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# Performance of Ground Enhancing Compounds During the Year

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***Abstract*— Grounding resistance could be reduced significantly with the usage of ground enhancing compounds in lightning protection systems. This paper presents the results of a series of field measurements on commercially-available ground enhancing compounds. It is the aim of this study to assess the behavior of ground enhancing compounds, which are widely used in grounding systems, in order to decrease the grounding resistance value. It is well known that most of the rise of potential of the grounding rod is determined by the soil resistivity surrounding the grounding rod and the magnitude of the applied current. As a result, the lowest feasible grounding resistance value is desirable, in order to provide the lowest impede path for fault currents to be dispersed into the earth, in the shortest time possible. For this purpose, five grounding rods were driven, each one of them, in different ground enhancing compounds. The measurement results are presented in relation to time and to rainfall. Furthermore, several thoughts, comments and proposals are presented about: a) the use feasibility of ground enhancing compounds, b) the choice of the suitable compound, in relation with the cost and the achieved grounding resistance value, c) the time and weather conditions influence on ground enhancing compound behavior.**

***Keywords-grounding system, soil resistivity, grounding resistance, ground enhancing compounds.***

## I. Introduction

Grounding plays an important role in transmission and distribution network for the safety operation of any electrical installation. A grounding system in order to be effective, its grounding resistance must be maintained in low levels during the whole year [1-2]. This is not possible all the time, as long as several times there is a lack of space for the installation of grounding system, or in case there is sufficient space for the construction, the cost maybe prohibitive.

Furthermore, besides the grounding system array, the soil type plays a major role in determining the grounding resistance value, in which the system is about to be installed, due to its high possible soil resistivity, or its particularly corrosive environment. The variable weather conditions on grounding system site also compose a complex factor, because of the alteration in the soil resistivity value they may cause during the year [3-4].

For this reason, several techniques are developed for reducing the grounding resistance value and preserving it in low levels [5-13]. Due to the fact that the expansion of an existing grounding system, with the installation of additional electrodes, either is much expensive or in many cases is impossible, an alternative with soil enriching is widely used by installing ground enhancing compounds around the grounding electrodes.

## II. Ground Enhancing Compounds

The usage of ground enhancing compounds is usually recommended, especially in rocky soil, which is a usual attribute on many sites in Greece, due to the large number of rocky mountains. These materials are laid inside the trench, where the grounding electrode is installed and mixed with the natural soil. In this way, a soil resistivity decrease is achieved, nearby the electrode, which results in a corresponding decrease of grounding resistance value.

Several studies have been carried out on natural and chemical ground enhancing compounds in the last decades. In the beginning, research addressed to bentonite and his properties. Kutter and Lange [5] and Mc Gowan [6] studied the bentonite properties, by comparing the soil resistivity achieved using bentonite as ground enhancing compound, to the initial soil resistivity of natural soil, under towers of transmission lines. In early '80s, Warren R. Jones [7] suggested an installation method using bentonite rods. In his experiment, bentonite rods were field tested against driven rods, at three sites with different soil texture. The results revealed a significant decrease on grounding resistance, up to 36% and the result was consistent during the year. In 1999, Kostic et al. [8] experimented on bentonite suspension, bentonite powder and waste drilling mud by using them as enhancing compounds for the improvement of the electrical properties of grounding loops. The measurements were performed at two sites and the results showed a restrain in the variations of the grounding resistance of the loops covered with these compounds. Moreover, the outcome was quite encouraging for the bentonite powder, as it could equally treated, as enhancing compound, to bentonite suspension. Yet, due to the high cost of this material in many countries, other materials were studied as close substitutes to bentonite, in order to be used as ground enhancing compounds, with a lower cost and an equal or even greater performance.

