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Axle Counter Grounding System on The PPI Madiun Railway Using the Wenner Method

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ABSTRACT

Axle counter is a railway detection equipment producing wave frequencies to count the number of axles passing over the track. The existence of a mismatch between the initial and final count numbers usually leads to a red signal and this can prevent the formation of a travel route. The components of axle counter are often damaged by lightning strikes both directly and through the distribution of excessive currents due to a poor grounding system. However, these excessive currents can be safely grounded without damaging the components through the application of a good grounding system. Therefore, this research aimed to plan an effective grounding system to anticipate the incidents using the Wenner method. Some requirements such as soil type, depth, and electrode rod diameter were used in the process to determine the appropriate resistance value. The design was made based on the simulations that closely resembled real field conditions using Aspix software and grounding resistance values were also measured directly on the field to determine the discrepancies between the planning and actual conditions.

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1. INTRODUCTION

Axle counter is one of the train presence detectors with the ability to count and evaluate the number of axles entering and exiting a specific railway detection area. The determination of a match between the number of axles entering and exiting usually allows the track to return to normal without being occupied. Axle counter has two main components including the outdoor and indoor equipment. The outdoor consists of wheel detectors and Wheel Device Equipment (WDE) which are interconnected to send information to the evaluator and provide power from the evaluation unit to the WDE. The indoor equipment is located in the Equipment Room and consists of different modules, each with its specific function. It is important to note that every outdoor railway signaling equipment needs an overcurrent protection system [4] to safeguard the components inside.

In the electrical engineering field, grounding is defined as an electrical circuit connected to eliminate potential differences between voltage and lightning currents by routing them directly to a specific point in the ground. The installation is usually through the usage of conductor cables and grounding electrodes with a dedicated circuit separated from other electrical installations. The process serves as a safeguard against excessive current and voltage in order to protect electronic components and electrical networks from current leaks and shield humans from electrical shocks [1]. This simply means grounding system is normally used to provide a path for electrical currents to the ground both under normal conditions and during faults without causing damage to equipment as well as to reduce the risk of electrical shock hazards in the surrounding area [2].

The use of grounding system in railways is regulated in PM 44 of 2018 which mandates their installation in both outdoor and indoor signaling equipment [4]. Therefore, this final project addresses issues related to axle counter grounding system and signals in the Railway Laboratory area at PPI Madiun. The problem intended to be solved is the damage caused to electronic components in axle counter by lightning-induced surges in the signal, resulting in excessive currents. The surges disrupt railway operations due to the existence of red track faults, which prevent the Operation Control Center (OCC) from establishing routes. This means grounding system to be installed should be capable of safely directing transient currents into the ground in order to reduce step and touch voltages [5]. Moreover, the installation process is also required to comply with standards through the effective selection of conductor cables and electrode rods [3]. This led to the preference for bare core (BC) as the conductor cable while copper-coated stainless steel was used for the electrode rod. It is also important to note that the effectiveness of grounding system can be influenced by the depth of electrode rod installation and the type of soil [6].

The disturbances in grounding system are required to be promptly directed into the ground [8]. Meanwhile, the level of current to be conducted within the system can be influenced by the difference in soil structure. This research focuses on determining the resistance value based on PUIL 2011 specifications to plan an efficient grounding system [8]. This was achieved using the Aspix simulation application to determine the requirements and factors which were further applied to optimize grounding system for axle counter through the Wenner method.

2. GROUNDING SYSTEM

All outdoor signaling equipment is required to have overcurrent protection system [4] from excessive current disturbances and electric induction having the potential to cause harm to the electronic components [1]. WDE axle counter has both internal and external protection system in the form of arresters and grounding. The external protection system consists of a ground rod connected to a conductor cable to route excessive current directly to grounding point in order to secure WDE against electric induction that can damage its micro-components [2].

