Ensuring the reliability of energy systems through the application of a new method for introducing soil-replacement mixtures during the installation of deep grounding devices

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Abstract. This paper discusses a method for using mixtures to optimize the electrical parameters of grounding devices during the installation of vertical composite ground electrodes. The authors propose a design for the coupling and tip for vertical composite ground electrodes. Various techniques for artificially reducing the resistance of the grounding circuit are examined. Results from vertical electrode soundings of the soil at grounding locations are presented. The proposed method allows for the introduction of a mixture simultaneously with the vertical composite grounding electrode, including designs for the coupling, tip, and auxiliary device. Experimental studies of the proposed design have been conducted, and results measuring the resistance to current spread of such grounding devices are presented for both standard and proposed couplings.

Keywords: resistance, grounding circuit, hydrogel, graphite, deep grounding device, near-electrode space, seasonality coefficient, deep grounding device, connecting coupling

Introduction

To ensure the safety of maintenance personnel and the reliability of energy equipment, it is essential that the resistance of the grounding device remains within established norms [1]. Due to changes in weather and climatic conditions, fluctuations in the soil's resistivity occur, which, in turn, leads to instability in the resistance values of the grounding circuit [2]. A number of methods are being developed [3-6] to reduce the grounding resistance in such conditions, each of which has its own advantages and disadvantages.

The objective of this work is to develop a method for introducing soil-replacement mixtures to optimize the electrical parameters of the soil during the installation of composite deep grounding devices without using vertical drilling technology.

1 Methods for Reducing the Seasonality Coefficient

When designing protective grounding for electrical installations exceeding 1000 V, it is essential to adhere to the requirements for their resistance, structural execution, and voltage limitation on the grounding device. The voltage on the grounding device during a ground fault should not exceed 10 kV. Any voltage above this level can be applied to protective devices without transmitting potential beyond the boundaries of buildings and external enclosures of electrical installations.

If the voltage higher 5000 volts, protective measures should be in place regarding the insulation of outgoing communication and telemechanic cables to prevent the transmission of dangerous potentials beyond the electrical installation. The grounding device used must have a resistance no greater than 0.5 ohms at all times throughout the year (including the resistance of natural grounding devices).

Reducing the seasonality of soil resistance allows for increased stability in the operation of grounding devices, ensures uniform electrical resistance throughout the year, and guarantees more reliable functioning of electrical systems. This is particularly important for systems requiring stable electrical conductivity, such as power engineering, telecommunications, industry, and agriculture.

It is also known that to avoid fire hazards in energy systems, appropriate electrical protection devices and appliances are employed. However, fires typically occur when protection fails to perform its functions. Regarding electrical station and substation equipment, it should be noted that the status of electrical protection for power supply, signalling, and control circuits is directly linked to fire safety issues, which are determined by the condition of protection devices and grounding circuits during the operation of energy facilities.

When designing artificial grounding systems in areas with high soil resistivity, the following measures are recommended:

- The use of vertical ground electrodes of increased length in cases where deeper soil layers exhibit a gradual decrease in resistivity, and natural deep

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grounding devices (such as wells with metallic casings) are absent;

- The application of remote grounding devices in cases where areas with lower soil resistivity are located nearby (up to 2 km) from the electrical installation;
- Laying horizontal grounding electrodes in trenches, followed by compaction and backfilling with gravel to the top of the trench in rock formations of wet clay soil.
- Artificial treatment of the soil to reduce its resistivity when other methods cannot be applied or do not yield the desired effect. Previous studies have shown that the resistivity of the soil at a depth of 0.3 m increases tenfold when the temperature drops from 0°C to -10°C, and at a depth of 0.5 m, it increases threefold [7]. The work in [8] discusses how an increase in depth, represented in an arithmetic progression, leads to a decrease in temperature amplitude in a geometric progression.

To mitigate the influence of temperature, vertical deep grounding electrodes longer than 10 meters are typically used. A similar solution involves using electrodes immersed in deep wells filled with conductive soil (such as coke dust, concrete, etc.). Deep grounding is preferred when the soil at significant depths exhibits good conductivity, especially when reaching a saturated layer. The simplest and most common solution is to create such a grounding system in the form of homogeneous long rods connected by couplings. Montage can be accomplished using various methods such as screwing, driving, drilling, etc. This solution generally provides more reliable grounding and improves protection against surges and leakage currents.

When designing grounding systems, the structure of the soil is often not considered, assuming it to be uniform, and the influence of groundwater is also overlooked. In the study [4], the authors conducted measurements of the grounding resistance depending on its length, concluding that as the vertical grounding electrode increases in height, the resistance decreases.

