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Research Original Article

Calculation of the Effect of Substation Configuration on the Resistance Value of the Grounding System

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Abstract
Generally, the configuration of the substation grounding system is in the form of a grid or mesh, where several conductor rods are installed vertically and horizontally or combined with conductor rods planted deep in the ground from each point or not. The substation configuration is very complex because of the many variables used in accordance with IEEE Standard 80-2013. This variable also influences the allowable and actual magnitude of the step voltage and touch voltage. The substation grounding system configuration can be designed in several shapes including rectangular, square, L-shaped and T-shaped. The parameters used are an area of 70 m x 70 m, a conductor rod depth of 0.5 meters with a total conductor length for a rectangle of 1540 meters without rods, an L-Shaped shape of 1755 meters and a T-Shaped shape of 3857 meters. The results obtained by the resistance of the grounding system without rods in the T-Shaped configuration were 2.39 Ω. For the resistance results, the grounding system uses a rod with the same area and a conductor length of 3917 meters with a resistance value of 2.39 Ω in the T-shape configuration. The results of the resistance values obtained with various forms of grounding system configurations and varying conductor lengths are still safe and below the threshold or standard of the grid grounding system.
Keywords: Resistance, Rectangular, L-Shaped, T-Shaped

Introduction
There are 2 (two) factors that cause disturbances at substations that cannot be denied, including internal disturbances and external disturbances (Amadi, 2017), (Ibrahim, 2011), (Pickett et al., 2015), (Zimba et al., 2017). Internal factors include technician errors, installation errors and equipment damage. External disturbances are caused by natural factors, for example landslides, floods, lightning strikes, strong winds, earthquakes and others (Jose & others, 2015), (Paul & others, 2020), (Shroder, 2021), (Keller & DeVecchio, 2019), (Smith et al., 2023). This causes the installation of protective equipment to secure the equipment at the substation (Putra et al., 2023). The substation is the link between the transmission line and the distribution network. The configuration or construction of the substation is also an important factor in meeting the requirements in accordance with the design standards for a substation (Hu et al., 2021), (Huang et al., 2016), (Altaher, 2018), (Krieg, 2019). Generally, the configuration of the substation grounding system is in the form of a grid or mesh, where several conductor rods are installed vertically and horizontally or combined with conductor rods planted deep in the ground from each point or not (Uzunlar & Kalenderli, 2009), (Adebayo & Ujam, 2023). The combination of these conductor rods can reduce the value of grounding resistance to as little as possible. The best ground resistance value is below 5 ohms or preferably 1 ohm (Cheema et al., 2015). The substation configuration is very complex because of the many variables used in accordance with IEEE Standard 80-2013 (Hardi et al., 2021). This variable also influences the allowable and actual magnitude of the step voltage and touch voltage (Kostić & Raičević, 2016). The substation grounding system configuration can be designed in several shapes including rectangular, square, L-Shaped and T-Shaped (IEEE 80-2000). Each form of grounding configuration is completed using the parameters contained in the IEEE 80-2013 standard (Gouda, 2024).

Literature Review
Based on the results of a series of field tests conducted by measuring ground rod electrodes in different types of soil at low soil depths on podzolic soil types with yellowish clay soil characteristics and red pebbles having a relatively high soil resistivity, podzolic soil resistivity values are a combination of wet clay and sand. Hence, it assumes 150 Ω.m. This is consistent with the significant grounding resistance seen when utilizing rod electrodes. The best grounding resistance is shown when using a galvanized iron type grounding rod electrode, particularly at a depth of 2 meters in the ground, where the resistance value using a galvanized type rod electrode is 10% to 20% lower than when using an iron type rod

electrode or a copper-coated iron type, indicating that the grounding resistance is not as good when using an iron type rod electrode or a copper-coated iron type (Uzunlar & Kalenderli, 2009). Its maximum allowable value varies from 10Ω (or lower) for lightning protection to 0.1Ω for sites where protective devices must operate very quickly. The grounding grid design is an important factor in a substation for fulfilling standard requirements formulated by IEEE Std. 80. Commonly, substation grounding is a grid configuration or combination of grid and rod. This study is designing a substation economically by considering the length of the rod conductor used. Some grid configuration models were used for analyzing viz. rectangular shape, T-shape, and L-shape. The models were compared with the existing design in the Galang substation to find the minimum conductor length (Hardi et al., 2021).