In 2008 N. Kumarasinghe [9], and in 2009 G. Eduful and J. E. Cole [10] introduced natural materials such as coconut coir peat, paddy dust and Palm Kernel Oil Cake as backfill materials and the results were compared with one using bentonite. Experimental results showed that these compounds presented remarkable capability of retaining the soil moisture and reducing grounding resistance substantially, without being lost by rainfall. Two years later, in 2010, J. Jasni et al. [11] experimented on bentonite, coconut coir peat, planting-clay soil and paddy dust. In this project, planting-clay soil has been identified as the most effective enhancing compound, compared to the others, as it gives the lowest grounding resistance during the project period and, generally, the highest percentage reduction of it.

In the same year (2010), A. D. Galván et al. [12] and W. F. Wan Ahmad et al. [13] presented the experimental results, from experiments they carried out in México and Malaysia respectively, on chemical-powder compounds. These compounds added in the vicinity of grounding rods, also demonstrated a significant decrease on grounding resistance. However, the usage of some chemical-powder materials (e.g. $Na_2S_2O_3$, $NH_4Cl$ etc.) is totally restricted in E.U., because of the serious environmental damage they cause in soil and plants, so this paper deals with bentonite basis chemical compounds.

## III. Experimental Procedure

### A. Installation and Experimental Array

In this work, several ground enhancing compounds were evaluated in field conditions. Five main grounding rods, *St/e-Cu* type A, dimensioned 17x1500mm, with a minimum copper thickness 254μm, have been driven, each one of them in different ground enhancing compounds, as shown in Fig. 1. Apart from the five main rods, another one has been driven directly to natural soil as a reference electrode. The installation procedure is presented in Fig. 2 and Fig. 3. The distance between two successive rods is 10m, as shown in Fig. 4, and they were tagged as follows:

- $G_1$: natural soil
- $G_2$: conductive concrete
- $G_3$: bentonite
- $G_4$: chemical compound A
- $G_5$: chemical compound B
- $G_6$: chemical compound C

Additionally, seventeen auxiliary electrodes, of the same type with the main one, but 0.5m length, were installed permanently, at different spots, for soil resistivity and grounding resistance measurements (Fig. 4). $G_{i,d}$ auxiliary electrodes are used for the grounding resistance measurements, where subscript (i) indicates the main grounding rod to be measured, and subscript (d) the distance of the $G_{i,d}$ electrode from the corresponding rod $G_i$. In the same way, $A_d$ auxiliary electrodes are used for the soil resistivity measurements at several distances (Wenner method), where subscript (d) indicates the distance of the $A_d$ electrode from the grounding rod $G_1$.

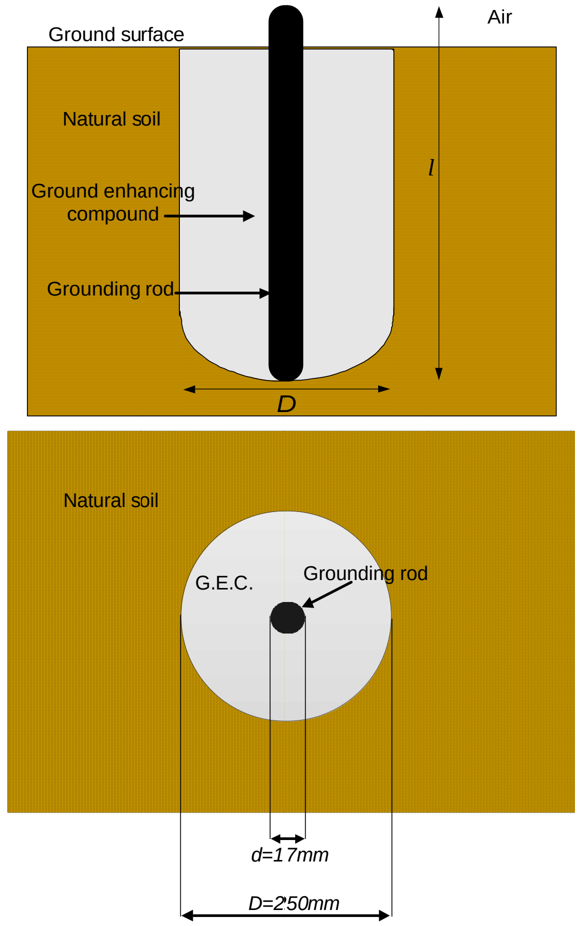


Figure 1. Grounding rod arrangement with ground enhancing compound.

