Parameters as indicators of grounding rod corrosion in substation in port area

Surya Hardi[1*], and *Tania Octavia* Harahap[2]

[1] Department of Electrical Engineering, Universitas Sumatera Utara, Medan 20155, Indonesia
[2] Post graduate student of Electrical engineering Study Program, Department of Electrical Engineering, Universitas Sumatera Utara, Medan 20155, Indonesia

Abstract. Grounding rods are an important component in electrical power to protect equipment from overvoltage and current disturbances. However, corrosion can cause a significant decrease in performance and reduce system efficiency. Therefore, the diagnosis of corrosion on grounding rods is important to ensure the reliability and continuity of substation operations. In this research, a corrosion structure diagnosis was done on the grounding rod in the Belawan Port area using COMSOL Multiphysics 5.3 software. The element method is used to model the electrochemical corrosion phenomena that occur in grounding rods. Corrosion-causing factor parameters such as soil resistance, pH, temperature, humidity, and salt content are measured and evaluated. The analysis results show that there is significant corrosion on the grounding rod, especially in areas exposed to sea water and corrosive environments. The potential distribution shows uneven potential along the grounding rod. Based on this research, additional maintenance and protection measures can be proposed to reduce the risk of corrosion and extend the life of grounding rod equipment. Based on the analysis results, the input parameters differentiate electrolyte reactions which further determine grounding rod.

1 Introduction

An electrical system that does not comply with standards can result in potential electrical hazards. Minimizing the influence and effects that arise can be done by paying attention to the grounding equipment system used. The grounding system is a medium used to channel current to the ground originating from neutral line fault currents from equipment and lightning fault currents [1].

The grounding system is a very important part as a security system for devices that use electricity as a power source from electrical current surges, including lightning. Apart from its use in security systems, grounding rod systems or Grounding rod very susceptible to damage, which is usually called corrosion. It is necessary to observe the use of materials used in the electrical system, for grounding generally copper, iron, aluminium, steel and the like are used. It is necessary to pay close attention to the use of the materials used in the containment to see the rate of corrosion caused by several factors such as oxygen content, water content, humidity, bacteria, and cathodic reactions [2].

The grounding equipment used in the system mostly uses copper-coated steel electrodes because of their good electrical conductivity and economy, but copper-based equipment corrodes more quickly and is affected by ground conditions. Land has different characteristics, including value *Potential of Hydrogen* (pH), water level, and salt level contained in the soil [3].

The use of grounding equipment needs to be considered by taking resistivity into account. Soil resistivity is the resistance of the soil to electric current. The higher the resistivity, the more difficult it is to experience corrosion. If the resistivity of the electrolyte increases and the electron flux is slowed down, the corrosion rate of the equipment decreases. By taking measurements, it can be useful to find out the constituent materials found in the soil [4].

Ground electrodes embedded in the soil are susceptible to corrosion, which is influenced by leakage current and soil properties such as humidity, pH, soil structure, soil temperature, and soil salt content. The corroded surface of the ground electrode affects the current flow process and reduces the performance of the grounding system. The performance of the grounding electrode functions directly to influence the safety and stability of the power system. Corrosion is a serious problem in metal materials and causes losses. This is because corrosion can reduce the ability of equipment to transmit short circuit current to the ground in an installed electrical system [5].

The level of corrosion resistance in grounding grid materials, especially in environments close to sea water, namely in ports, causes damage and rust on grounding equipment which has a major impact on loss. Therefore, it is necessary to carry out research to diagnose and

* Corresponding author: surya.hardi@usu.ac.id

analyze the rate of corrosion in grounding materials. Indonesia's condition, which has a tropical climate and is close to the sea, is a factor that can accelerate the corrosion process [6].

This is also related to the Port of North Sumatra where the minimum temperature is 23ºC – 24.1 ºC and the maximum temperature is 30.6 ºC – 33.1 ºC [7]. This research was carried out to diagnose the structure of ground corrosion by taking into account the parameters that cause corrosion such as pH value, temperature, humidity, water content and salt content at substations in the port area.

