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Modeling of Glugur Substation grounding systems using MATLAB graphical user interface

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ABSTRACT

The grounding system in substations generally uses electrode rods, because electrodes can affect the effectiveness of fault current conduction, so the equipment will be safer. Considering the importance of the grounding system, the installed grounding system must be considered and maintained properly. One of them is the grounding found in Glugur. The main objective of this research is to comprehensively evaluate the substation grounding system by modeling the grounding system at the Glugur Substation using MATLAB graphical user interface (GUI). The grounding resistance follows a grid system with an area of 20×15=300 m² with specific resistance being clay using 100 rod electrodes. From the results of ground resistance simulation modeling using MATLAB GUI, it can be concluded as follows: for a certain resistance value, the number of electrodes for 100 Ωm is 3.55 Ω, for ground resistance with a constant depth and a varying number of 100 electrodes, it is 3.45 Ω, and for. The grounding resistance with a constant and varying number of 1,000 rods is obtained at 2.65 Ω. From these results, the modeling carried out is in accordance with the standards of electricity regulations in Indonesia.

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1. INTRODUCTION

Electrical substations are critical components of power distribution networks, serving as hubs for the transmission and distribution of electricity from generating stations to consumers. Substation grounding systems are fundamental to the safe and reliable operation of these facilities [1], [2]. They provide a low-impedance path for fault currents to dissipate into the earth, thus reducing the risk of electric shock to personnel and damage to equipment during fault conditions. Substation grounding plays a vital role in ensuring the safety of personnel, protecting equipment, and maintaining system reliability [3], [4]. Without effective grounding, fault currents could pose significant hazards to both individuals and infrastructure [5]. Grounding systems are designed to limit the potential rise in voltage of equipment and surrounding surfaces, thereby minimizing the risk of electrical accident and ensuring the continuous operation of the substation [6], [7].

Analyzing substation grounding systems presents several challenges due to the complexity of the system components and the dynamic nature of electrical networks. Substation layouts can vary widely and include a multitude of grounding elements such as ground rods, conductors, grids, and connections to equipment [8]. Modeling these elements accurately is essential for assessing system performance [9]. Soil properties [10], such as resistivity and layering [11], vary spatially and can significantly affect the performance of grounding systems [12], [13]. Understanding and accounting for soil variability is crucial for designing effective grounding solutions. Substations are susceptible to transient events like lightning strikes [14] and switching operations, which can introduce high-frequency currents [15] into the grounding system [16]. Analyzing the transient response of grounding systems is essential for evaluating their effectiveness under dynamic conditions.

Trevino *et al.* [17] describes that the performance of grounding systems under direct lightning strikes on a power substation is analyzed using a new model that is described in this study. The substation shielding conductors and the substation grounding system are represented by three different kinds of multi-conductor transmission lines in the proposed model. Hardi *et al.* [18] in his research explained about as one of the defenses against equipment damage from fault currents, the grounding system is a crucial component of the electric power system. Software is utilized to calculate the substation grid design in order to streamline computations and provide quick, reliable answers. This study generated an application called "design of grounding grid" that uses MATLAB App software to calculate substation grid designs in accordance with IEEE Std 80-2013 [18]. This application can calculate grid designs in three configurations: square, rectangular, and L-shaped, either with or without rods [18].

Thus, the grounding system at the substation is very important to ensure personnel safety and the reliability of the electric power system. The grounding system must safely eliminate fault currents to earth, maintain low impedance, and ensure that step voltage and touch voltage are within safe limits. The Glugur substation, like other substations, requires a strong and well-designed grounding system. The main objective of this research is to comprehensively evaluate the substation grounding system by modeling the grounding system at the Glugur Substation using MATLAB graphical user interface (GUI) [19]. Develop MATLAB GUI models [20] to simulate the behavior of substation grounding systems under various operating conditions. Assess the performance of different grounding system configurations in terms of safety, equipment protection, and system reliability.