As previously stated, grounding is a safeguard against excessive current and voltage in order to protect electronic components and electrical networks from current leaks and shield humans from electrical shocks [11]. PUIL 2011 is designed to protect equipment and safety within the protected area at a maximum grounding resistance of 5 Ω. Moreover, PM 44 of 2018 states that the maximum grounding resistance for axle counters is 5 Ω and this is in line with specifications to protect equipment from excessive current disturbances. The two grounding system methods usually used include the series and parallel.

Figure 1 shows the flow of the current injected into grounding electrode into the ground in a forward direction along the electrode. This is referred to as IE current which usually causes an increase in ground potential through grounding resistance Rg. Moreover, there is a longitudinal impedance ZI at the electrode which normally leads to a voltage drop along the component during the flow of current Ii. The flow to the end of the electrode also affects the final grounding impedance. This simply means current Ii flow and the voltage drop generated within the electrode can contribute to the total resistance or impedance of grounding electrode.

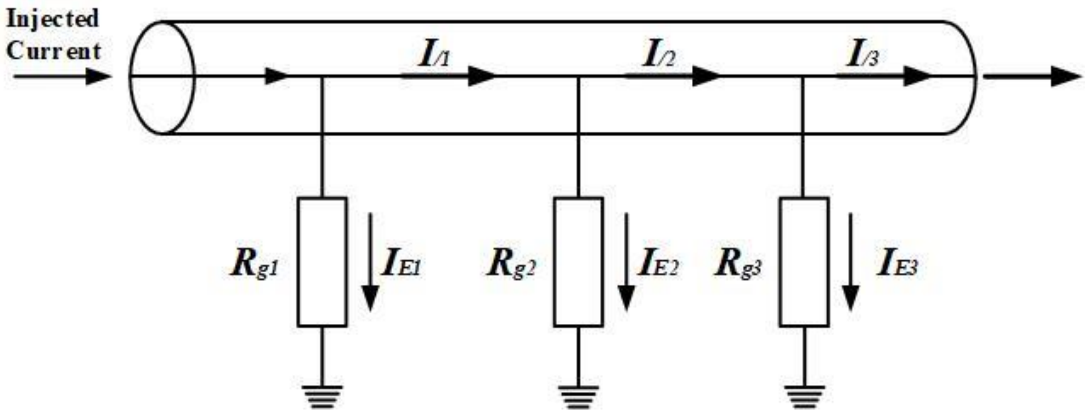


Figure 1. Equivalent model of grounding network

Grounding or earthing system is very crucial in protecting equipment and people from electrical hazards. This means there is a need to comprehend the currents and voltages within the system to ensure safety and proper performance.

The Wenner method is a process where three-electrode rods considered highly effective in obtaining low grounding resistance values are buried in the ground [17]. The primary goal is to estimate the distribution of earth resistivity at different depths. Moreover, resistivity is defined as the property indicating the level at which a material can inhibit the flow of electrical current. A higher resistivity value indicates a lower conductivity in a material and vice versa. The Wenner method is usually represented using the following equation [26]:

$$\rho = 2\pi a R \qquad (1)$$

Description:
R = Bar electrode grounding resistance (Ω)
ρ = Soil resistivity (Ωm)
a = Electrode rod diameter (m)

An equation is normally used to determine grounding resistance values in the process of planning a grounding system. It usually relates to the length of an electrode (IEEE Std 142-1007) [16], as follows:

$$R = \frac{\rho}{2\pi L}\left(log\ \frac{4L}{a} - 1\right) \qquad (2)$$

Description:
R = Bar electrode grounding resistance (Ω)
ρ = Soil resistivity (Ωm)
L = Embedded rod length (m)
a = Electrode rod diameter (m)

The Driven Grounds System (SDG) is a grounding system where electrode rods are buried in the ground at the desired depth. The resistance value is usually influenced by the depth at which the electrode rods are buried [17]. According to PUIL 2011, one of the specifications of grounding system in Indonesia is to have a minimum electrode rod length ranging from 1 to 5 meters [19]. Moreover, the depth is inversely related to the conductivity and resistance of grounding system. This is because higher depth is expected to lead to more conductivity and lesser resistance.