2 Literature Study

2.1 Grounding system

The grounding system plays an important role in electricity, especially in substations. The grounding system is used as an intermediary to release the high current into the ground. Equipment in the grounding system that is not grounded will experience interference, resulting in damage to the electrical network. The grounding network is part of an electrical measuring device that connects electrical components to the ground.

The substation is part of the electricity generation, transmission, and distribution system, which is useful for controlling equipment and networks and changing high voltage to low voltage. Grounding at substations was initially carried out vertically by planting electrode rods perpendicular to the ground surface, as the grounding system progressed, it could also be carried out horizontally by planting electrodes parallel to the ground surface.

2.2 Type of grounding equipment

The grounding equipment used is a grounding electrode (a *grounding rod*). A *grounding rod* is a conductor planted vertically whose function is to transmit electrical charges from the conductor cable to the earth. The purpose of grounding equipment is to prevent the occurrence of electric shocks, which have the potential to be dangerous for people around them.

Rod electrodes are grounding equipment that have a round or flat shape with a diameter of 5/8 – 3/4 inch. More than one electrode can be used in the installation to obtain low resistance.

Ribbon electrodes are grounding equipment shaped like a ribbon. The installation process uses ribbon electrodes, namely by fitting the ribbon electrodes so that they can be used as needed.

Plate electrodes are generally better used as grounding equipment, because they are often used in extreme areas that have rocky structures. Rectangular plate electrodes are made from the same material as rod and ribbon electrodes in the form of copper metal which has high conductivity properties.

2.3 Corrosion

Corrosion can be defined as a reduction in the quality of a material (usually a metal or metal mixture) as a result of gradual interactions between its environment which can occur due to physical, chemical interactions or the influence of living things. Corrosion is damage to objects, especially metal, that occurs due to direct contact with the environment such as oxygen and water.

The process of corrosion occurring in grounding equipment on this material is due to the reaction of the anode and cathode [8] [9].

The corrosion process occurs in equipment materials in the form of an anode which has a positive charge pole. Anode reactions generally occur in three earthing materials, namely copper, carbon steel and galvanized steel. The soil corrosion anode process of carbon steel is mainly a process of dissolving carbon steel. In strongly acidic soils, iron ions are mostly dissolved in soil moisture in the form of hydrated ions $Fe2+$ and $Fe3+$. In stable neutral and alkaline soils, $Fe2+$ continues to react with $OH-$ and $O2$ in the soil to form insoluble hydroxides such as in Eq. (1)

Reaction of the anode

$$\mathrm{Fe} \rightarrow \mathrm{Fe}^{2+} + 2\mathrm{e}$$
$$4\mathrm{Fe(OH)}_2 + 2\mathrm{H_2O} + \mathrm{O}_2 \rightarrow 4\mathrm{Fe(OH)}_3 \quad (1)$$

Copper in grounding equipment is a material that is resistant to soil corrosion and generally experiences uniform corrosion. The main anodic reactions are as such as in Eq. (2) and Eq. (3)

Anode reaction on copper

$$\mathrm{Cu} \rightarrow \mathrm{Cu}^{+} + \mathrm{e}$$
$$\mathrm{Cu}^{+} + \mathrm{OH}^{-} \rightarrow \mathrm{Cu(OH)} \rightarrow \tfrac{1}{2}\mathrm{Cu_2O} + \tfrac{1}{2}\mathrm{H_2O} \quad (2)$$

In strongly acidic soils, the cathodic process of metal corrosion is mainly a hydrogen evolution reaction. In slightly acidic and alkaline soils, the cathodic process is primarily a process of oxygen depolarization:

Reaction of the cathode

$$2\mathrm{H}^{+} + 2\mathrm{e} \rightarrow \mathrm{H}_2 \uparrow$$
$$\mathrm{O}_2 + 2\mathrm{H_2O} + 4\mathrm{e} \rightarrow 4\mathrm{OH}^{-} \quad (3)$$

2.4 Material

The research uses measurement tools such as a digital earth tester to measure grounding resistance, a soil analyzer tester to measure pH levels, humidity, temperature, and a salinity tester to measure salt levels.