2. METHOD

The Glugur Substation grounding system will be modeled using MATLAB. The steps for modeling the Glugur Substation grounding system are: i) Data on the substation and grounding available from the Glugur main Substation is a grid grounding type with a grid length of 20 m and a width of 15 m so that the grid grounding area is 20×15=300 m² then the next data needed for this substation analysis is the clay type; ii) From the existing data in the form of a graphical user interface with MATLAB as follows can be seen in Figure 1; and iii) Calculating the value of ground resistance in calculating ground resistance requires a system or formulation of grounding with girds using (1).

$$Rg = p\left[\frac{1}{Lt} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)\right] \tag{1}$$

where Rg is the ground resistance of the substation (Ω), ρ is the soil resistivity (Ωm), A is the area occupied by the ground network (m^2), h is the depth of the grid (m), and LT is the total length of buried conductors (m).

Then in the analysis using a user interface graphic is created.

– Calculate the ground resistance, namely by entering the grid length, width, number of rods and depth so that when you press the calculate ground resistance button the ground value will be produced.
– In the analysis of the substation grounding system, a simulation is carried out by making the area constant, the depth constant and the number of rods varied, then if you press the button to plot the grounding resistance vs these rods, this will result in exes1 in the form of a plot graph of the grounding resistance vs the variation of the existing rods < 5Ω.
– Then the area is constant, the number of rods is constant, and the depth varies in this simulation, what are the rods, the number of rods and the range, so that when you press the plot grounding resistance vs depth button, click on it and this will be displayed on exes1 in the form of a graph of grounding resistance vs depth.

– For the last simulation, a 3-dimensional (3D) graph is made, the area is constant, the depth and number of bars vary, if you click on the ground resistance plot as a function of the depth bar, exes1 will produce a 3D graph where the graph shows the ground resistance value as a function of stem and depth.
– Then analyze what is expected that in the analysis using this user interface graphic, the grounding resistance is < 5Ω, if it is then analyzed, if not, then review the existing user interface graphic design and the progress of this research can be seen in Figure 2.