Another important factor is the diameter of the electrode rod and this is because a larger value usually leads to a smaller percentage of resistance. The standard technological paper 108 (A) is normally used to compare the effect of electrode rod diameter based on the laboratory tests conducted in Chicago (B) and Pittsburgh (C) [17]. Moreover, PUIL 2011 states that the minimum diameter for grounding system in Indonesia ranges from 10 mm², 16 mm², 25 mm², to 35 mm² [19].

Geographical conditions are one of the factors influencing the resistivity value of the soil because the materials used to make the surface of the Earth have low electrical conductivity [24, 23]. This is the reason soil resistivity value is normally affected by weather and seasons [24], leading to significant heterogeneity in the flow of current into the ground [16]. These variations depend on the depth of the electrode rod and parameters such as humidity, temperature changes, and soil salt content. Moreover, soil resistivity values have been reported to be lower beneath the water table [17, 23]. This is related to the objective of grounding which is to rapidly distribute excess current into the ground [6]. It has been discovered that the characteristics of the ground determine its resistivity values and grounding resistance [14].

The addition of salt to the soil is a temporary treatment to reduce resistivity values but is not long-lasting due to the possibility of depletion over a period [16]. The resistivity value (Ω/m) of different types of soil including paddy, clay, dry, and rocky soils [23] is presented in the following Table 1.

Table 1 - Resistivity based on ground type

Ground Type	Resistivity(Ω/m)
Paddy	10
Marshland	30
Clay	100
Wet Sand	200
Wet Gravel	500
Dry Sand and Gravel	1000
Rocky soil	3000

The resistivity values can change depending on the chemical elements of the soil. For example, paddy is a type of soil formed from the weathering of organic materials found in the upper layer and has a high water absorption capacity. It also has a loose texture due to the high nutrient content from the decomposition of organic matter, making it very fertile for cultivation. This soil has a resistivity value of 10 **Ω**/m based on a test conducted [2, 16, 18, 19].

Environmental factors are observed to have the ability of causing measurement errors [22]. The determination of the errors in grounding resistance values can strengthen the data to be used in a research due to the differences in planning, simulation, and test results. The percentage of error can be calculated using the following equation [22] where the experimental value is obtained from planning and simulation while the accepted value is from direct test:

$$Error = \frac{|experimental\ value - accepted\ value|}{accepted\ value}\ \mathrm{X}\ 100\% \tag{3}$$

$$Error = \frac{|supporting\ data - test\ data|}{test\ data}\ \mathrm{X}\ 100\% \tag{4}$$

The percentage of error in the planning process can be calculated by changing the existing equation to:

$$Error = \frac{|planning\ result - test\ result|}{test\ result}\ X\ 100\% \tag{5}$$

The percentage of error in the simulation can also be calculated by changing the existing equation to:

$$Error = \frac{|simulation\ result - test\ result|}{test\ result}\ X\ 100\% \tag{6}$$

3. METHOD

The Wenner grounding system was planned by setting the depth of electrode placement at a maximum depth of 250 cm and the rod diameter was varied at 10 mm², 16 mm², and 25 mm² for both the paddy fields and marshland. These variations were intended to determine and select the appropriate grounding resistance for the system.

Grounding system model was created and the supporting data such as soil resistivity and material specifications were added according to PUIL 2011. This was followed by simulations to determine the modeling results. Moreover, specialized grounding system software was used for the modeling in line with the IEEE 80 Guide for Safety in AC Substation Grounding standard. ASPIX software was also used to calculate grounding resistance, touch voltage, and step voltage for different models. Furthermore, the two-dimensional and three-dimensional graph formats were used to enable the assessment of the effectiveness and safety of grounding system planned. The model was simulated by inputting the relevant parameters into the Aspix software to produce a grounding design and the graphs obtained were used to determine the optimal effectiveness and safety.

