Identification of Subsurface for Grounding Installation System Using Geoelectrical Method: Case Study of Waru Substation, Sidoarjo, East Java

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Abstract. In the substation planning process, a study of subsurface conditions is needed for a good grounding system. Therefore, information on soil resistivity values is needed that can be used as a reference for related parties to carry out development, which is to determine the grounding locations. This research is to identify the recommended and optimal grounding depth point in the case study of Waru Substation, Sidoarjo, East Java. A good soil for grounding installation is to have a resistivity of less than 1 Ohm. In this research, 2D geoelectric method is used to determine the subsurface resistivity value. The configuration used in this measurement uses Wenner-Schlumberger which is a combination of the Schlumberger configuration which has sensitivity to vertical layer changes and the Wenner configuration which is sensitive to horizontal layer changes. In addition, measurements were also made using the Three Point Method to measure the soil resistance value of the research area, then compared with the resistance value measured using the 2D geoelectric method. The output produced in 2D geoelectric measurements is in the form of apparent resistivity values which will then be processed using Least Square inversion to obtain 2D cross-section modeling. The value and 2D resistivity cross section are a reference for interpretation of where the appropriate depth is for grounding installation. The results of the 2D resistivity cross section show that the subsurface layer is water saturated wet clay with a resistivity value of 0 Ωm -2 Ωm and wet clay with a resistivity value of 3 Ωm - 6 Ωm. Optimal grounding installation occurs at 7 meters depth with 0 Ωm -2 Ωm resistivity in moist soil. Grounding electrode measurements that have been installed on switchyard components can validate each other with the results of 2D cross-section interpretation in determining the optimal grounding depth.

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1 Introduction

The substation is an installation system consisting of various electrical equipment that connects electrical power from the power plant to the transmission network and then distributes it to the primary distribution network [1]. As a component of the power system, substations are highly susceptible to hazardous disturbances caused by lightning or overloads. Due to their critical role in transmitting power supply and connecting electricity from the power plant to the transmission network, a protection system for substation installations is essential. The required safety measure in this context is the implementation of a grounding system that complies with standards and protection system requirements, commonly known as the Grounding System. Generally, the equipment used to measure grounding resistance is called an Earth Resistance Tester [2]. This study aims to determine the effective depth for grounding installation at the Waru Substation, Sidoarjo Regency, East Java, based on soil resistance values and subsurface lithology types.

1.1 Regional Geology

Based on the geological map of the Malang Sheet, Java, published by the Geological Research and Development Center [3], the morphology and geology of the Sidoarjo area consist of alluvium, Quaternary volcanic rocks, Rabano Tuff, and Middle Quaternary volcanic rocks. The study area itself falls within the alluvial deposit zone and partly in the Kabuh Formation, as shown in Figure 1. The Alluvium Formation (Qa) consists of Holocene-aged sedimentary rocks, including cobbles, gravel, sand, silt, and clay. Meanwhile, the Kabuh Formation comprises Pleistocene-aged sedimentary rocks, including conglomerates, sandstone interbedded with claystone, marl, and tuffaceous rocks, which are generally loosely compacted.

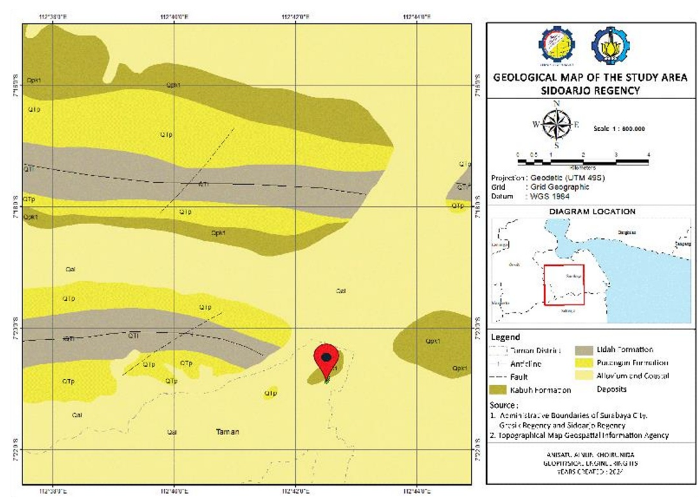


Fig. 1. Regional geology of the study area Geoelectrical Resistivity Method

1.2 Grounding System

The grounding system is a conductive system that connects the equipment and electrical installations to the earth's surface to protect living organisms, equipment, and electrical currents and voltages from electrical surges, lightning, and other disturbances. The most important parameter in determining the quality of grounding is by determining the soil resistivity or resistance value in Ohms. The smaller the resistance value, the better the grounding, meaning that electrical fault currents, such as lightning, can flow more quickly to the earth without significant resistance [14].

