by the earthing system. The first thermal process is via low-energy absorption due to resistive heating, wherein the temperature of the soil increases. The latter will increase the soil conductivity and reduce its resistivity. This mechanism causes the resistance of the soil to decrease with increasing current. The second thermal process occurs because, with excessive energy and heating of the soil, water contained in the soil medium is vaporized, thereby leading to drying of soil. Hence a significant reduction in the conduction level of the medium occurs, thereby increasing the resistance of the soil as the current magnitude increases. The process of ionization, on the other hand, occurs via electric field enhancement in voids and interfacial surfaces within the soil medium, which leads to localized arcing, consequently, reducing the soil resistance. This process is highly dependent on the dielectric constant of soil as well as on the applied voltage. In order to obtain a more accurate discrimination of the heating and ionization effects, it is important to estimate the energy absorbed by wet soil for a given voltage and water content, and to then correlate with changes in characteristics under high impulse current magnitudes. However, due to a nature of the water settling process, it is difficult to estimate the energy absorbed by wet soil for a given voltage and water content. This paper is therefore aimed at observing the characteristics of dry soil under high impulse conditions, which is presumed to be mainly caused by the process of ionization. By understanding the latter process, it may be possible to differentiate the

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thermal and ionization processes, when the impulse tests are conducted on wet soils. This paper also contributes to the study of the characteristics of poor earthing systems under high impulse conditions, due to high soil resistivity in dry soil. Because there is no water path in dry soil, the gaps between the soil particles are filled with air voids. The latter may cause the ionization process to occur mainly in dry soil. As is generally known, air is affected by the polarity of an applied impulse voltage. In order to show that the ionization process is the main phenomenon that occurs in dry soil, the effects of impulse polarity on dry soil are considered and investigated in this study. Our observations reinforce the following assumptions for dry sand:

(a) For the same voltage level, positive impulse currents are higher than negative impulse currents.
(b) The impulse resistance for positive polarity is lower than that for negative polarity.
(c) The time to breakdown, t_D depends on voltage magnitude.
(d) Values of t_D for positive impulse polarity are shorter than those for negative impulse polarity. Also, $t_D$values for impulses of both polarities are found to be statistical in nature, as is the case for air breakdown.
(e) The breakdown voltage of test samples is higher for negative impulses than for positive impulses.
(f) Because the ionization process is highly dependent on dry sand characteristics and applied voltage, ionization characteristics are expected to be repeatable, as observed in this study.

However, thermal process may also have little effect on the conduction current in dry soil, such that, when electrons collide with air molecules in air voids, air ions are produced. These ions may move around in the test sample, for example; on the surface of cylindrical container and rod electrode of the test cell (as described in Section 3). The energy due to ion transfer at these metallic surfaces may increase the temperature of the soil, thus producing more current. Thermal effects, however, are mainly noted after the breakdown of the test cell (see Section 3). In this work, the results have shown that the characteristics of dry sand under high impulse conditions are similar to those of air, thus suggesting that ionization processes are the main conduction mechanism in dry soil.

2. Test setup

Fig. 1 shows the test arrangement used for the impulse tests. A commercial Marx generator capable of producing voltage levels from 10 to 120 kV and of producing a standard lightning response of 1.2/50 μs was adopted, as given in IEC-60 standard [6]. An insulating SF6 gas controlled the triggering voltage of the test circuit. The maximum current magnitude allowed for this generator is 20 kA. The voltage measurement was achieved using the Haefely divider with a ratio of 10,000:1 and a response time of 40 ns. The current measurement was achieved using two commercially available current transformers of sensitivity 0.01 and 1 V/A and both with a response time of 20 ns. Both transducers were found to be reliable for voltage and current measurements. The voltage and current signals were captured on a LecCroy WaveRunner500 MHz Digital Storage Oscilloscope (DSO), which has built-in facilities for data acquisition and analysis. The test cell adopted in this study, shown in Fig. 2, consisted of a cylindrical container of 30 cm diameter, with an inner rod of 1.2 cm diameter, and an effective length of 15 cm. Impulse tests of both polarities were conducted for different voltage magnitudes from 10 to 120 kV on dry sand in order to observe the effects of ionization processes in the soil. In this

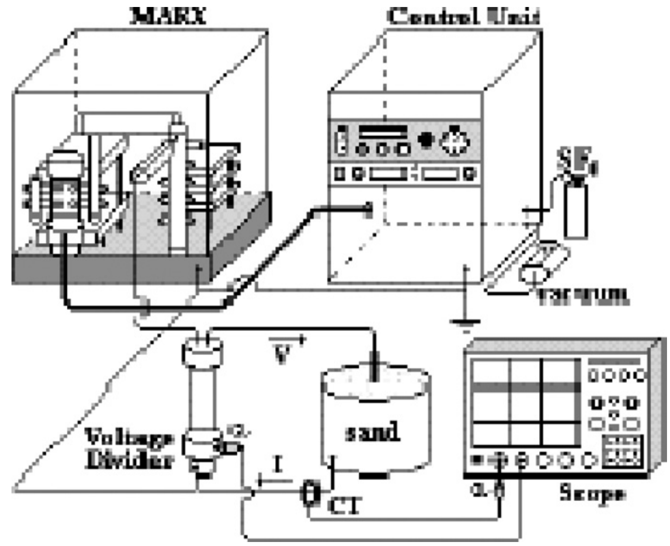

Fig. 1. Impulse test circuit.

Fig. 2. Cylindrical test cell used to simulate earthing systems.