Soil resistance measurements can be carried out using the three-point method of an analog or digital earth tester. The scheme for measuring soil resistivity as shown in Figure 1.

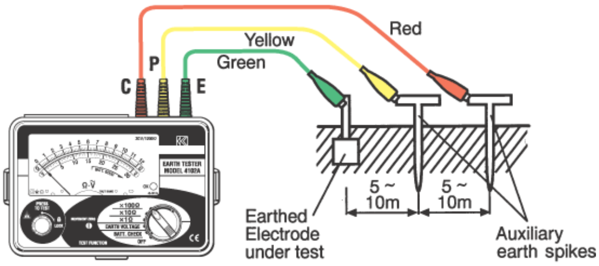

Fig. 1. Grounding Resistance Measurement

Temperature, pH, and humidity measurements were carried out using a soil analyzer tester. Measurement is carried out by inserting a probe or measuring rod directly into the soil by first looking at the condition of the soil to be measured. After inserting the probe into the soil, the pH, temperature and humidity values will be visible on the measuring instrument screen as shown in Figure 2.

Fig. 2. Measurement soil analyser

A salinity tester is used to measure salt levels at the research location. The higher the salt content at a location, the faster the equipment at that location can corrode. A salinity tester can be used by first checking whether the measuring instrument is functioning properly.

Before using the salinity tester, first clean the prism of the salinity tester using drops of distilled water until it coats the entire surface of the prism and then clean it. Use a pipette to take the liquid to be measured and place it on the prism, close the prism cover plate back to its original position.

To obtain salinity results, can be seen at the round tip of the salinity tester and see one or more scale numbers. The salinity scale is marked 0/00 which means parts per thousand, from 0 at the bottom of the scale to 50 at the end. Salinity can be seen on the line where the white and blue meet, as shown in Figure 3.

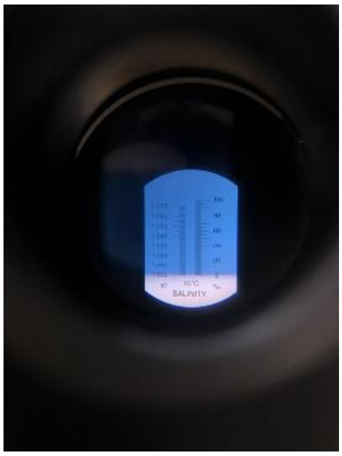

Fig. 3. Measurement Salinity tester

2.5 Software COMSOL Multiphysics 5.3

COMSOL Multiphysics is software used to simulate and create a model using Finite Element Method (FEM). COMSOL Multiphysics are used to design various science and technology problems, such as electricity, magnetism and others.

Application software COMSOL Multiphysics which helps in carrying out designs and plans by imagining a tangible object. The designs designed can be 1 dimensional, 2 dimensional and 3 dimensional to suit the needs and accuracy of the design to be designed. The COMSOL operation requires input parameters such as pH, temperature, humidity and salt content. From these results, grounding rod designs and electrolyte reactions to cause corrosion will be obtained.

Domain setting is the stage for providing the type of material that will be used in the geometric design grounding rod. Boundary setting is used to determine part geometry grounding rods that have not been contaminated by corrosion and those that are corroded. The mesh parameter is used to determine the accuracy of the data from the designed design. Parameters indicate the time period of the simulation process for solving corrosion problems in grounding rods. Section solver parameter settings are carried out with the aim of obtaining corrosion diagnosis results on the grounding rod. The design depends on the parameters studied [10].