According to IEEE Std 81™ (2012), the standard for grounding system installation in larger networks is less than 1 Ohm. Meanwhile, the commonly used value is based on the Persyaratan Umum Instalasi Listrik (PUIL), 2011, which is between 0 and 5 Ohms [15].

2 Metodology

2.1 Research Acquisition Design

The measurement of 2D geoelectric data was carried out in the area of operating voltage development from 70kV to 150 kV GI Waru, Sidoarjo, East Java.

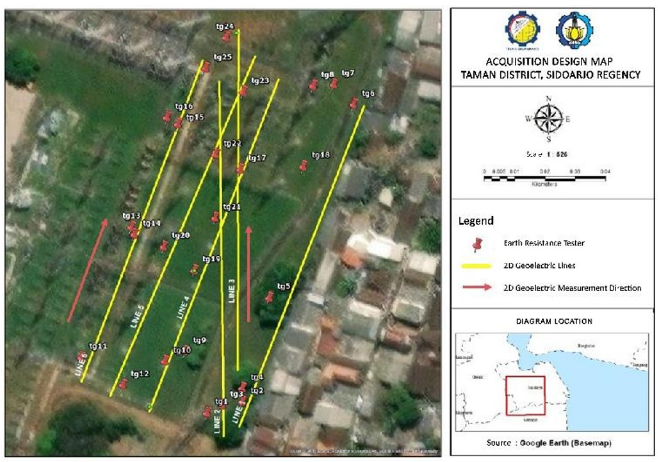


Fig. 5. Design of data acquisition

The resistivity data acquisition was conducted along 6 lines, each with a length of 120 meters, crossing from the southwest (measurement base) to the northeast, as shown in Figure 5. The measurement traverses are labeled LA1, LA2, LA3, LA4, LA5, and LA6. Meanwhile, the measurement of resistance values using the Earth Resistance tester was carried out at 25 points in the research area, with the length of the electrode depth in the ground is about 30 cm.

2.2 Resistivity Method

The geoelectrical resistivity method is one of the geoelectrical techniques used to study the resistivity properties of subsurface rock layers. This method involves injecting an electric current into the ground using two current electrodes and measuring the potential difference using two potential electrodes. Based on the measured potential difference, calculations can then be performed to determine the resistivity variations of the subsurface lithology in the surveyed area [4].

In the geoelectrical resistivity method, it is fundamentally assumed that the Earth has homogeneous and isotropic properties. However, in reality, the lithology and geological structures of the subsurface vary, indicating that the Earth is not homogeneous. Consequently, it can be inferred that these different layers should also have varying resistivity values, which means the measured potential is influenced by multiple layers [5]. Thus, the resistivity obtained from measurements does not represent a single layer but rather a combination of layers. The resistivity measured in this method is referred to as apparent resistivity. Apparent resistivity is the resistivity value of a hypothetical homogeneous medium equivalent to the layered medium under consideration [6]. An illustration of equipotential lines resulting from current injection is shown in Figure 2, where increasing the distance between the current electrodes (A and B) allows the electrical current to penetrate deeper rock layers.

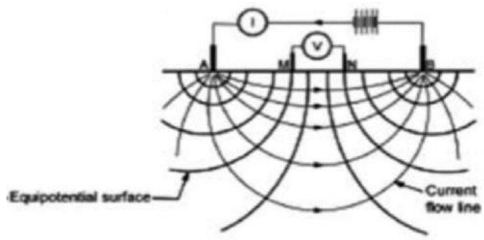


Fig. 2. Electric Current Flow and Resulting Potential Difference Forming Equipotential Fields [6]

The variation of several types of materials based on their resistivity values is shown as follows:

Table 1. The rock resistivity value variation

MATERIAL	Resistivitas (Ωm)
Groundwater[7]	0.5 - 300
Clay[8]	1-100
Sand[8]	1-1000
Silt[8]	10-200
Alluivum[8]	10-800
Water Saturated wet Clay[9]	<2
Wet Clay[9]	2-5
Silty Clay[9]	2-25