As shown previously [4-6, 5, 6, 9, 10], to reduce the resistivity of the soil at the location of the grounding electrodes, various soil-replacement mixtures can be used. These mixtures help retain moisture more reliably in the electrode space using hydrogels; moreover, containing graphite and clay, they help lower the overall soil resistance.

However, the application of such mixtures in conjunction with deep grounding electrodes usually requires prior drilling of a hole for the grounding electrode and mixture [11, 12]. This method allows the distribution of the compositional mixture along the entire length of the deep grounding electrode, which reduces the overall resistance of the grounding system and maintains its stable value throughout its operational life. This leads to increased construction costs. To reduce these expenses, we propose a method for introducing these mixtures without the need for prior drilling of a hole for the electrode.

2 Experimental Studies

During the field experiment, a control deep ground electrode was installed, made of standard composite rod electrodes and factory couplings included in the kit. A similar ground electrode was made using the mixture, and the experimental ground electrode was assembled using the couplings and tip developed by us, as shown in Figure 1 below. To optimize the electrophysical parameters of the grounding devices, a previously developed mixture was used [11, 13 14, 15].

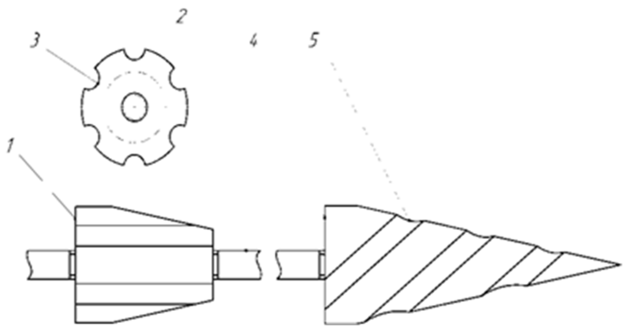

Fig. 1. Appearance of the tip and coupling: 1 – coupling, 2 – composite grounding electrode, 3 – grooves on the coupling, 4 – tip, 5 – grooves on the tip.

Before the installation of deep grounding electrodes, we conducted measurements of the soil's specific electrical resistance at the installation sites using the vertical electrical soundings (VES) method. The results of the VES are presented in Figure 2. The VES data obtained allow us to conclude that the optimal length of a deep ground electrode should be 11-15 meters.

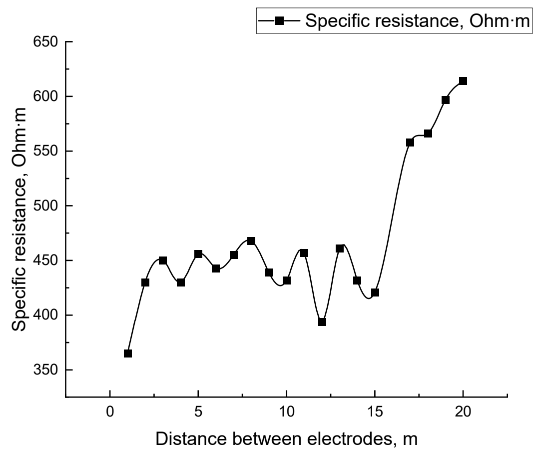

Fig. 2. Results of the VES

After the installation of these grounding systems, resistance measurements were conducted, which were repeated every few weeks over the course of a year. The graphs are presented in Figure 3.

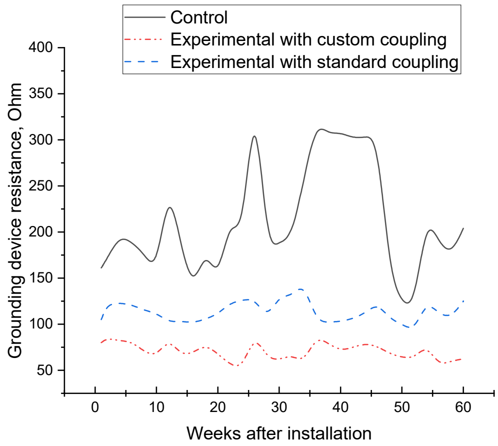

Fig. 3. Annual variations in the resistance of the control, experimental with a non-standard coupling, and experimental with a standard coupling of deep electrodes.

From the obtained dependencies, it is evident that the resistance of the experimental grounding systems (GS) is significantly lower than that of the control grounding electrode. Furthermore, for the developed couplings, this resistance is noticeably lower than that of standard couplings, which can be attributed to the larger volume of the mixture surrounding the electrode body. Additionally, the graph indicates that for standard couplings, the seasonality effect reduces by approximately 1.64 times, while for the developed couplings, the reduction in seasonality is 2.1 times. This can be explained by the much better distribution of the mixture composition along the entire length of the grounding system. Such distribution leads to a reduction in resistance, as due to the capillary effect of the hydrogel (transport functions) [16], moisture is pulled up from the depths and distributed along the entire length of the grounding electrode.