3 Research Method

3.1 Research process

The research method that will be carried out begins with identifying problems that occur by conducting literature studies, and collecting measurement data directly as needed, carrying out designs according to the substation, making simulation designs, testing designs on simulations, and drawing conclusions and suggestions. The flow diagram as shown in Figure 4.

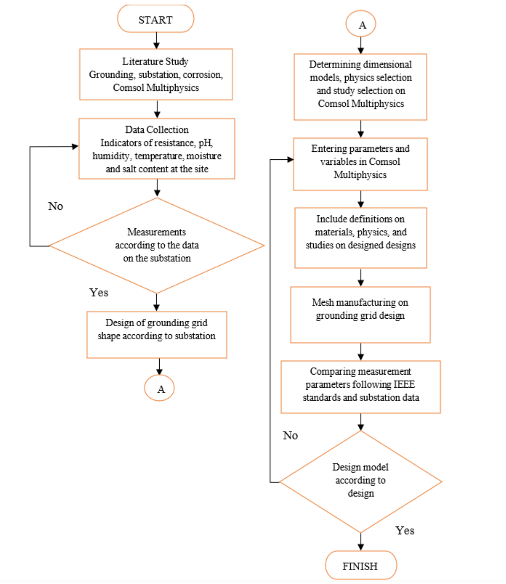

Fig. 4. Research method flowchart

3.2 Parameter data used

Primary data such as resistance, temperature, pH, water content, salt content, and humidity, as well as secondary data in the form of grid data at the substation location. The grounding rod design was built in accordance with the substation at the research site, taking into account the dimensions, parameters, and material models used in the COMSOL Multiphysics 5.3 software.

COMSOL Multiphysics has many built-in physics interfaces aimed at specific applications. In many generic cases, however, the modeler has to make some basic assumptions about his system before starting to build his model. Under the assumption of a linear relation of current density to the electric field, Ohm's law is obeyed for the electrolyte current. This is the assumption of primary current distribution, where one also assumes infinitely fast electrode kinetics, resulting in negligible potential drops over the electrode-electrolyte interfaces. If the electrode reaction kinetics proceed at a finite rate, then the system has a secondary current distribution

The electrochemistry module was used as a method for completing this research. Secondary current distribution is a solution method used to develop models due to reactions at the electrodes. The linear Butler-Volmer equation can be used to investigate reaction rate of buried electrodes [11].

$$\boldsymbol{i_{corr}} = \boldsymbol{i_o}\left(\boldsymbol{exp}\left(\frac{\boldsymbol{\alpha_\alpha F\eta}}{\boldsymbol{RT}}\right) - \mathbf{exp}\left(\frac{\boldsymbol{-\alpha_c F\eta}}{\boldsymbol{RT}}\right)\right) \quad (5)$$

In this equation, i_o is the exchange current density of the buried electrode reaction. α_α and $-\alpha_c$ is the change transfer coefficient of the anode and cathode, respectively. R is the general gas coefficient. T is temperature. F is Faraday's constant. η is the overpotential of the interface between the electrode and the electrolyte.

The internal electrode surface is used to define and see the capacitance of the electrode's reaction with the electrolyte. The total current can be measured experimentally by calculating an electrode by integrating of the local current density. The total current density is the sum of the Faradaic components (electrode reactions). To find the total current, can be used the following equation [12]:

$$i_{total} = \sum_m i_{loc,m} \quad (6)$$

$\sum_m i_{loc,m}$ shows the local charge transfer current density for the reaction. is the electrode reaction current density of the charge displacement electrode reaction index m.

The electrical conductivity of an electrode is usually several orders of magnitude greater than the conductivity of the electrolyte. The ionic strength of the solution must remain approximately constant for the constant conductivity approximation to be valid. When the conductivity is large relative to the drawn current, the electric field in the solution becomes negligible. The value of electrical conductivity uses the value of the material used. Calculating the conductivity of a conductor can be calculated using Ohm's law, as in Equation (7) [13]:

$$\sigma_c = \frac{I \cdot L}{V \cdot A} \quad (7)$$

σ_c = Conductivity of conductor (S/m)
I = Current flow in the conductor (ampere)
L = Length of conductor (m)
V = Conductor potential (V)
A = Cross sectional area (mm^2)

The parameters used to design geometry in COMSOL multiphysics 5.3 are shown in Table 1.