Table 2 - Setting features

Properties	Value
Project name	New Project
Upper layer resistivity (Ω/m)	100
Lower layer resistivity (Ω/m)	200
Upper layer thickness (m)	2
Crushed rock resistivity (m)	20000
Thickness of crushed rock surfing (m)	0.2
Fault duration (s)	0.5
Maximum ground fault current (A)	5000
Remote Current Contribution (%)	100

Table 3 - Rods features

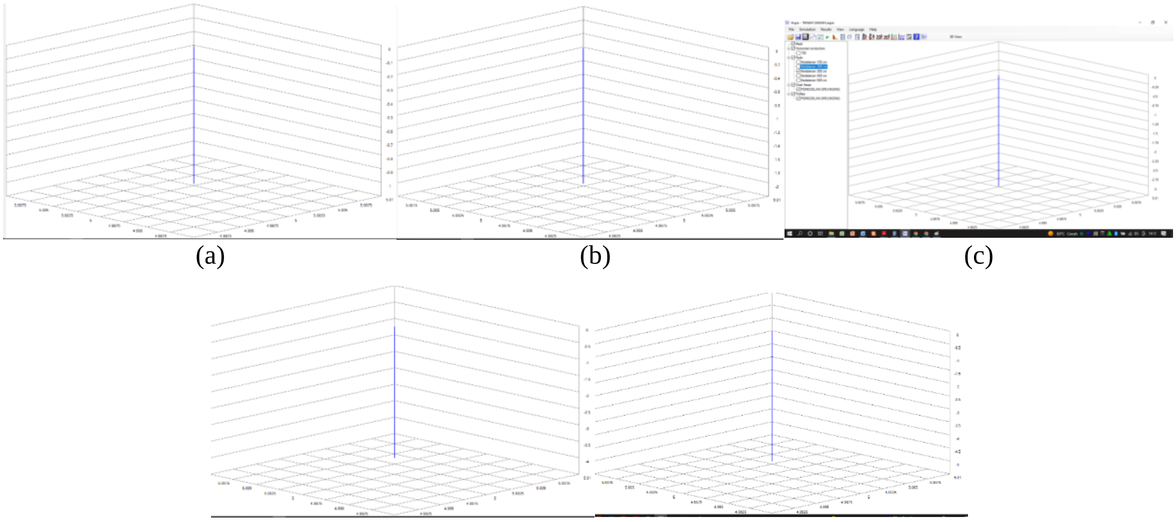
Properties Name	Value
X (m)	0
Y (m)	0
L (m)	0
h (m)	0
r (m)	0

The attributes of the electrode rods used in modeling were X and Y as coordinates, L was the depth, h was the distance between the rods and the soil layer, and r was the diameter.

Table 4 - Chart Area

Properties	Value
Name	
Initial X for touch and step voltage (m)	0
Number of points in X	0
Initial Y for touch and step voltage (m)	0
Number of points in Y	0

The profile features provided the simulation results in the form of touch and step voltage graphs with adjustable curve shapes based on the parameters provided. Therefore, grounding depth modeling is shown in the following Figure 2.



(a) (b) (c)

(d) (e)

Figure 2. Grounding depth modeling, (a) 50 cm grounding design, (b) 100 cm grounding design, (c) 150 cm grounding design, (d) 200 cm grounding design, and (e) 250 cm grounding design

In figure 2 represented grounding system modeling design with a depth of 50 cm at coordinates X = 5 and Y = 5. Grounding system modeling design with a depth of 100 cm at coordinates X = 5 and Y = 5. Grounding system modeling design with a depth of 150 cm at coordinates X = 5 and Y = 5 and 8. The coordinates were also placed on X1= 5, Y1= 5, X2= 8, Y2= 5. Grounding system modeling design with a depth of 200 cm at coordinates X = 5 and Y = 5. And grounding system modeling design with a depth of 250 cm at coordinates X = 5 and Y = 5.