Materials & Methods

The grid grounding system used in this research is a grounding system configuration in rectangular shape, L-shaped shape, and T-shaped shape using rods and without rods. The rod grounding system uses 20 conductor rods that are plugged into the ground. Other parameters used are the grounding resistance value of 400 ohms, the depth of the conductor rod is 0.5 meters with a total conductor length for a rectangle of 1540 meters without the rod, 1690 with the rod, the L-Shaped shape is 1755 meters and the T-shaped shape is 3857 meters, can be shown in the flowchart below:

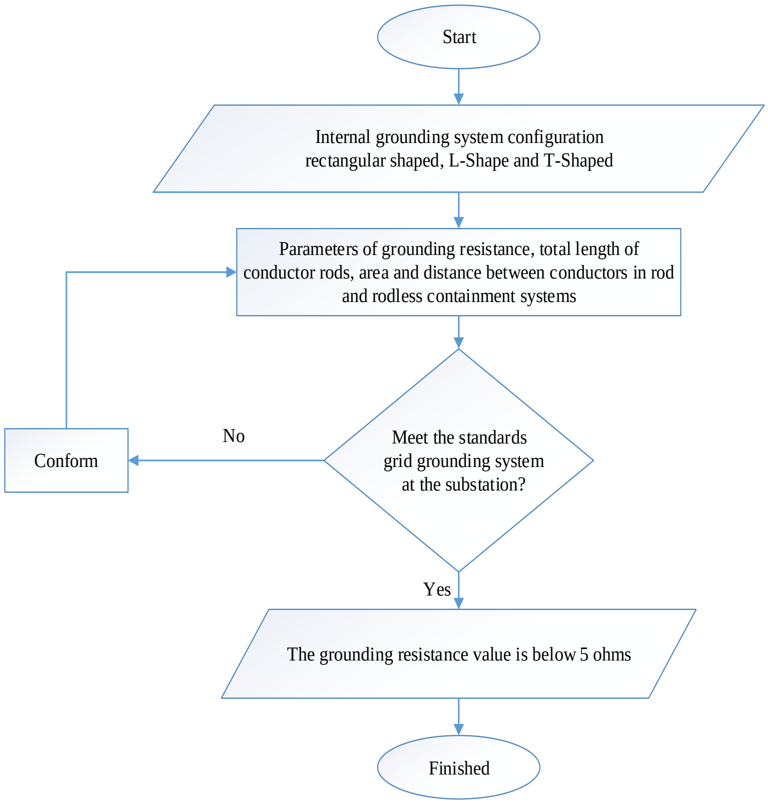
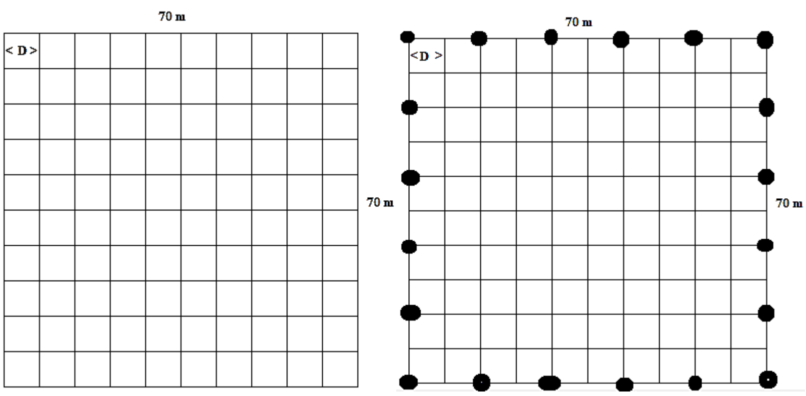


Figure 1. Research Flowchart

Results and Discussion

Configure the Grounding System in a Square Shape

The assumption for the grid grounding area without rods is 70 m x 70 m with the same distance between conductors, namely D = 7 meters, with a depth of embedding the conductor rods, namely h = 0.5 meters, which can be shown in Figure 2 below:



(a) (b)

Figure 2. Grounding System Configuration in Square Shape Without Rod and With Rod

Determining the resistance of grounding without rods using the equation for the total length of the grounding rods L_T = 1540 m and area A = 4900 m² is:

$$R_G = \rho\left[\frac{1}{Lt}\right] + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)$$

$$R_G = 400\left[\frac{1}{1540}\right] + \frac{1}{\sqrt{20.4900}}\left(1 + \frac{1}{1+0{,}5\sqrt{\frac{20}{4900}}}\right) = 2{,}78\ \Omega$$