2.3 Wenner-Schlumberger Configuration

The Wenner-Schlumberger configuration is a combination of the Schlumberger configuration, which is sensitive to vertical layer changes, and the Wenner configuration, which is sensitive to horizontal layer changes [10]. The electrode spacing rule in this method is constant, with the comparison factor "n" being the ratio between the distance of the current electrodes (AM) and the distance of the potential electrodes (MN), as shown in Figure X. In other words, if the distance between the potential electrodes MN is "a," then the distance between the current electrodes AB is equal to 2na + a [11].

The arrangement of double electrodes on a homogeneous surface for the Wenner-Schlumberger configuration is shown in the following Figure 2:

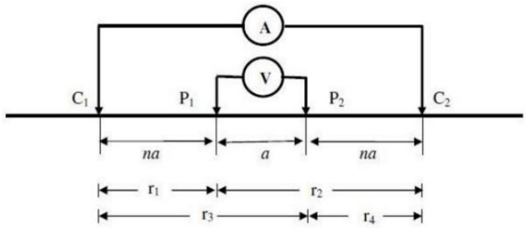


Fig. 3. Wenner-Schlumberger configuration electrode array [12]

The parameters measured in the geoelectrical method are the distances between the electrodes (AB/2 and MN/2), current (I), and potential difference (ΔV). The parameters that are calculated include the geometric factor (K) and resistivity (ρ), which are determined using the following formula:

$$\rho = K\frac{\Delta V}{I} \qquad (1)$$

With the geometric factor:

$$K = \pi n\,(n + 1)a \qquad (2)$$

2.4 Three Points Method (Fall of Potensial Method)

Grounding systems generally use the Three-Point Method for the purpose of measuring ground resistance. This method is also commonly referred to as the Fall of Potential Method. Fall Of Potential Method is a method that involves flowing current between the Ground electrode (G) and the current probe C, then measuring the voltage between G and the potential electrode (P), as shown in Figure 4. To minimize the influence of electrodes due to mutual resistance, current electrodes are generally placed at a considerable distance from the Ground electrode being tested. The distance between electrodes is usually more than 5 m with the potential electrode placed in the same direction as the current electrode (but can also be placed in the opposite direction to the current electrode) [13].

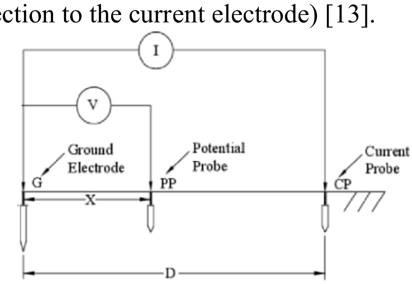


Fig. 4. Illustration of fall-of-potential method [13]

2.5 Research Flowchart

This study was carried out following the procedure outlined in the diagram below.

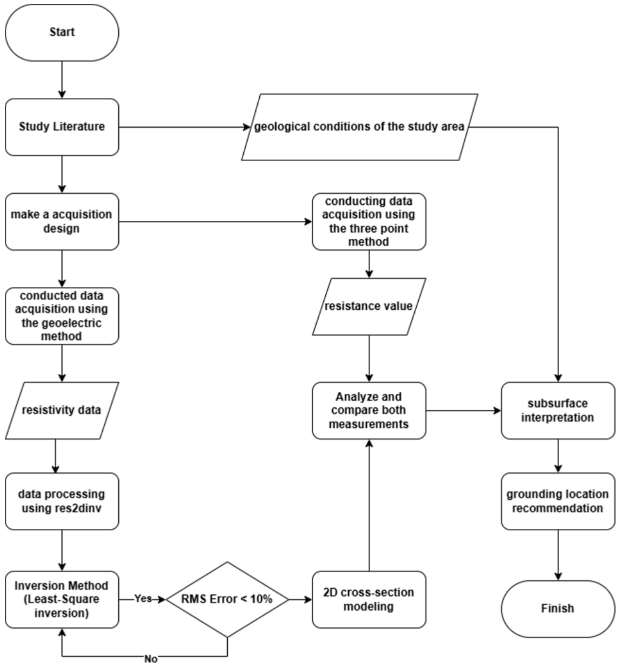
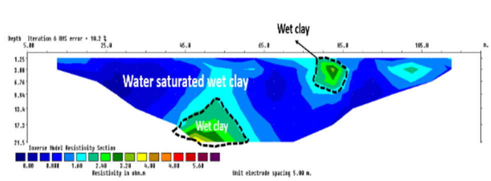


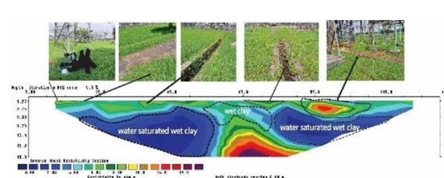
Fig. 6. Flowchart of Research.