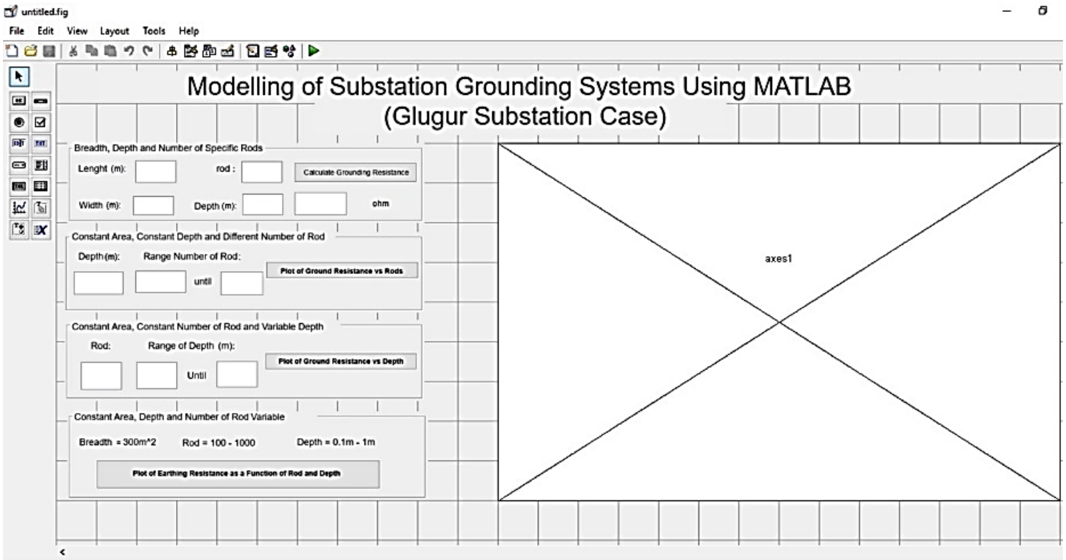

Figure 1. MATLAB GUI display

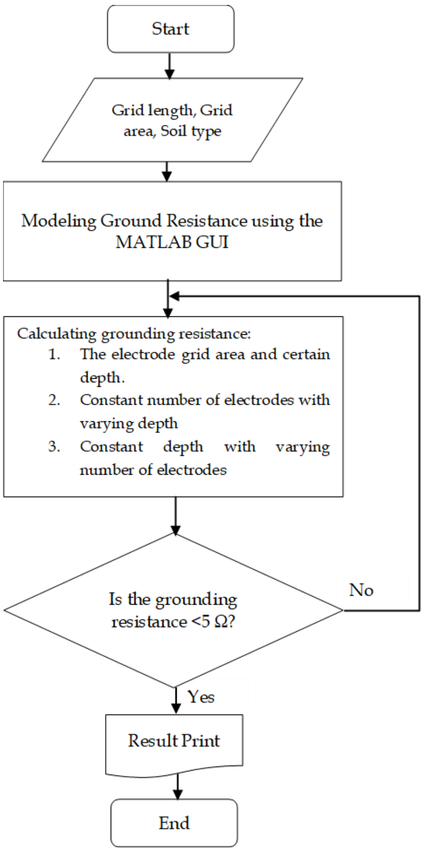

Figure 2. Research flow chart

2.1. Substation

A substation is a key component of an electrical system that plays a crucial role in the transmission and distribution of electricity [21]. It serves as an intermediary point between the high-voltage transmission [22] network and the lower-voltage distribution network [5], allowing for the transformation, switching, and control of electrical power. Substations are equipped with transformers that can step up or step down the voltage of electricity as needed. Step-up transformers increase the voltage for long-distance transmission, while step-down transformers decrease the voltage for local distribution to consumers.

The substations contain various switching devices such as circuit breakers [23], switches, and disconnectors [22] that allow for the control and isolation of electrical circuits. Protective relays are also installed to detect faults [24] and initiate protective actions to prevent damage to equipment and ensure the safety and reliability of the electrical system. Substations include busbars, which are conductive bars or rails that serve as electrical highways to connect various components within the substation. Conductors are used to carry electrical current between components such as transformers, circuit breakers, and switches [25].

The substations are equipped with control systems that allow operators to monitor and control the operation of equipment remotely [26]. Supervisory control and data acquisition (SCADA) [27] systems are commonly used to provide real-time monitoring of parameters such as voltage, current, and temperature, enabling operators to respond quickly to changes in the electrical system. Substations incorporate various safety measures [12], [5] to protect personnel and equipment from electrical hazards [10]. These may include fencing, warning signs, safety interlocks, grounding systems, and personal protective equipment (PPE) for workers [28]. Substations can vary in size, complexity, and function depending on their location and role within the electrical system.

2.2. Grounding system

A grounding system is an essential component of electrical installations designed to provide a safe path for electrical currents to flow to the earth in the event of a fault or surge [24], [29]. The primary purpose of a grounding system is to protect people and equipment from electrical hazards [30]. By providing a low-impedance [25] path to the earth, it helps to dissipate fault currents, reducing the risk of electric shock and fire. Grounding helps to protect electrical equipment by providing a path for fault currents to safely dissipate, reducing the risk of damage caused by overvoltages or short circuits [31].

The grounding systems are an integral part of lightning protection systems, providing a path for lightning currents to safely dissipate into the earth, thereby reducing the risk of damage to structures and equipment [7]. Proper grounding helps to stabilize the electrical system and ensure its reliable performance by reducing electromagnetic interference (EMI), minimizing voltage fluctuations [32], and improving the effectiveness of protective devices such as fuses and circuit breakers. Components of a grounding system may include:

- Ground rods: These are typically copper or galvanized steel rods driven into the ground to establish a connection with the earth. Multiple ground rods may be used to achieve the desired level of grounding effectiveness.
- Grounding conductors: These are conductive wires or cables that connect electrical equipment and structures to the grounding electrodes, providing a low-resistance path to the earth.
- Grounding grids or Mats: In larger installations or where high fault currents are expected, a grounding grid or mat consisting of interconnected conductors buried beneath the surface may be used to enhance the effectiveness of the grounding system.
- Bonding conductors: These are used to connect metal structures, equipment, and other conductive elements within a facility to ensure electrical continuity and prevent differences in potential that could lead to hazards or equipment damage. It is important for grounding systems to be designed, installed, and maintained in accordance with relevant standards and regulations to ensure their effectiveness and safety. Additionally, periodic testing and inspection are necessary to verify the integrity of the grounding system and identify any issues that may arise over time.

3. RESULTS AND DISCUSSION

In this grounding analysis, it is carried out in four conditions, namely, the first by providing a certain grounding depth and number of electrode rods, the second by providing a certain grounding depth and varying number of electrode rods, the third by providing a certain number of electrode rods and varying grounding depth, the last by varying the grounding and number of electrode rods. The four states of the Glugur Substation grounding system were analyzed with grounding values below 5 Ω, each value of which is displayed in 2-dimensional (2D) and 3-dimensional (3D) graphs.

a. Glugur Main Substation grounding analysis depth of specific number of electrode rods

Basically, the type of soil at the Glugur Substation is clay type with a soil resistivity of 100 Ωm, with an area of the substation that is grounded with a grid system, namely 20×15=300 m² with a grid size of 0.1 m depth and a number of electrode rods of 100 m, then the grounding resistance value is obtained as.

$$Rg = p\left[\frac{1}{Lt} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)\right] = 100\left[\frac{1}{100} + \frac{1}{\sqrt{20\,x\,300}}\left(1 + \frac{1}{1+0{,}1\sqrt{\frac{20}{300}}}\right)\right] = 3.55\ \Omega$$

The grounding resistance value of the Glugur Main Substation obtained from the results of manual calculations is the same as the simulation results using the MATLAB user interface (GUI) graphic as in Figure 3, namely 3.55 Ω. The grounding resistance value of the Glugur Substation is in accordance with PUIL 2000 below 5 Ω.

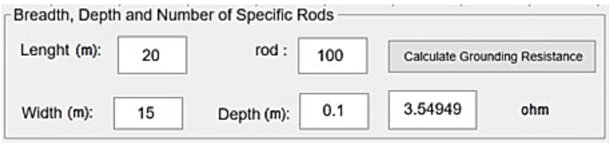

Figure 3. Simulation results of the grounding resistance of the Glugur Main Substation with a number of 100 rods and a depth of 0.1 m

b. Grounding resistance with constant depth and varying number of electrodes

Simulation of the condition of the grid grounding resistance system at the Glugur Substation was carried out by making the depth constant, namely 0.5 m and the number of rod electrodes varied from 100 to 1,000 rods. This condition was carried out to see the effect of changing the number of electrode rods on the grid grounding resistance value of the Glugur Main Substation with single grounding. inputting the value of the grounding depth and number of electrodes and the number in the MATLAB user interface are shown in Figure 4 and the results are shown in Figure 5.

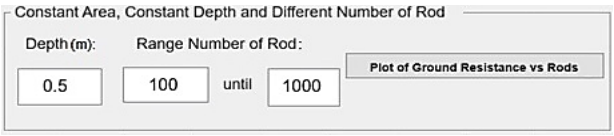

Figure 4. Input values for depth and number of electrode rods in MATLAB user interface graphics

