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Ground Resistance Measurements and Evaluation of Grounding Electrodes Performance

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***Abstract*—This paper presents an experimental study on grounding resistance measurements carried out at the University of Patras. Seven case studies are examined to analyze the impact of soil type, electrode geometry, and grounding system configuration on measured resistance values. The findings highlight key factors affecting grounding performance and provide a basis for optimizing system design in varying soil conditions.**

***Index Terms*—Earth Electodes; Grounding system; Ground Resistance; Soil Resistivity.**

I. Introduction

THE primary purpose of an electrical grounding system is to ensure safety, support reliable operation, and extend the longevity of electrical installations. It provides a low-resistance path for fault currents, thereby preventing electric shock, reducing fire hazards, stabilizing system voltage, and protecting sensitive equipment. Grounding effectiveness is typically assessed through resistance measurements, as low grounding resistance enhances safety and mitigates back flashover risk due to lightning surges.

Ground resistance (R_g) is determined by the grounding system's geometry and the soil resistivity (ρ) in which it is embedded. Key factors influencing R_g include electrode characteristics (length, diameter, burial depth, shape, material, and number), soil resistivity, moisture content, and temperature.

This study investigates the variation of grounding resistance across seven experimental configurations, considering different soil types, electrode parameters, and grounding system arrangements. The experiments were conducted at a designated site within the University of Patras, where six ground electrodes were installed. Resistance measurements were taken from October 2024 to May 2025. Results for each case are analyzed and compared, providing quantitative insight into electrode performance, with observed deviations from theoretical predictions further discussed.

II. The Location Under Study

The experimental process of measurement of grounding resistance was carried out in the area of the University of Patras and more specifically in the area opposite of the Department of Electrical Engineering. In figure 1 the selected area is indicated by red colour.

Figure 1. Location of the expirement.

The selected location is well-suited for repeated measurements, as it is an open, unoccupied area within the University of Patras, free from interference by other departments. Its large size enhances the validity and accuracy of the measurements by allowing sufficient spacing between test points. Six ground electrodes were installed at different positions to capture variations in soil conditions: three were placed in an open, tree-covered area, and the remaining three near the High Voltage Laboratory building.

III. Materials and Methods

A. Materials and Equipment

In this study for all the six different cases the materials used to conduct the experiment was copper rod 1.5 meters long and 16 millimeters in diameter as presented in figure 2 below.

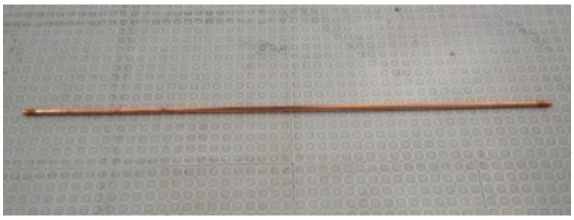

Figure 2. Copper rod 16×1500 mm

Whereas the following equipment and tools were used in carrying out the resistivity measurement as seen in Figure 3 below:

- Digital - Earth Resistance Tester
- Meter Hammer (to drive probes)
- Measuring tape
- Test Electrodes three insulated wire conductors

Figure 3. Resistivity Measurement / Test Equipment

B. Resistance Measurement Method

In this experiment the drop voltage method is adopted for measuring the earthing resistance of an earth electrode. Fall-of-Potential measuring technique [7] is the most recognized method for measuring the resistance to earth of a grounding system, or the ground system performance. This method is based on an IEEE standard [1] and is suitable for use in transmission line structure earths, or areas of difficult terrain. Furthermore, it provides a very accurate result when properly performed.

Figure 4 presents the measurement of the earth resistance using the fall of potential method. First, the Earth Resistance Tester is connected to the earth electrode of interest (T) whose resistance is to be measured. Then two auxiliary electrodes (A) and (P) are placed in the ground in a direct line – away of the earth electrode. The distance T-A is large compared to the length of the earth electrode. A known current (I) generated by the Earth Resistance Tester flows between the auxiliary electrode (A) and the earth electrode (T). Furthermore the drop in voltage potential is measured between the auxiliary electrode (P) and the earth electrode (T). Using Ohm's Law ($U = IR$), the tester automatically calculates the resistance of the earth electrode. Therefore, the resistance value will be U/I.