4. MEASUREMENT AND TEST

Measurement and test were conducted to determine grounding resistance values using an Earth Tester. The differences between the measurement and grounding system model were also evaluated by directly burying electrode rods at intervals of 50 cm to a depth of 250 cm using the Fall of Potential method. The resistance values were determined at the Railway Laboratory of PPI Madiun with electrode rod diameters of 10 mm², 16 mm², and 25 mm². Moreover, the length of the rods used was 120 cm and two pieces were buried incrementally using a shock method to reach a depth of 250 cm. The topology of the Wenner grounding system applied in this research is presented in the following Figure 3.

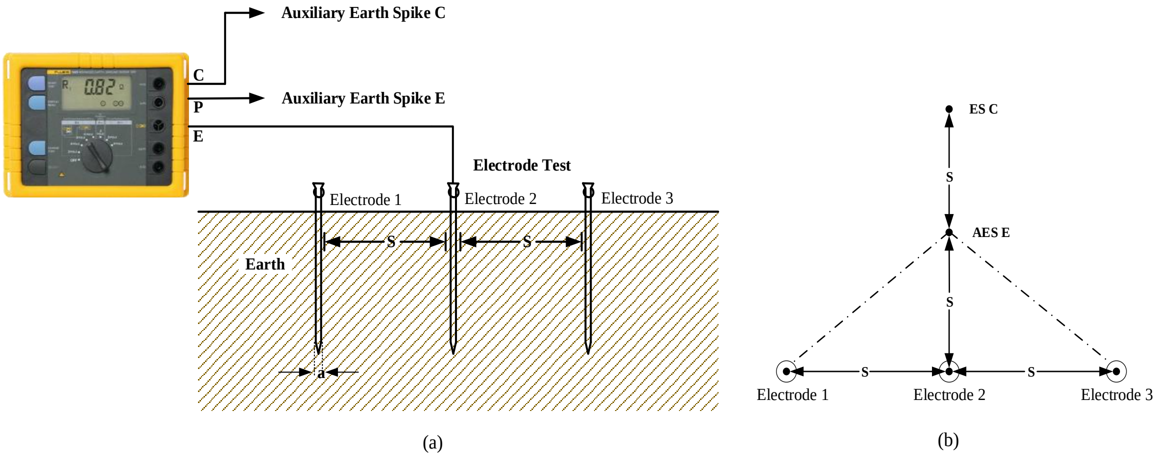


Figure 3. Test scenario, (a) Grounding test topology, (b) Top view

5. RESULTS AND DISCUSSION

Table 5 - The Wenner grounding planning calculations

Soil Testing Depth (m)	Electrode Diameter (Ω)		
	10 mm^2	16 mm^2	25 mm^2
0,5	16,85	6,66	6,04
1	9,53	3,81	3,50
1,5	6,78	2,73	2,52
2	5,32	2,14	1,99
2,5	4,39	1,78	1,65

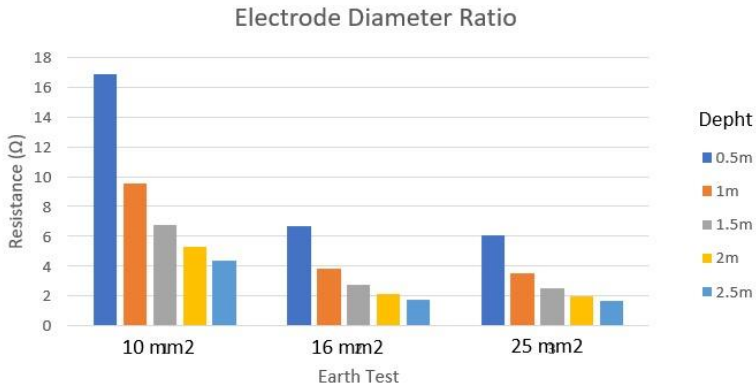


Figure 4. Electrode diameter ratio for the planning process

The graph in Figure 4 explains the influence of the installation depth and diameter of the electrode rods on resistance for the plan. The results showed the ground resistance value was reduced significantly to the standard by the depth used in the Wenner method.