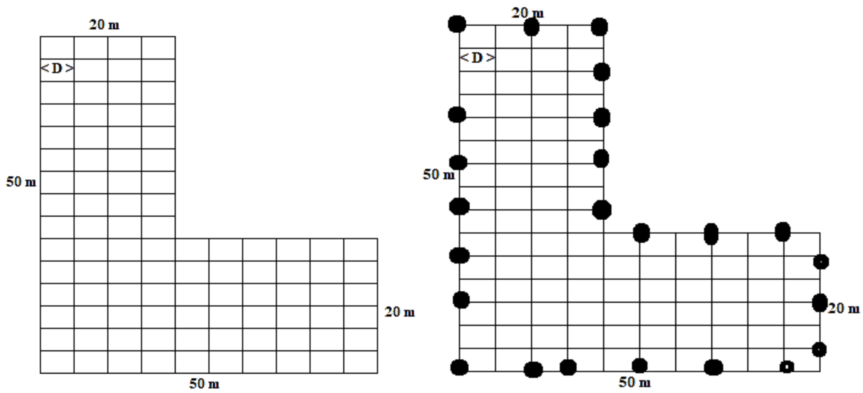
The assumption for determining the grounding resistance with rods is 20 rods with a rod length of 7.5 meters. Determining the grounding system with rods uses the equation for the total length of the grounding rods L_T = 1540 + 20 + 7.5 = 1690 m² and area A = 4900 m²,

$$R_G = \rho\left[\frac{1}{Lt}\right] + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)$$

$$R_G = 400\left[\frac{1}{1690}\right] + \frac{1}{\sqrt{20.4900}}\left(1 + \frac{1}{1+0{,}5\sqrt{\frac{20}{4900}}}\right) = 2{,}75\ \Omega$$

Grounding System Configuration in L-Shaped Form

Assumption for the grid grounding area without rods is 70 m x 70 m with the same distance between conductors, namely D = 7 meters, with a depth of embedding the conductor rods, namely h = 0.5 meters, and the overall length of the conductor rods, namely L^T = 1575 m, can be shown in Figure 3 below:



(a) (b)

Figure 3. Grounding System Configuration in L-Shaped Form Without Rod and With Rod

Determining an L-Shaped grounding system without rods using the equation for the total length of the grounding rods L_T = 1575 m and area A = 4900 m2 is:

$$R_G = \rho\left[\frac{1}{Lt}\right] + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)$$

$$R_G = 400\left[\frac{1}{1575}\right] + \frac{1}{\sqrt{20.4900}}\left(1 + \frac{1}{1+0{,}5\sqrt{\frac{20}{4900}}}\right) = 2{,}67\ \Omega$$

Determining an L-Shaped grounding system without rods using the equation for the total length of the grounding rods LT = 1575 m + (24) (7.5 m) = 1755 m and area A = 4900 m2 is:

$$R_G = \rho\left[\frac{1}{Lt}\right] + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)$$

$$R_G = 400\left[\frac{1}{1755}\right] + \frac{1}{\sqrt{20.4900}}\left(1 + \frac{1}{1+0{,}5\sqrt{\frac{20}{4900}}}\right) = 2{,}64\ \Omega$$

Grounding System Configuration in T-Shaped Form

The assumption is that the grid grounding area without rods is 70 m x 70 m with the same distance between conductors, namely D = 7 meters, with the depth of embedding the conductor rods, namely h = 0.5 meters, and the overall length of the conductor rods, namely L_T = 3857 m without rods, can be shown in Figure 4 below:

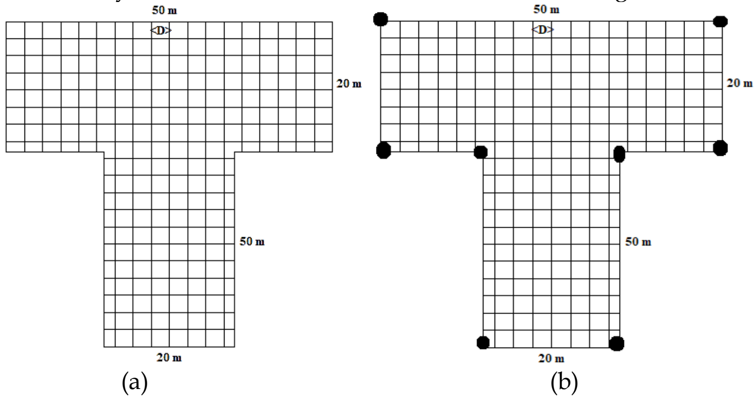


Figure 4. Grounding System Configuration in T-Shaped Form Without Rod and With Rod

Determining a T-Shaped grounding system without rods using the equation for the total length of the grounding rods L_T = 3857 m and area A = 4900 m2 is:

$$R_G = \rho\left[\frac{1}{Lt}\right] + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)$$

$$R_G = 400\left[\frac{1}{3857}\right] + \frac{1}{\sqrt{20.4900}}\left(1 + \frac{1}{1+0,5\sqrt{\frac{20}{4900}}}\right) = 2,39\ \Omega$$

Determine the L-Shaped grounding system with rods using the equation for the total length of the grounding rods L_T = 3857 m + (8) (7.5 m) = 3917 m and area A = 4900 m2 is:

$$R_G = \rho\left[\frac{1}{Lt}\right] + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)$$

$$R_G = 400\left[\frac{1}{3917}\right] + \frac{1}{\sqrt{20.4900}}\left(1 + \frac{1}{1+0,5\sqrt{\frac{20}{4900}}}\right) = 2,39\ \Omega$$

The grounding resistance value for each type of configuration can be shown in Table 1 below.