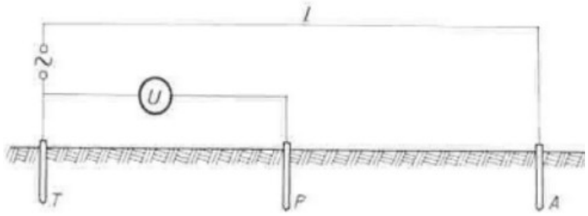

Figure 4. Fall of Potential Method

When performing a measurement, the aim is to position the auxiliary electrode (A) far enough away from the earth electrode under test so that the auxiliary electrode (P) will lay outside the effective resistance areas of both the ground system and the other test electrode.

IV. Experimental Procedure

The experimental procedure of this study was based on seven different cases depending on the grounding system

TABLE I. Experimental Study Cases

	EXPERIMENT CASE STUDY TABLE					
	Test Ground Electrodes common characteristics					
	Material			***Diameter***		
	Copper			16mm		
Case Study	**Case Studies Parameters**					
	Rod No	***Resistance (Ohm)***	***Grounding System***	***Electrode Length***	***Electrode Depth***	***Type of Soil***
1	1	R1	Single rod	1.50	1.30	Soft & Sifted & Dry
2	2	R2	Single rod	1.50	1.10	Stoney
3	3	R3	Single rod	1.50	1.30	Stoney Soil with TERRAFFIL improved materials
4	1	R4	Single rod	1.50	1.30	Soft & Sifted & Wet
5	4	R5	Ending of an active 6x8 grounding grid, placed at a depth of 4m, which consists the active laboratory grounding.	1.50	1.30	soft
6	5	R6	Single rod	2.0	2.0	Stoney
7	6	R7	Single rod	2.0	2.0	Stoney

used, the test electrode depth and the type soil. In table I below each of the seven study cases is presented. During the collection of resistance data, the values of the grounding electrode resistance are recorded for each case study.

Case Study 4 is a variation of Case Study 1, with the addition of 1 liter of water applied to the soil to simulate wet conditions and assess the impact of moisture on grounding resistance. In Case Study 3, the electrode was installed in stony soil that had previously been treated with TERRAFFIL, a material used to lower soil resistivity. As the treatment occurred some time ago, this case evaluates whether TERRAFFIL's effectiveness persists over time.

Case Studies 6 and 7 involve electrodes with identical characteristics placed in similar soil conditions. However, construction activity around Electrode 6 led to partial soil removal, leaving the rod partially exposed. This case examines how incomplete soil coverage affects grounding resistance.

For all seven case studies, resistance measurements were conducted twice daily at 12:00 and 15:00, from October 2024 to May 2025, resulting in 29 measurements per case. Ambient temperature and precipitation were also recorded during the measurement period to support analysis of environmental influences on the results.

V. Results

Table II presents the collected grounding resistance data. Grey-shaded cells indicate measurements taken during wet periods with recorded precipitation, while white cells correspond to dry periods. The wet period includes December, March, April, and selected days in May, whereas the dry period comprises October, November, and the remaining days of May. No measurements were taken in January and February.

The table also highlights the maximum and minimum resistance values for each case study. In general, resistance values peak during dry periods and reach their lowest during wet conditions. An exception is observed for electrode R5, whose maximum and minimum values both occurred during the wet period. Notably, while minimum resistance values are spread across the wet months, maximum values are predominantly recorded in October. This observation aligns with reports from the Hellenic Meteorological Service, which characterized October as unusually warm with minimal rainfall [5].

A. Variation of Value of Grounding Resistance in regards to Temperature

In Figure 5 the variation of the average resistance value in relation to temperature during the wet and dry periods is illustrated.

According to Figure 5, the recorded resistance values during wet period are much lower than the ones during dry period. However, this is not the case for the average resistance values (R5) of electrode 4, as the average values in the month of March and April (wet period) are higher than the ones recorted in dry period of time.