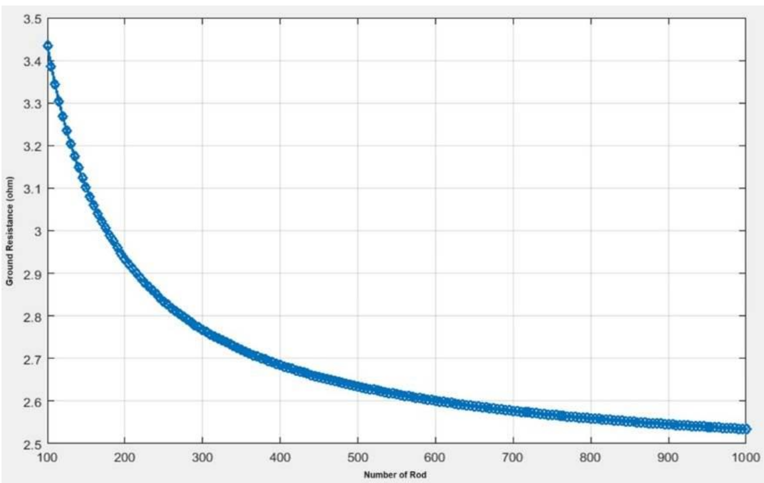

Figure 5. Effect of number of electrodes on grounding resistance

Figure 5 shows the results of the ground resistance simulation in the MATLAB GUI with a depth of 0.5 m and the number of rod electrodes varied from 100-1,000 rods. The number of electrodes influences the grounding resistance value of the Glugur Main Substation. The number of electrodes of 100 rods gives a grounding resistance value of 3.45 Ω, while the number of electrodes of 1,000 rods gives a grounding resistance value of 2.53 Ω. This shows that with a constant grounding depth and by increasing the number of electrodes, the grounding resistance value of the Glugur Substation will be smaller. This meets the PUIL 2,000 standard because the grounding resistance value of the Glugur Substation obtained is still below 5 Ω.

c. Grounding resistance with constant and varying number of rods with MATLAB user interface graphics

The simulation of grounding resistance in MATLAB with both constant and varying numbers of rods provides crucial insights into how electrode configurations affect system performance at substations. The grounding resistance, a key factor in ensuring electrical safety, decreases as the number of rods increases, due to the parallel arrangement of grounding electrodes that distribute current flow across multiple paths, thus reducing the overall resistance. Simulation of the grounding resistance of the Glugur Substation was also carried out by making the number of electrode rods constant, namely, 100 rods and by varying the grounding depth from 0.1 to 1 m. Inputting the electrode rod value and grounding depth is shown in Figure 6, and the results are shown in Figure 7.

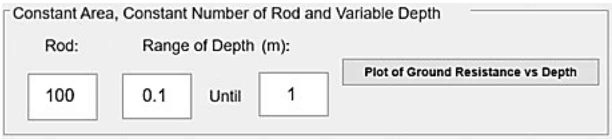

Figure 6. Input a number of electrode rods of 1,000 rods and a depth variation of 0.1-1 m

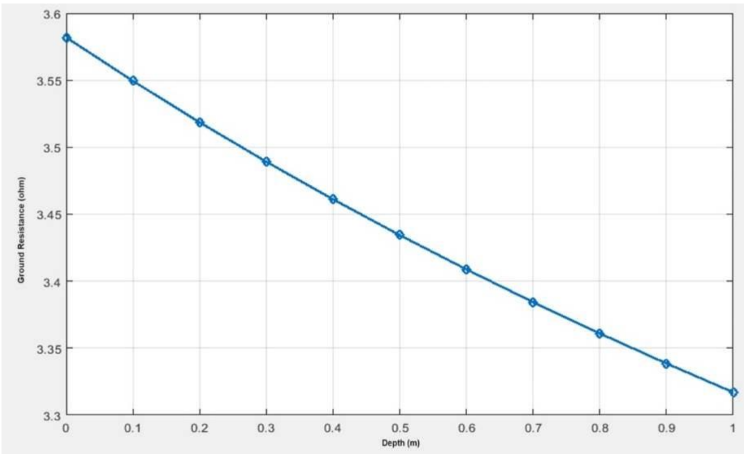

Figure 7. The influence of grounding depth on the grounding resistance of the Glugur Substation