Table 1. Parameter description

Name	Description
E_eq_Cu	Copper reduction
E_eq_H2	Hydrogen reduction
E_eq_cell	Equilibrium cell potential
cE_salt	Salinity
E_pol	Cell overpotential
E_cell	Cell potential applied

4 Results and discussion

In this research, measurements of corrosion-causing factors such as soil resistance, pH, temperature, humidity, and salt content were taken from 2, November 2023 to 24, November 2023 in the port area at the

Belawan Substation. Based on the results, the data obtained is used as a reference for diagnosing grounding rods in the substation. Measurements are carried out, taking into account weather factors, to make it easier to obtain appropriate data. The measurement data result is shown in Table 2.

Table 2. Substation area measurement data

No	Measurement Data					
	DAY	Resistance	pH	Temp	Humidity	Salt
1	2/11/23	0.1 Ω	5.0	32°C	Wet	5%
2	6/11/23	0.1 Ω	7.0	37°C	Dry+	5%
3	8/11/23	0.1 Ω	6.6	33°C	Dry	5%
4	10/11/23	0.1 Ω	4.5	31°C	Wet	3%
5	13/11/23	0.1 Ω	5.0	32°C	Wet	3%
6	15/11/23	0.1 Ω	4.5	31°C	Wet	3%
7	17/11/23	0.1 Ω	6.6	35°C	Dry	2%
8	20/11/23	0.1 Ω	7.0	36°C	Dry+	2%
9	22/11/23	0.1 Ω	6.8	35°C	Dry	2%
10	24/11/23	0.1 Ω	7.0	35°C	Dry	2%

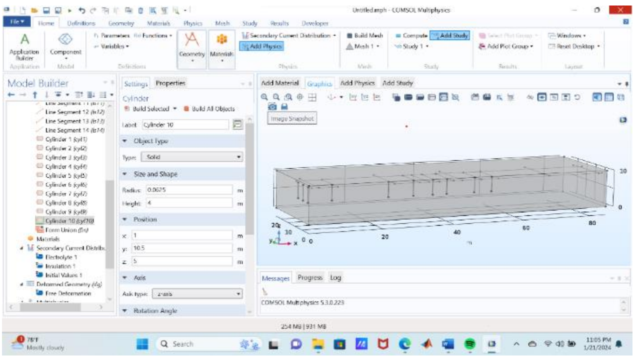

Fig. 5. Design

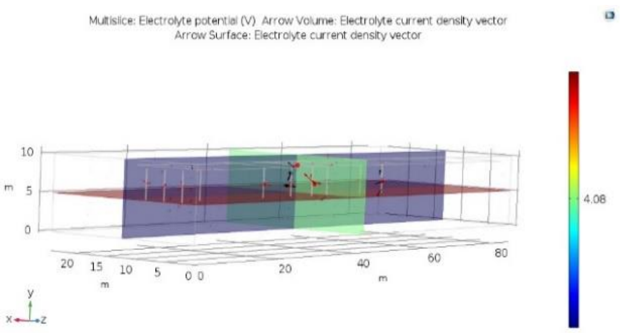

Fig. 6. Result Geometry

4.1 Design results of geometry studies

The grounding electrode design in COMSOL Multiphysics 5.3 is adapted to the substation at the research location. COMSOL uses Geometry Block 1 to describe the land area at the substation location. The size and shape of Block 1 is width 24 m, depth 10, height 85 m with axis type Z-axis. Geometry Line segments 1 – 14 are used to describe grounding grid lines from one point to another, which can be seen in Figure 5.