Table II. Recorded data

Recorded Data							
Temperature (°C)	***Electrode Resistance R (Ω)***						
	R1	R2	R3	R4	R5	R6	R7
19	440	850	560	400	1.37	350	200
19	400	850	600	370	1	350	150
18	400	1000	700	350	0,9	350	180
18	350	1000	600	320	1,1	400	175
19	400	1100	650	350	1,1	400	150
17	450	1250	700	400	0,8	395	170
17	440	1350	720	400	1	400	180
16	450	1150	750	400	0,75	400	150
16	400	1250	750	350	0,7	350	180
16	505	1535	800	467	1,35	420	173
16	550	1590	840	460	0,5	**500 max**	**200 max**
16	546	**1855 max**	**898 max**	**495 max**	0,95	418	176
11	**619 max**	743	378	440	1,1	436	182
10	222	285	231	208	0,35	107	88
10	161	465	**146 min**	105	0,23	89	83,3
10	146	**194 min**	209	93	**0,19 min**	85	74,5
10	141	203	198	123	0,55	83	77,1
6	185	500	258	171	0,48	**76 min**	61,4
7	189	204	178	176	1,91	113	84
13	**105 min**	519	427	**92 min**	0,35	92	79
14	122	285	179	108	4,5	112	84,4
8	114	237	182	102	**4,9 max**	131	87,5
12	107	232	172	95	1,47	86	58,4
11	112	230	232	101	3,63	90	**56,5 min**
8	132	321	251	112	1,21	101	71,3
23	342	1145	567	319	0,35	234	133
16	361	1261	577	339	0,34	231	144,1
21	375	1280	575	356	0,33	240	153,1
24	345	1310	453	328	0,68	260	140

Furthermore, the value of the grounding resistance varies proportionally with temperature. During the wet period of time the increase of temperature from 10 oC to 19,5 oC results in the increase of grounding resistance. Similarly, the fluctuation of temperature during dry period results in grounding resistance value variation. This finding is in accordance to theory [1, 4].

Figure 5. Variation of the Resistance value in relation to temperature during the wet and dry periods.

B. *Variation Grounding Resistance depending on Electrode Depth*

The investigation of the impact of test electrode depth on the value of grounding resistance is based on the comparison of three of the seven case studies. Namely, case study 2, 3 and 7 are selected from table I because the remaining parameters (earthing system and type of soil) that these study cases are built on are similar. Specifically, for all the three case studies, the type of soil is stoney and the grounding system is single rod.

In figure 6 below the variation of value of earthing resistances R2, R3 and R7 is illustrated. Additionaly, the maximum and the minimum value of each resistance is depicted.

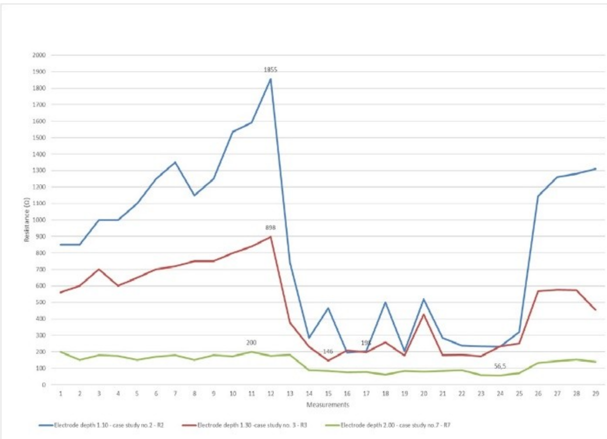

Figure 8. Variation of grounding resistance value in regards to electrode depth

As shown in Figure 6, the earthing resistance of Case Study 7 (Table I and II), corresponding to a 2.00 m electrode depth, consistently exhibits significantly lower values throughout the measurement period compared to those of Case Studies 2 and 3. The highest resistance values are recorded in Case Study 2, which corresponds to a 1.10 m electrode depth. This observation aligns with theoretical principles, which indicate that grounding resistance decreases with increasing electrode depth due to higher moisture content and more stable temperature conditions at greater depths, enhancing soil conductivity [1–3].

To isolate the effect of electrode depth from moisture influence, Figure 7 presents grounding resistance values for single-rod electrodes at fixed soil resistivity. For a soil resistivity of 218 Ω·m, an electrode depth of 1.10 m results in a resistance of 167.4 Ω. Increasing the depth to 1.30 m reduces the resistance by 13%, while a further increase to 2.00 m results in a total reduction of 39%.

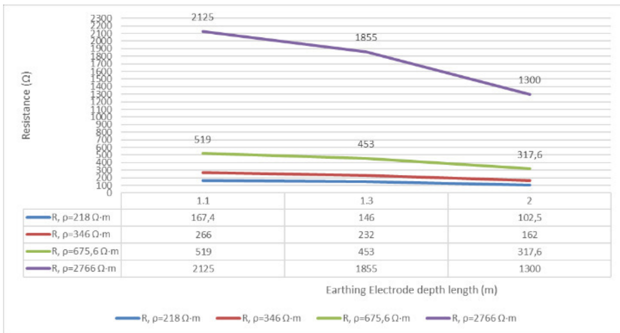

Figure 7. Variation of grounding resistance value in regards to electrode depth – moisture effect disabled

Similarly, for a soil resistivity of 346 Ω·m, an electrode depth of 1.10 m results in a grounding resistance of 266 Ω. This value decreases by 13% when the depth increases to 1.30 m, and by 39% when extended to 2.00 m. The same trend is observed for the remaining two cases presented in Figure 7, confirming the consistent influence of electrode depth on grounding resistance across different soil resistivities.