3 Result and Discussion

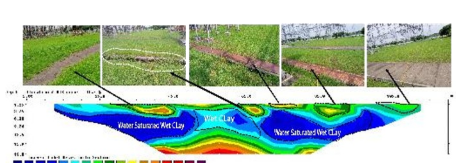
The measurement data of the resistivity geoelectric method obtained from the acquisition results is the apparent resistivity value which is then processed using Res2dinv software to obtain the true resistivity value of the subsurface layer of the measurement point with the smallest error value. The results are shown in the form of a 2D cross section as shown in Figure 7. In addition, the data obtained from the measurement of soil resistance using the three-electrode method (Three point method) using an Earth Resistance Tester with measurement electrodes planted to a depth of 30 cm. The results of measuring the resistance value using the Three Points Method will be compared with the results of the resistance value of the inversion geoelectric resistivity method at a depth of 1.25 m. as shown in Figure 8.



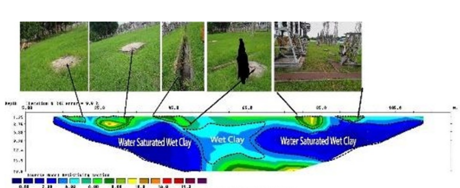
(a)



(b)



(c)



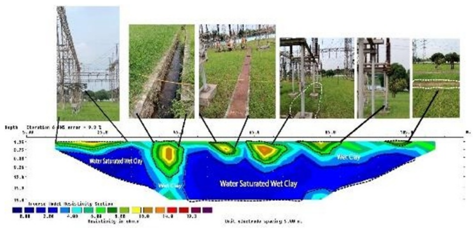
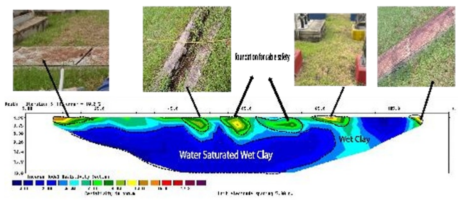
	(d)
 (e)	 (f)

Fig. 7. 2D resistivity cross section (a) Line 1, (b) Line 2, (c) Line 3, (d) Line 4, (e) Line 5 (f) Line 6

The results of processing on this line are shown in Figure 7. which shows the results of a 2D resistivity cross section at a depth of 19.8 meters, with the resistivity scale range set the same as the other lines, from 0 Ωm to 19.3 Ωm. However, for Line 1, the resistivity scale range is set between 1 Ωm and 5.6 Ωm due to the relatively low resistivity values in that area, allowing for a better understanding of the layer distribution. The errors resulting from each line are as follows: 9.9% (Line 1), 9.1% (Line 2), 10.5% (Line 3), 9.9% (Line 4), 9.3% (Line 5), and 10.2% (Line 6).

Based on the results of the 2D cross section on line 1, the resistivity value is relatively small, between 0 - 2 Ωm, so it is suspected that this area is dominated by a layer of water saturated wet clay. In addition, because this area is overgrown with fresh grass and trees. The small resistivity value in the upper layer is thought to be due to the influence that the roots can cause the small resistivity value. Meanwhile, on line 2 to line 5, the layer type pattern is relatively the same. In the upper layer to a depth of about 6 m there is an anomaly with high value resistivity marked by green to orange color contrast which based on actual field conditions is caused by the influence of asphalt, sewers, old foundations of switchyard components, and foundations of cable covers below the ground surface. then in the next layer at a depth of 6.38 m to 19 m is dominated by dark blue visualization with resistivity values between 0 Ωm - 2 Ωm which is thought to be a layer of water-saturated wet clay with wet clay interspersed marked with light blue to light green with resistivity values between 3 Ωm - 6 Ωm. In the drill data research by (Syaifudin, 2016) entitled "*Microtremor study of Gunung Anyar mud volcano, Surabaya, East Java*" states that in the area the lithology is also dominated by clay. besides that it is also supported by the results of research (Widodo et al, 2019) entitled "*Identification of the subsurface structures of kadipaten terung site using surface 3d resistivity method*" classifies that the range of resistivity values < 2 Ωm and 2-5 Ωm are water saturated wet clay and wet clay, respectively. The areas of the two studies still have the same geological unity as the Taman district, so this can support the assumption that the subsurface lithology of the waru substation research area is in the form of clay.