The start points and end point coordinates are adjusted to the distance between the rods obtained at the substation. A geometry cylinder is used to describe the shape of a ground rod embedded in the ground. The size and shape of the cylinder is a radius of 0.0625 m and a length of 4 m with an axis type Y-axis [14].

The research results showed that the underground anode and cathode reacted around the grounding equipment rod. It is shown in Figure 6, with the red and black arrows around the silver grounding rod, that the electrolyte potential surrounds the grounding rod and shows in that part the corrosion reaction that occurs.

The results of field measurements are as shown in Table 2. To investigate the differences between reactions of the parameters pH, temperature, humidity, and salinity have constructed as Condition_1, Condition_2, and Condition_3. The geometry results in the COMSOL simulation for condition_1 such as in Figure 7. In condition_1 the temperature is 37°C, pH 7.0, salinity 5% and humidity conditions are Dry+.

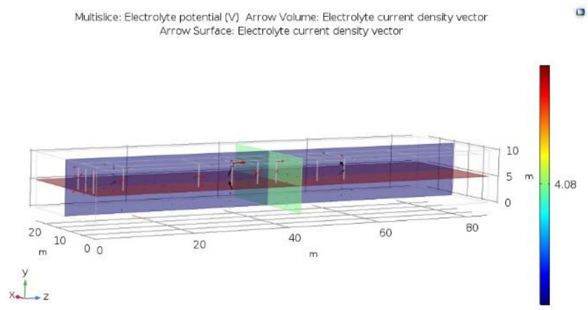

Fig. 7. Condition_1

Condition_2 is a temperature of 31°C, pH of 4.5, salinity of 3%, and wet humidity conditions. Geometry results in the COMSOL simulation for the Condition_2 is shown in Figure 8.

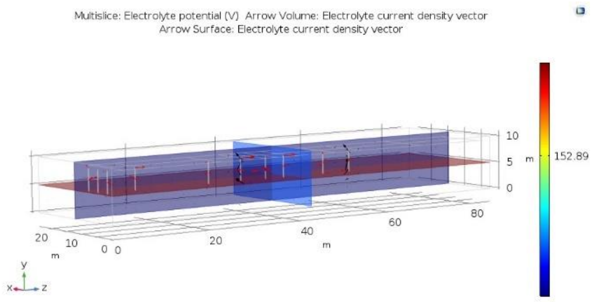

Fig. 8. Condition_2

In condition_3, the temperature is 35°C, pH 6.8, salinity 2% and dry humidity conditions. Geometry results in the COMSOL simulation for condition 3 are as in Figure 9

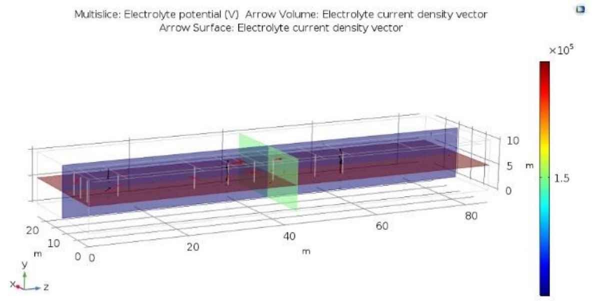

Fig. 9. Condition_3

The Figures show the electrolyte reaction. Observations show that based on different temperatures, pH, humidity and salinity, the electrolyte reaction will also be different.

In this study there are 3 conditions taken to investigate the differences in the level of corrosion experienced, condition 1 the temperature is 37°C, pH 7.0, salinity 5% and humidity conditions are Dry+, condition 2 is a temperature of 31°C, pH 4.5, salinity 3% and wet humidity conditions, and condition 3 the temperature is 35°C, pH 6.8, salinity 2% and dry humidity conditions. The highest level of corrosion is in condition 1, the temperature in condition 1 experiences a high temperature increase thereby accelerating chemical reactions including corrosion, a neutral pH of around 7 is generally considered the most corrosive, and the salinity level in condition 1 is 5%, so the higher the temperature, the pH, and the higher the level of food salt, the higher the corrosion that occurs. The medium level of corrosion is found in condition 2, the temperature in condition 2 has decreased from condition 1 of temperature, pH and salinity of 3%. The lowest level of corrosion is condition 3, there is an increase in temperature and pH compared to condition 2 but the salinity in condition 3 is 2% so it is lower than condition 2.