Table 6 - The Wenner grounding simulation

Soil Testing Depth (m)	Electrode Diameter (Ω)		
	10 mm^2	16 mm^2	25 mm^2
0,5	16,85	6,66	6,04
1	9,53	3,81	3,50
1,5	6,78	2,73	2,52
2	5,32	2,14	1,99
2,5	4,39	1,78	1,65

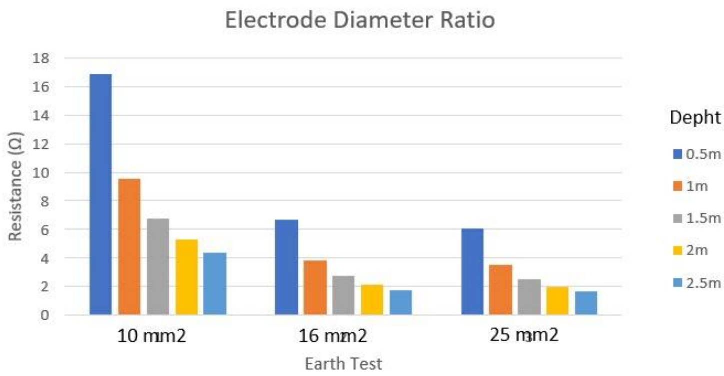


Figure 5. Electrode diameter ratio simulation

Figure 5 shows the influence of installation depth and diameter of electrode rods for the simulation. The results also showed that the installation depth and soil type had a significant impact on the resistance value while the influence of the diameter was minor. This was indicated by the observation of the smallest resistance value at a diameter of 25 mm^2. Moreover, the electrode rods with larger diameters and installed deeper in the ground also had smaller resistance values.

Table 7 - The Wenner grounding test

Soil Testing Depth (m)	Electrode Diameter (Ω)		
	10 mm^2	16 mm^2	25 mm^2
0,5	19,38	10,79	7,61
1	11,76	5,56	4,42
1,5	9,45	4,14	3,56
2	6,19	2,91	2,14
2,5	5,83	2,45	1,94

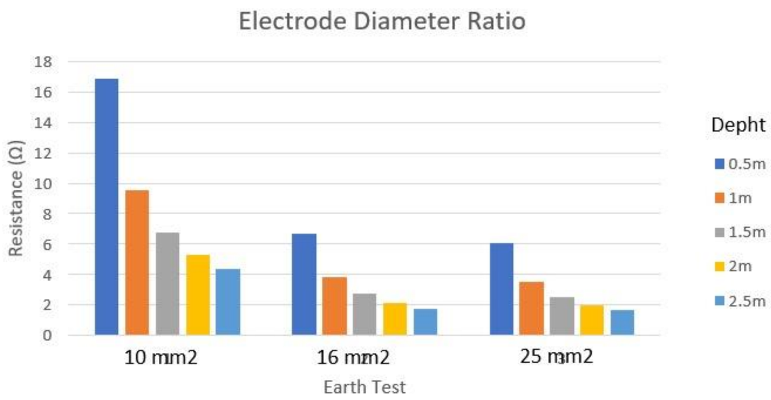


Figure 6. Electrode diameter ratio test

Figure 6 shows the influence of installation depth and diameter of electrode rods for the field test. It was observed that the installation depth and soil type had a significant impact on the resistance value while the influence of the diameter was minor. This was indicated by the observation of the smallest resistance value at a diameter of 25 mm². Moreover, the electrode rods with larger diameters and installed deeper in the ground also had smaller resistance values. The data obtained from the measurement and test were used to calculate the percentage of error between the planning, simulation, and field test values.