Figure 2. Installation of grounding systems at NTUA Campus.

Figure 3. Installation of grounding rod with ground enhancing compound.

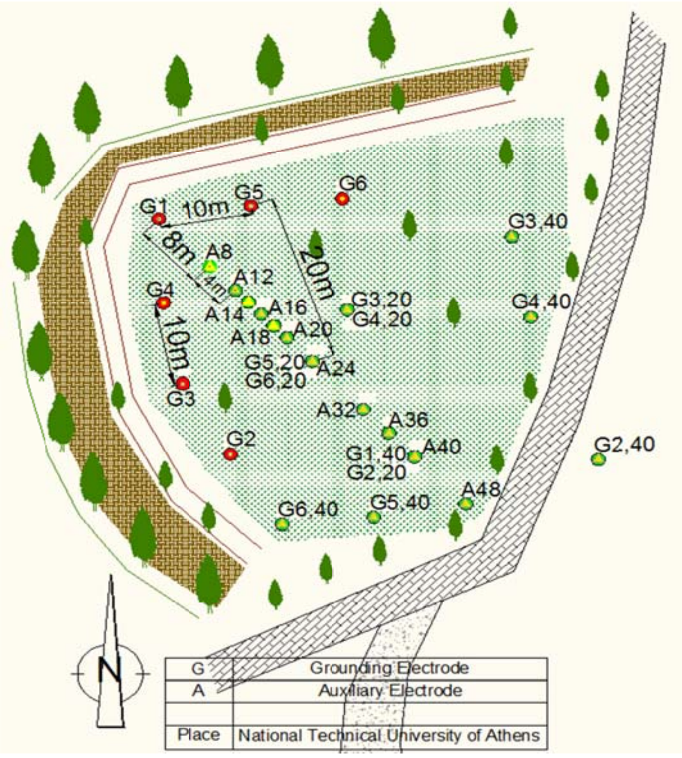


Figure 4. Experimental field and electrodes array.

The mean particle size fraction resulting from the texture analysis on samples at the experimental field [14] is presented on Table 1:

TABLE I. MEAN PARTICLE SIZE FRACTION

| Soil Type | Mean Particle Size Fraction % |
|---|---|
| Cobbles and gravel | 54.8 |
| Sand | 39.5 |
| Silt-Clay | 5.7 |

## *B. Results and Discussion*

All the measurements were performed according to [2], which provides complete description of the methods of measuring grounding resistance, instrumentation and safety precautions while making ground tests. The field measurements, which have been performed in daily basis for one year, are:

- soil resistivity.
- grounding resistance of grounding rods.
- rainfall, air temperature, air humidity and soil humidity.

Soil resistivity was measured by using the 4-electrode method (Wenner method), at different distances (α), of 2m, 4m, 8m, 12m and 16m. The device used to measure the soil resistivity and the grounding resistance, in this project, was a Megger DET2/2 auto earth tester, while the rainfall height data have been collected from the database of the meteorological station which is installed inside the Athens Technical University Campus. The rainfall measurement has been performed automatically every 10 minutes a day, within the whole year, by special sensors. The experimental results for soil resistivity and rainfall height measurements are presented in Fig. 5.

The 3-pole method, also known as the fall of potential method, was used to accurately measure the grounding resistance of each main rod, using two auxiliary electrodes driven into the soil at the distances of 20m and 40m from main rod, respectively. The experimental results are presented in Fig. 6 for natural soil and Fig. 7 for the rest of the enhancement compounds.