4.2 Indicator parameter chart

Data obtained from measurements such as the form of pH, temperature and humidity can influence changes in the resistance of grounding equipment at the substation as shown in Figure 10.

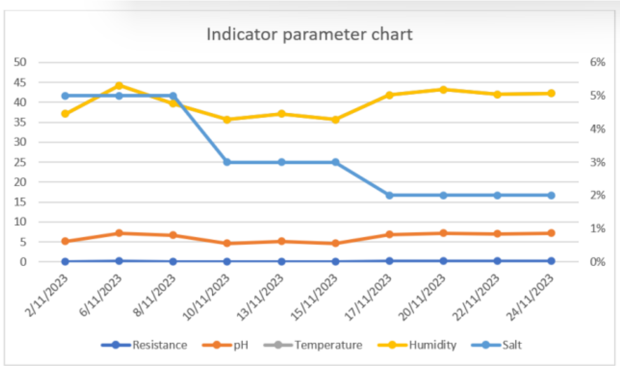

Fig. 10. Indicator Parameters

Figure 10 explains the changes in the measurement results obtained. The vertical indicator values 0 to 50 explain the results of changes in measurements from 2 November 2023 to 24 November 2023 with respect to the resistance parameter value remaining at 0.1, while the pH value from 4.5 to 7.0 changes. The vertical indicator value 0 to 50 explains that the change in the value of the temperature and humidity parameters has a significant value, that is, from the value range of 31°C to 37°C There are changes in temperature every day according to the wet or dry humidity information. The vertical indicator value of 0% to 6% explains the results of changes in the value of the salt parameter, which can be seen from the horizontal change in value from left to right.

From Figure 10 can be observed that the soil resistivity is influenced by the electrolyte content consisting of moisture, and sea salt. The pH value of the soil can affect its resistivity. Temperature can affect soil resistivity, when temperature decreases, soil resistivity increases. Increasing temperatures can cause soil resistivity to decrease. The relationship between temperature and soil resistivity is an important thing to consider when designing and installing a grounding system, because changes in soil temperature throughout the year can affect the performance of the grounding system.

The soil's resistivity is greatly influenced by soil moisture. When the water content in the soil increases (wetness), the resistivity decreases, making it easier to achieve lower soil resistance. Conversely, when soil dries out, its resistivity increases which can lead to higher soil resistance and potential problems with grounding system performance.

5 Conclusion

In this research, corrosion indicator parameters were measured using COMSOL Multiphysics 5.3 software. The element method is used to model the electrochemical corrosion phenomenon that occurs in grounding rods. Based on the research and analysis results, several conclusions can be drawn:

1. Corrosion on substation grounding rods is a significant phenomenon and has the potential to reduce system performance. The presence of corrosion can cause a decrease in the conductivity and reliability of the grounding grid.
2. Environmental factors such as pH, temperature, humidity, and the presence of corrosive materials have a major influence on the level of corrosion in grounding rods. Areas exposed to seawater or corrosive environments tend to experience higher levels of corrosion.
3. Using COMSOL Multiphysics 5.3 software provides an efficient approach using the electrochemical element method that occurs to model corrosion phenomena on grounding rods.
4. Based on condition_1, condition_2, and condition_3 have different electrolyte reaction results, because the parameters in the form of pH, temperature, humidity, and salinity are different in each condition that is input into COMSOL. The results of different electrolyte reactions show that there is a corrosion reaction on each grounding rod.

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