Table 8 - Percent error of the Wenner grounding plan

Soil Testing	Electrode Diameter		
Depth (m)	10 mm^2	16 mm^2	25 mm^2
0,5	13,05%	38,28%	20,63%
1	18,96%	31,47%	20,81%
1,5	28,25%	34,06%	29,21%
2	14,05%	26,46%	7,01%
2,5	24,70%	27,35%	14,95%
Total	99,03%	157,6%	92,62%
Average error	1,41%	5,04%	3,95%
Total Errors		3,4%	

The percentage of error between the values obtained from the planning process and field test was found to be at an average of 3.4% as presented in the table.

Table 9 - Percent error of the Wenner grounding simulation

Soil Testing	Electrode Diameter		
Depth (m)	10 mm^2	16 mm^2	25 mm^2
0,5	13,05%	38,28%	20,63%
1	18,96%	31,47%	20,81%
1,5	28,25%	34,06%	29,21%
2	14,05%	26,46%	7,01%
2,5	24,70%	27,35%	14,95%
Total	99,03%	157,6%	92,62%
Average error	1,88%	6,10%	4,71%
Total Error		4,2%	

The percentage of error between the values obtained from the simulation and field test was found to be at an average of 4.2% as presented in the table. Furthermore, the following graph was used to explain the validation of the difference in errors between the planned and simulated soil for each diameter. It was found that the simulation had higher errors compared to the plan. Therefore, the type of soil used for the measurements and tests significantly influenced grounding resistance values.

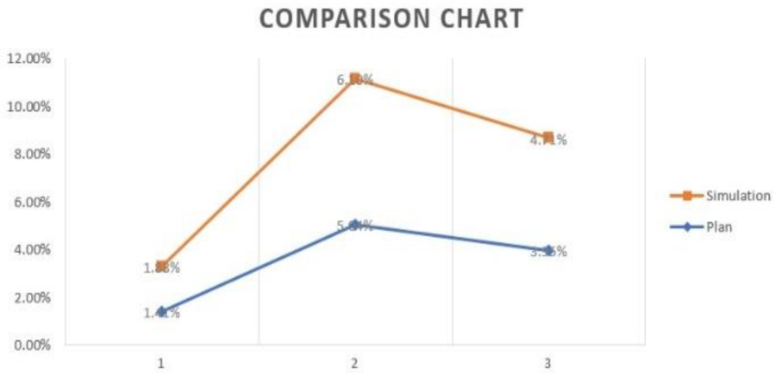


Figure 6. Comparison of plan and simulation errors

The application of electrode rod in axle counter grounding system was found to be more advantageous for limited space because it was more economical and easier to replace. The system was observed to need maintenance to ensure the resistance values were within the standards required. This was required due to the possibility of corrosion in the rods which could increase the resistance values. The Wenner grounding system was also found to be the most effective in testing the soil but had high grounding resistance values. The smallest value recorded was inefficient because more space and costs were required to insert the electrode.

6. CONCLUSION

In conclusion, soil resistivity was observed to have a significant effect on grounding resistance values based on the planning, simulation, and test conducted. This was indicated by the fact that different types of soil tested produced different resistance values due to the differing resistivity. Moreover, the field tested had the lowest grounding resistance values and this was based on the soil resistivity used in the Wenner method. The depth of electrode placement also had an effect and this was indicated by the smaller values recorded for rods placed deeper in the ground. The most optimal depth found during the test conducted at the PPI Madiun Laboratory was 1.5 m. Meanwhile, the electrode diameter was found to have a minor impact on grounding resistance values. This was observed from the fact that the rods with larger diameters produced smaller values because the rods carried a greater current. The results showed that 10 mm² diameter had the highest resistance value while 25 mm² had the lowest for each soil type. Therefore, the most optimal diameter recorded for an effective grounding system was 25 mm².

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