C. *Variation of Grounding Resistance in regards to Ground Moisture*

The effect of soil moisture on grounding resistance is examined through Case Studies 1 and 4, both involving Electrode 1. The key difference lies in the application of 1 liter of

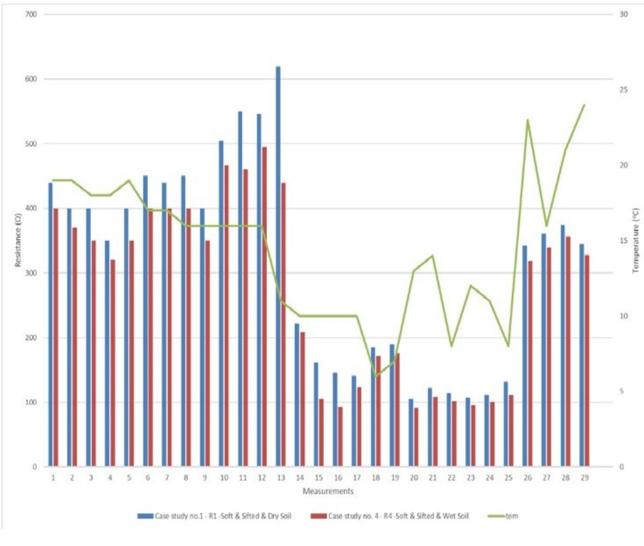

Figure 9. Ground Moisture effect on Grounding Resistance

water in Case Study 4 to simulate increased moisture content.

Figure 9 illustrates the variation in grounding resistance for Electrode 1 before and after water addition. A clear reduction in resistance is observed following the increase in soil moisture. These experimental results confirm that higher soil moisture, along with elevated ambient temperature, contributes to a decrease in grounding resistance.

D. Variation of Grounding Resistance in regards to type of Soil

The following line chart present the variation of the grounding resistance value in regards to type of soil for all case studies with single rod grounding system. Therefore, figure 10 depicts all the case studies besides no. 5.

In order to to disable the depth length effect of grounding electrode on grounding resistance value, the grounding resistance values are calculated with grounding electrode depth length equal to 2.00m, as it results in the maximum grounding resistance decrease. Therefore, for all the 29 measurements and for the five case studies where depth length is 1.10m and 1.30m the soil resistivity (ρ) is calculated. Based on the calculated soil resistivity (ρ) the grounding resistance values is calculated with grounding length equal to 2.00m.

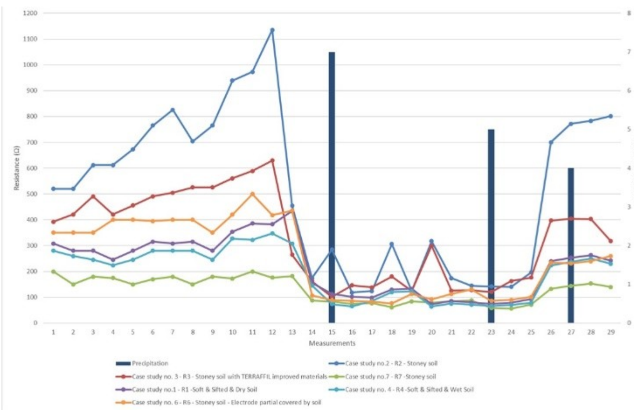

Figure 10. Type of Soil effect on Grounding Resistance – depth length effect of grounding electrode disabled

According to Figure 10, the R_2 grounding resistance has recorded the highest values, followed in most measurement period by R3 grounding resistance which refers to stoney soil with TERRAFFIL improved materials, which in its turns followed by R6 grounding resistance which is measured in stoney soil but there is a lack of soil around the corresponding electrode 6. Afterwards, ground resistance R1, which is measured in soft, sifted and dry soil, follows and then resistance R4, which is measured in soft, sifted but wet soil, is recorded. Finally, the lowest grounding resistance values are recorded for electrode 7.