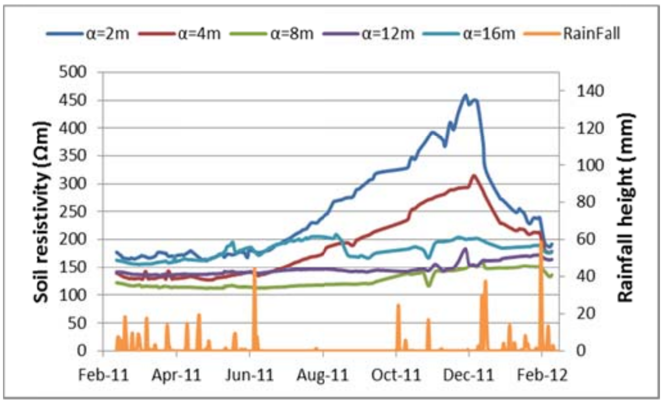


Figure 5. Soil resistivity versus time and rainfall.

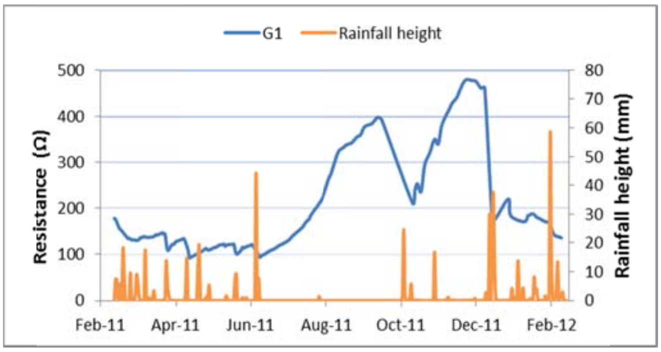


Figure 6. Grounding resistance versus time and raifall.

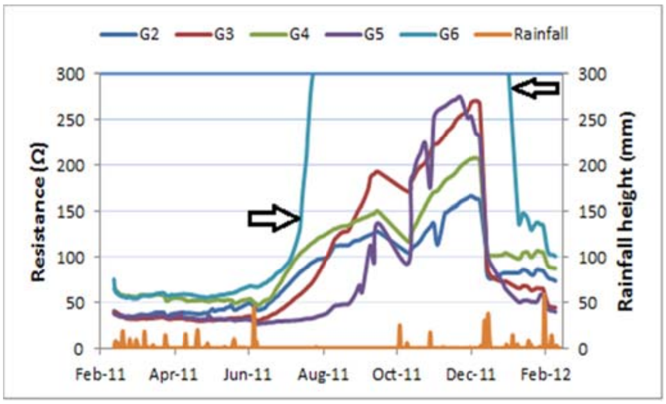


Figure 7. Grounding resistance of ground enhancement compounds versus time and rainfall.

Figs. 6 and 7 confirm that soil moisture, which is closely related to rainfall, plays a major role on the grounding resistance variation. In winter months, when rainfall height is considerable and soil is constantly wet, enhancement materials maintain grounding resistance in low values and, moreover, a remarkable stability is observed. In summer, when air temperature is constantly too high (over 35˚C) for a long period of time and drought is the main characteristic of this season in Greece, the grounding resistance of the systems, under test, rises considerably. Thus, the capability of the enhancing compounds to retain the soil moisture, particularly in summer months, is the main consideration to be taken into account when choosing different types of ground enhancing compounds.

Enhancing compounds performance can be defined as their capability of reducing the grounding resistance value. Hence, the relative efficiency factor may be formulated as:

$$n_i = \left(1 - \frac{R_i}{R_1}\right) \tag{1}$$

$R_i$: grounding resistance of grounding rods

$R_1$: grounding resistance of reference rod

Fig. 8 shows that, at the beginning of the experiment, all the enhancing compounds present a significantly high performance, which diminishes as time passes by. For this reason, compounds like bentonite, conductive concrete and chemical compound B, which demonstrate high performance at first, have the advantage against the other materials tested. At this point, it is important to mention that, the conductive concrete tested in this experiment is the same type as the concrete used on building foundations, in order to have a more practical evaluation of this material.