Figure 7 shows the simulation results of the grounding resistance of the Glugur Substation with a total of 100 electrode rods and a grounding depth of 0.1 to 1 m. The depth of the grounding has an influence on the grounding resistance value of the Glugur Substation. At a grounding depth of 0.1 m and with a number of electrodes of 100 rods it gives a grounding resistance value of 2.65 Ω. Meanwhile at a grounding depth of 1 m and with a number of electrodes of 1,000 rods it gives a grounding resistance value of 2.42 Ω. This shows that the deeper the ground resistance is made, the smaller the ground resistance value obtained will be. This is in accordance with the PUIL 2000 standard, namely, the grounding resistance value is still below 5 Ω.

d. Grounding resistance by varying the value of grounding depth and number of electrodes

The analysis of grounding resistance by varying both the grounding depth and the number of electrodes reveals important design considerations for grounding systems, especially in electrical substations. The grounding resistance is inversely related to both parameters: as the depth of grounding electrodes increases or the number of electrodes is raised, the overall grounding resistance decreases, thereby improving system performance. Simulation of grounding resistance using the MATLAB interface user graph at the Glugur Substation was carried out by varying the grounding depth value, namely from 0.1 to 1 m and by varying the number of electrodes from 100 rods to 1,000 rods as shown in the MATLAB user interface graphic Figure 8.

Varying the number of electrode rods and grounding depth was carried out to determine the influence of these two variables. Regarding the grounding resistance value at the Glugur Substation which is formed in a 3-dimensional (3D) graph as in Figure 9, this shows that the greater the number of electrodes and the deeper the grounding, the smaller the grounding resistance value will be. The grounding resistance values of the Glugur Substation are still below 5 Ω as shown in Figure 9.

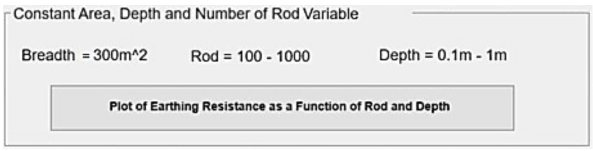

Figure 8. Display of variations in electrode rods and grounding depth

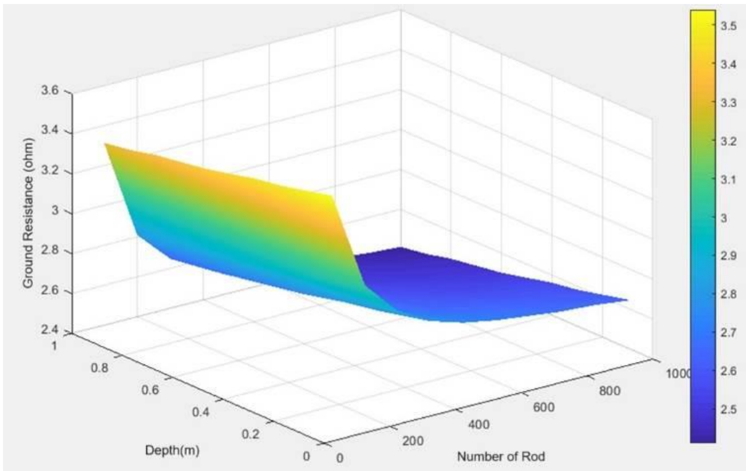

Figure 9. The effect of depth and number of rods on the value of grounding resistance

4. CONCLUSION

The ground resistance system of the Glugur Substation is carried out using the MATLAB GUI. The grounding resistance follows a grid system with an area of 20×15=300 m² with specific resistance being clay using 100 rod electrodes. From the results of ground resistance simulation modeling using MATLAB GUI, it can be concluded as follows: for a certain resistance value, the number of electrodes for 100 Ωm is 3.55 Ω, for ground resistance with a constant depth and a varying number of 100 electrodes, it is 3.45 Ω, and for the grounding resistance with a constant and varying number of 1,000 rods is obtained at 2.65 Ω. From these results, the modeling carried out is in accordance with the standards of electricity regulations in Indonesia.

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