Furthermore, Figure 10 illustrates rainfall data at the bar column. It is worth mentioned that during wet period of time, where the higher rainfalls occurred, there are slight variations in the aforementioned ranking of grounding resistances. This finding is explained by the increase of moisture content in the soil affect, which affects soil resistivity.

Table III below summarize the aforementioned ranking of grounding resistance values in descending order.

TABLE III. RANKING GROUNDING RESISTANCES

Ranking of grounding resistance values in descending order		
Resistance	***Type of Soil***	***Reference to case study in Table I***
R2	Stoney	Case study no. 2
R3	Stoney Soil with TERRAFFIL improved materials	Case study no. 3
R6	Stoney with lack of soil around the grounding electrode 6	Case study no. 6
R1	Soft & Sifted & Dry Soil	Case study no. 1
R4	Soft & Sifted & Wet Soil	Case study no. 4
R7	Stoney	Case study no. 7

According to Table III stoney soil is reporded as high earthing resistance soil, which become higher during dry seasons. Stoney soil with TERRAFFIL improved materials comes second in ranking, which is explained by the decreased effect of TERRAFIL on stoney soil during time. Soft, sifted and dry soil comes fourth in ranking and it is followed by the soft, sift and wet soil. The stoney soil surrounding electrode 7 results in the lowest grounding resistance. Data in table III are in accordance with theory.

E. Variation of Grounding Resistance in regards to grounding system

Two grounding systems were investigated in the case studies: a single rod system and a grounding grid system. The grounding grid, shown in Figure 11, is an active 6 m × 8 m grid installed at a depth of 4 m and serves as the laboratory's primary grounding system. Case Study 5 evaluates the effect of this grounding grid on earthing resistance.

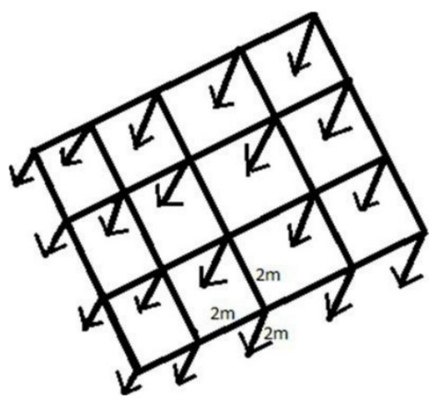

Figure 11. Grounding system based on 6mx8m grounding grid

Table IV below summarize the variation of the mean values of grounding resistance in regards to grounding system.

Table IV. Ranking grounding resistances

Ranking of grounding resistance values in descending order			
Resistance	***Mean Grounding Resistance Values (Ω)***	***Grounding System***	***Reference to case study in Table I***
R1	314	Single Rod	Case study no. 1
R2	834	Single Rod	Case study no. 2
R3	475	Single Rod	Case study no. 3
R4	277	Single Rod	Case study no. 4
R5	1	Grounding grid	Case study no. 5
R6	252	Single Rod	Case study no. 6
R7	129	Single Rod	Case study no. 7

According to Table IV, grounding system with grid results in the lowest earthing resistance value. This finding is explained due to the larger contact area of grounding grid with the ground and the uniform distribution of the leakage current. Furthermore, the grounding grid is less sensitive to local changes in soil conditions such as drought and frost than a single electrode, ensuring a more stable and reliable grounding.

VI. Conclusions

The analysis of grounding resistance was conducted across seven experimental cases, considering soil type, electrode characteristics, and grounding system configuration, while also accounting for ambient temperature and soil moisture effects.

Results show that grounding resistance varies proportionally with temperature and is significantly lower during wet periods compared to dry seasons. Increased soil moisture consistently reduces grounding resistance.

Regarding electrode depth, measurements confirm that resistance decreases with greater burial depth, attributed to higher moisture content and more stable temperatures at depth, which improve soil conductivity [1–3].

In terms of soil type, stony soil exhibited the highest grounding resistance, particularly during dry seasons. Stony soil treated with TERRAFFIL ranked second, reflecting a diminished long-term effectiveness of the material. Soft, sifted dry soil ranked fourth, followed by soft, sifted wet soil. The stony soil around Electrode 7 produced the lowest resistance values among soil types tested.

Finally, the grounding system with a grid demonstrated the lowest earthing resistance, due to its larger contact area and more uniform leakage current distribution. This system also offers greater stability and reliability, being less affected by variations in soil conditions.

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