Using the reverse modelling method, the calculation of the "apparent" diameter of the grounding electrode was conducted when using a soil-replacement mixture. The calculation demonstrates the effectiveness of applying this mixture in conjunction with the grounding electrode.

The resistance of the current dispersion of the deep grounding electrode was calculated without taking into account the mixture, using the seasonality coefficient recommended in the regulatory documentation for the Minsk region. According to the expression presented in [17], we obtained:

$$R_V = \frac{\varphi \cdot \rho}{2 \cdot \pi \cdot l_v} \cdot \left(\ln \frac{2 \cdot l_v}{d} + \frac{1}{2} \cdot \ln \frac{4 \cdot t + l_v}{4 \cdot t - l_v} \right),\ Ohm \qquad (1)$$

where: t – depth of the vertical electrode installation (measured from the ground surface to the midpoint of the electrode, in meters);

l_v – length of the vertical deep grounding electrode, in meters;

d – diameter of the grounding electrode, in millimeters;

ρ – specific resistance of the soil at the installation site, in ohm-meters;

φ – seasonality coefficient [17]

According to measurements, the specific resistance of the soil is 526 Ohm·m, so by substituting these values into the expression, we obtain:

$$R_V = \frac{2,4 \cdot 526}{2 \cdot \pi \cdot 11} \cdot \left(\ln \frac{2 \cdot 11}{0,012} + \frac{1}{2} \cdot \ln \frac{4 \cdot 6 + 11}{4 \cdot 6 - 11} \right) = 146,4\ Ohm$$

This value is close to the actual resistance of the grounding system obtained experimentally, the average value of which is 156.4 Ohms. Using the expressions from work [18], a calculation of the resistance of the deep grounding electrode was performed when using a soil-replacing mixture to optimize the electrical parameters of the grounding device:

$$R_V = \varphi \cdot \rho_{eq} \frac{1}{2\pi l_v} \left(\ln \frac{2l_v}{d} + \frac{1}{2} \ln \frac{4t + l_v}{4t - l_v} \right), \qquad (2)$$

where φ – experimental seasonality coefficient for the mixture;

ρ_{eq} – specific resistance of the soil at the installation site according to the formula, Ohm·m.

$$\rho_{экв} = \rho_g \cdot 0,98^{\frac{d_{mixtures}}{d_з}} \cdot \left(\frac{\rho_{mixtures}}{\rho_g} \right)^{\frac{1}{3\pi}}, \qquad (3)$$

ρ_{eq} – the desired calculated specific resistance, ohm·m;

ρ_g – specific resistance of the soil, ohm·m;

$d_{mixtures}$ – equivalent diameter of the grounding electrode and mixture ($d_{mixtures} = \sqrt{\frac{V_{mixtures}}{l}}$), m;

d_g – diameter of the grounding electrode, m;

$\rho_{mixtures}$ – specific resistance of the mixture, ohm·m.

$$d_{mixtures} = \sqrt{\frac{0,02}{3}} + 0,012 = 0,082 + 0,012 = 0,094\ m$$

$$\rho_{eq} = 526 \cdot 0,98^{\frac{0,1}{0,012}} \cdot \left(\frac{50}{526} \right)^{\left(\frac{1}{3\pi}\right)} = 349,75\ Ohm \cdot m$$

$$R_V = 1,64 \cdot 349,75 \frac{1}{2\pi \cdot 11} \left(\ln \frac{2 \cdot 11}{0,012} + \frac{1}{2} \ln \frac{4 \cdot 6 + 11}{46 - 11} \right) = 66,5\ Ohm$$

The obtained value is close to the experimental data, which is equal to 70.7 ohms. Using the method of reverse modelling, the calculation of the "imaginary" diameter of the grounding electrode when using a soil-replacing mixture was carried out. The calculation demonstrates the effectiveness of using this mixture in conjunction with the grounding electrode. To do this, let's express the value of d from formula (1):

$$d = \frac{2 \cdot l_в}{e^{\left(\frac{R_V - \frac{\varphi \cdot \rho}{2 \cdot \pi \cdot l_V} \cdot \frac{1}{2} \cdot \ln \frac{4 \cdot t + l_V}{4 \cdot t - l_V}}{\frac{\varphi \cdot \rho}{2 \cdot \pi \cdot l_V}} \right)}} \qquad (4)$$

The reverse calculation of the imaginary diameter of the grounding electrode showed that when using this mixture in conjunction with a deep grounding electrode, the imaginary diameter of the electrode increased. For standard couplings, it is 0.07 m, while for the embedded type, it is 0.94 m. The use of these devices allows for a twofold reduction in the costs of installing the grounding loop. The demonstrated decrease in resistance of the grounding device and the overall increase in the stability of its value throughout the year, regardless of seasonal changes in climatic conditions, completely offsets the increase in the production costs of the specified devices. The maximum increase in the production costs of couplings and tips will not exceed 10-15%.