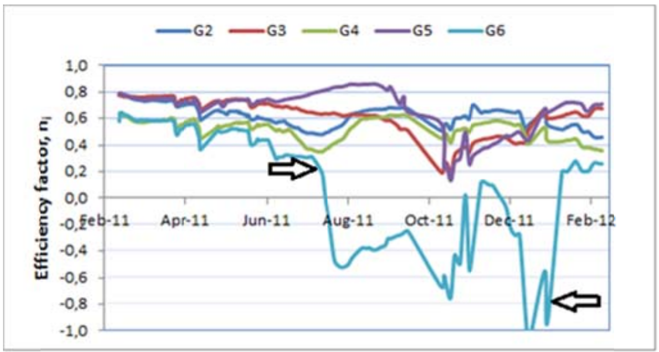


Figure 8. Efficiency Factor of ground enhancement compounds.

Figure 9. Compound shrink.

Figure 10. Compound loss.

Besides rainfall and soil humidity, the performance decrease is probably associated with the compound absorbance by the soil, which is great or small, dependent on compound type. For example, it is noticed that, from July and beyond, compound C presented a remarkable decrease of its performance and the corresponding efficiency factor received negative values, an indication that the grounding resistance of the rod ($G_6$), surrounded by this material, increased tremendously over the corresponding values of natural soil ($G_1$). This negative efficiency factor is attributed to material shrink and finally its loss, probably due to the lack of moisture, which resulted in the formation of large air gaps between the electrode and the surrounding ground (Fig. 9). The electrode situation, after the compound loss, is clearly depictured in Fig. 10. Apparently, instead of decreasing the grounding resistance, the use of this material has led to the opposite result.

The first arrow (July 2011), in Fig. 7, indicates the start of the period when an apparent material shrink was observed and the second arrow (January 2012) indicates the date when the ditch of $G_6$ rod (compound C) was supplemented with extra quantity of material. Obviously, beyond the last mentioned date in January 2012, a noticeable decrease in the grounding resistance value of $G_6$ system is observed, which is accompanied by a corresponding improvement in its efficiency factor, as shown in Fig. 8.

## IV. Conclusions and Future Work

The performance of the enhancement compounds presents no consistency throughout the year; on the contrary, it's strongly dependent on rainfall and soil humidity. These variations cause great changes on grounding resistance, on developing step voltages and touch voltages, as well as on step voltage and touch voltage permissible limits. Material shrink and its consequent loss has to be taken severely into consideration in designing a power system or any electrical installation, as this fact could lead to unpredicted and irreparable damages into the grounding system and, therefore, into the whole installation. It is well known that these undesirable conditions may jeopardize personnel safety and equipment integrity.

After thorough investigation of Figs. 7 and 8, one could suggest that conductive concrete and bentonite, which are the cheapest and most frequently used materials, in compare to materials A, B and C, are still a quite reliable solution to high resistance problems, appeared in ground types with high soil resistivity values.

In the future, a lot of work has to be done; further field measurements are needed to be obtained, for over a period of 3 to 5 years, in order to observe the performance of ground enhancement compounds in variable conditions from season to season and from year to year. This is very important for the credibility of the comparison among the different materials and in order to ensure safe conclusions.

In addition, more grounding systems with ground enhancing compounds must be installed in different soil types, aiming an integrated evaluation of their performance under various ground conditions. The investigation on compound performance in different soil types may provide valuable information about material shrink and loss and, more specifically, about the factors that cause or even contribute to this phenomenon. Significant improvements could be suggested and applied in material formation, in order to avoid such material failures and to achieve the most suitable combination "soil type - enhancing compound" with the best possible results.

Laboratory tests must also be performed, in order to investigate, the behavior of the substances under impulse current and the possibility of degradation of their capability to maintain grounding resistance in low values, in case of impulse stress.

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