Of the 6 lines, the subsurface layer that is in accordance with the requirements of the Grounding installation system with the optimal resistivity value is at a depth of about 6.38 m or 7 m more optimal. because at that depth it is in contact with a layer of soil that is dominated by a small resistivity value, which is around 0 Ωm to 2 Ωm. The higher the soil moisture, the better the soil for grounding. So the moisture level in the layer at a depth of about 7 m is very high and can be a reference for the proper location for grounding installation.

A comparison is then made between the resistance value of the measurement results using the Three Points Method with the results of the resistance value of the resistivity geoelectric method shown in the following graph.

Fig. 8. Comparison chart of resistance data on (a) Line 1, (b) Line 2, (c) Line 3, (d) Line 4, (e) Line 5, (f) Line 6.

Based on the comparison graph of resistance data measured using the Earth Resistance Tester with the results of measurements using the Wenner-Schlumberger method on lines 1 to 6, it can be seen that the resistance value (resistance) measured using the Earth Resistance Tester is very high which ranges between 25.1 Ω - 31. 7 Ω with an average of 30.9 Ω (line 1), 11.4 Ω - 22.54 Ω with an average of 17.8 Ω (line 2), 9.76 Ω - 12.3 Ω with an average of 11.03 Ω (Line 3), range 20.6 Ω - 63. 8 Ω with an average of 38.41 Ω (Line 4), 9.76 Ω - 35.2

Ω with an average of 22.48 Ω (Line 5) and a range of 10.54 Ω - 12.3 Ω with an average of 11.42 Ω (Line 6). Meanwhile, the resistance value measured using the Schlumberger wenner geoelectric method shows that the average resistance value is constant below 1 Ω, with an average of 0.1513 Ω. The high resistance value in the measurement results using the Earth Resistance Tester is due to the type of soil obtained at the measurement depth is in the form of topsoil where the soil has been mixed with other materials. In addition, at the length of the 8.79 meter track there is a high resistance value (82.1 Ω) which is thought to be caused by the influence of the foundation in the measurement point area. besides that on the 4th line also obtained measurement results with high resistance values of 63.8 Ω and 46.7 Ω which are thought to be influenced by foundations around the measurement point area.

On lines 2 to 6, resistance measurements were also taken using an Earth Resistance Tester at the Grounding electrode connection in one of the switchyard components installed at a depth of about 6m. In the graph, the resulting resistance value is marked in red with an average value of 0.318 Ω when viewed from the results of the 2D resistivity cross section at a depth of about 7m depth dominated by the type of rock lithology water saturated wet clay with a range of resistivity values between 0 - 2 Ωm and a wet clay intersection with a resistivity value of 3 - 6 Ωm. Both of them produce depth differences that are not so far away. Therefore, it can be justified that at that depth a small resistance value has been obtained and is suitable for grounding installation.

4 Conclusion

Based on measurement and data processing analysis indicate that the lithological condition of the Waru Substation development area, Sidoarjo Regency is in the form of water saturated wet clay with a resistivity value between 0 Ωm - 2 Ωm at a depth of about 6.38 m with an interspersed wet clay layer with a resistivity value between 3 Ωm - 6 Ωm. A good and optimal depth for grounding installation in the research area is at a depth of 7 m. because at depth the layer is dominated by low resistivity values and high soil moisture levels. From the results of the comparison of the two tools, measurements using the Three Point Method only measured the topsoil area (the soil has been mixed by other materials) with a depth of 30 cm. Then, using this tool, electrode measurements were also made on switchyard components that had been installed with grounding at a depth of 6 m where the average resistance value was 0.318 Ω. So that it justified each other with the results of the 2D resistivity cross section that at a deeper depth of 7 m it was optimal for locating the grounding point.

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