Conclusion

The use of a special coupling allows for moisture movement between individual segments of the grounding device and achieves lower resistance values for the loop than when using standard couplings. Additionally, it significantly reduces seasonal variations in resistance to current dispersion in vertical composite grounding electrodes. The results of the calculations indicate that the use of a hydrogel-based mixture has led to a tenfold increase in the imaginary diameter of the grounding electrode, positively impacting the resistance of the grounding device and the stability of its properties. This makes the proposed method promising for enhancing the reliability of power systems.

References

1. PUE-6. Rules for Electrical Installations, 6th ed., Energoservice (2002), 342 p. (Introduced 01.06.1985).
2. V.I. Glushko, O.E. Yamny, E.P. Kovalev, Energy, Reports of Higher Educational Institutions and Energy Associations of the CIS, No. 2, 60-68 (2001).
3. Al-Ammar, E., Khan, Y., Malik, N., & Wani, N. (2010, December). Development of low resistivity material for grounding resistance reduction. In 2010 IEEE International Energy Conference (pp. 700-703). IEEE.
4. Khan, Y., Malik, N. H., Al-Arainy, A. A., Qureshi, M. I., & Pazheri, F. R. (2010, November). Efficient use of low resistivity material for grounding resistance reduction in high soil resistivity areas. In *TENCON 2010-2010 IEEE Region 10 Conference* (pp. 620-624). IEEE.
5. Al-Arainy, A. A., Malik, N. H., Qureshi, M. I., & Khan, Y. (2011). Grounding pit optimization using low resistivity materials for applications in high resistivity soils. *International Journal of Emerging Electric Power Systems*, *12*(1).
6. Harahap, P. H. P., & Al-Ani, W. K. A. (2021). The Effect of Charcoal on the Improvement of Grounding Resistance as a Soil Treatment in Reducing Grounding Resistance. Journal of Renewable Energy, Electrical, and Computer Engineering, 1(1), 12-15.
7. L.M. Vedeneyeva, A.V. Chudinov, Bulletin of Perm National Research Polytechnic University, Geology, Oil and Gas and Mining, 16, 1, 89-100 (2017).
8. Coelho, V. L., Piantini, A., Almaguer, H. A., Coelho, R. A., Boaventura, W. D. C., & Paulino, J. O. S. (2015). The influence of seasonal soil moisture on the behavior of soil resistivity and power distribution grounding systems. Electric power systems research, 118, 76-82.
9. N.M. Zaitseva, B.B. Isabekova, M.Ya. Kletsel, Electricity, No. 7, 19-24 (2011).
10. Meng, Q., He, J., Dawalibi, F. P., & Ma, J. (1999). A new method to decrease ground resistances of substation grounding systems in high resistivity regions. IEEE Transactions on Power Delivery, 14(3), 911-916.
11. S. Baraishuk et all.. The use of hydrogels in mixtures to reduce the transient resistance of the soil - grounding device 5th International Conference on Energetics, Civil and Agricultural Engineering/ E3S Web Conf., 497 (2024) 03001/ ICECAE 2024. DOI: https://doi.org/10.1051/e3sconf/202449703001
12. M.A. Drako, S.M. Barayshuk, I.A. Pavlovich, News of Higher Educational Institutions, Problems of Energy, 23, 1, 80-92 (2023).
13. S.M. Barayshuk et al., Agropanorama, 5, 28-33 (2021).
14. I.A. Pavlovich, S.M. Barayshuk, Energy, Reports of Higher Educational Institutions and Energy Associations of the CIS, 66, 4, 322-332 (2023).
15. S.M. Barayshuk, I.A. Pavlovich, Mixture for Reducing Electrode-Soil Transition Resistance, Patent BY 24181 (Published 28.02.2024).
16. GOST R 58882-2020, Grounding Devices. Technical Requirements.
17. A.V. Smagin, N.B. Sadovnikova, E.A. Belyaeva et al., Soil Science, 55, 9, 1150-1164 (2021).
18. I.A. Pavlovich, S.M. Barayshuk, V.V. Bogdanovich, Bulletin of FFI, 4(106), 146-157 (2023).