Table 1. Resistance Calculation Results for a Grid Grounding System Without Rods

Configuration Form	Area (m^2)		Conductor length (m)	Resitance Grid (Ω)
	X	Y		
Rectangle	70	70	1540	2,78
L-Shaped	70	70	1575	2,67
T-Shaped	70	70	3857	2,39

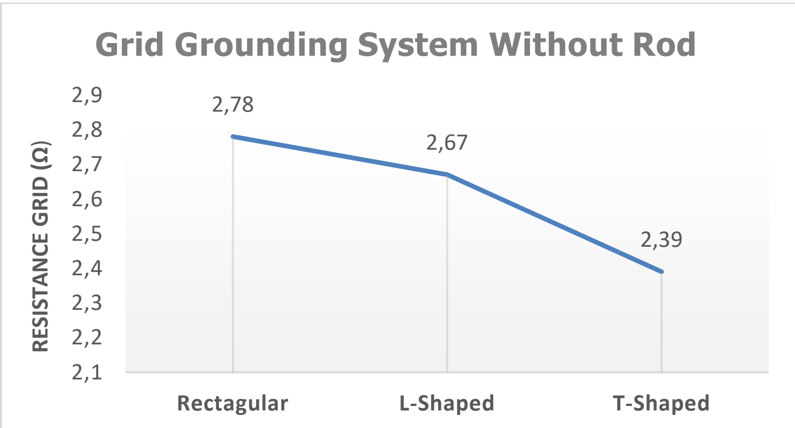


Figure 5. Graph of a Grid Grounding System Without Rods

The results of the calculation of the resistance of the grounding system using rods are shown in Table 2 below.

Table 2. Results of Grid Grounding System Resistance Calculations Using Rods

Configuration Form	Area (m^2)			Conductor length (m)	Resitance Grid (Ω)
	X	Y	Rod		
Rectangle	70	70	20	1650	2,75
L-Shape	70	70	24	1755	2,64
T-Shape	70	70	8	3917	2,39

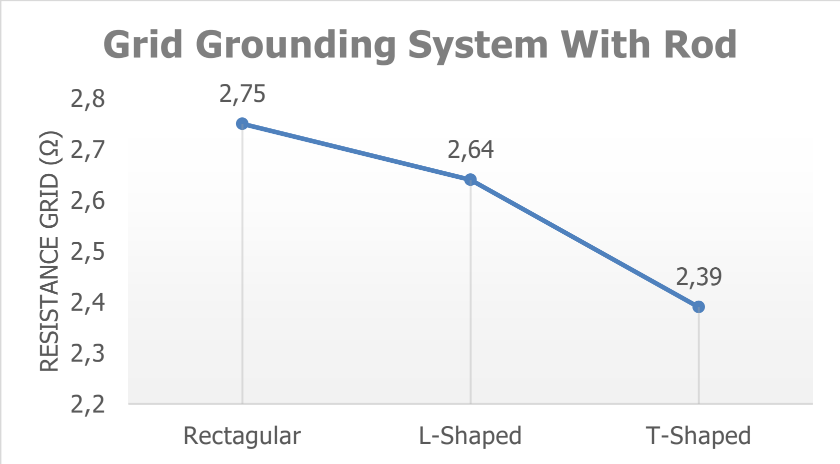


Figure 6. Graph of a Grid Grounding System With Rods

From graph 5 and graph 6 it shows that with the same area, the length of the installed conductor varies with different grounding configurations, the smallest grounding resistance results are found in the grounding system with a T-shaped configuration, namely 2.39 Ω. The results of grid grounding resistance calculations using rods are also in the T-shaped configuration with the same value, namely 2.39 Ω.

Conclusions

From the results of the calculation of the resistance value of the grounding system without rods and using rods in a grounding system configuration in square, L-Shaped and T-Shaped with a resistance value of 400 Ω, with rods installed in various ways, the results of the resistance of the grounding system without rods are obtained. In the T-Shaped configuration with an area of 70 m x 70 m, the conductor length is 3857 meters with a resistance value of 2.39 Ω. For the resistance results, the grounding system uses a rod with the same area and a conductor length of 3917 meters with a resistance value of 2.39 Ω in the T-shape configuration. The results of the resistance values obtained with various forms of grounding system configurations and varying conductor lengths are still safe and below the threshold or standard of the grid grounding system.

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