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Parallel Grounding Effects on Transformer Resistance and Distribution Substation Reliability

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ABSTRACT

The grounding system is an essential component of power installations that provides a low-impedance path for fault currents to flow safely into the earth, thereby protecting personnel and equipment from hazards associated with touch and step voltages. Excessive grounding resistance can reduce the effectiveness of protection systems and increase the risk of disturbances and equipment damage. This study aims to analyze the effect of adding a parallel grounding electrode on the grounding resistance of a 250 kVA distribution transformer at the Customer Service Unit of PT PLN (Persero) Cirebon Kota. The research was conducted through field measurements using a Duoyi DY4 100 Digital Earth Tester and the fall-of-potential (three-point) method. Measurements were performed using a single grounding electrode, followed by the installation of an electrode connected in parallel. Measurements were then conducted under conditions to evaluate resistance changes. The data were analyzed by comparing resistance values before and after parallelization based on PUIL 2011, using a grounding resistance criterion of ≤ 5 Ω. The results show that grounding resistance decreased from 2.90 Ω to 0.85 Ω, representing a 70.8% reduction. This result demonstrates that parallel grounding reduces resistance and improves the safety and reliability of the transformer grounding system.

Keywords: Grounding System; Parallel Electrodes; Grounding Resistance; SPLN 2011

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1. INTRODUCTION

The grounding system is a crucial element in electrical installations, acting as a path for fault currents to flow to the ground. This system is specifically designed to protect the safety of people and electrical equipment, while ensuring the reliability of the electrical network by reducing the risk of touch voltages and step voltages [1], [2]. Extremely high grounding resistance can cause the protection system to fail to operate optimally, while increasing the risk of damage to electrical equipment [3].

In distribution substations, the grounding system serves as the primary barrier, ensuring that fault currents travel quickly and safely to the ground. However, the resistance value of this system is often influenced by various factors, including soil type, electrode depth, environmental conditions, and the electrode installation technique used [4][5].

An effective method for reducing grounding resistance is by adding electrodes simultaneously. When electrodes are arranged in parallel, fault current can flow through multiple paths simultaneously, reducing the overall resistance to the ground [6]. Previous studies have shown that combining multiple electrodes in parallel can improve grounding system performance while significantly reducing ground resistance [7].

In the Cirebon area of PT. PLN (Persero) ULP, the grounding resistance of distribution transformers varies due to soil conditions and the type of grounding system. In BJPH substations located in fields, the grounding resistance tends to be higher due to the dry soil and minimal water content. Therefore, this research is essential to assess the effect of adding parallel electrodes on the grounding resistance value of these distribution transformers.

This study aims to analyze changes in grounding resistance values before and after the use of parallel electrodes, while evaluating the increase in the reliability of the grounding system in accordance with electrical safety standards. A low grounding resistance value is required to ensure that fault current can be safely discharged into the earth and reduce the risk to equipment and personel [8].

Grounding system optimization is important because grounding resistance, step voltage, and touch voltage are key parameters in electrical installation safety [9].

2. RESEARCH METHOD

This study adopts a quantitative experimental approach through direct field measurements and comparative analysis of grounding resistance values before and after the installation of parallel grounding electrodes. This method was chosen to ensure the data obtained is objective in assessing the effectiveness of reducing grounding resistance through parallel arrangement of the transformer grounding system, so that its effect on increasing the reliability of protection in the electricity distribution system can be studied in depth.

2.1 Research Location

The BJPH substation was selected because its initial grounding resistance, although below the maximum allowable limit of 5 Ω, was not considered sufficiently low to achieve the desired level of protection performance. This substation is located on dry and porous field soil, resulting in high grounding resistance. This location was chosen because these conditions have the potential to reduce the effectiveness of the *grounding system,* necessitating improvements to improve equipment safety and the reliability of electrical energy distribution.

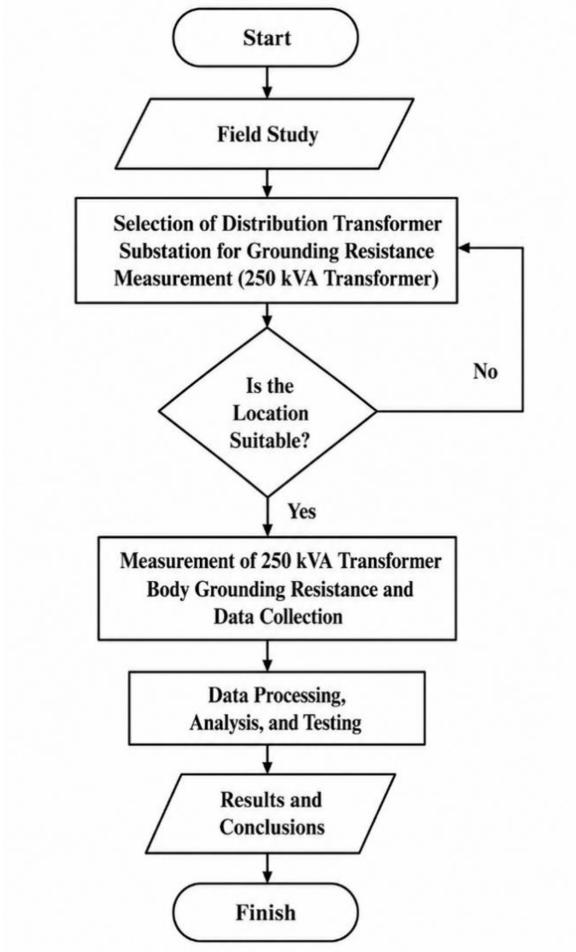
2.2 Data Measurement and Validation Techniques

In this study, technical accuracy was maintained through the consistent implementation of the measurement method before and after the installation of the parallel grounding electrode. Grounding resistance was measured using a Digital Earth Tester with the fall-of-potential method (three-point method), involving three electrodes: the main electrode (E), which was connected to the transformer body, the current electrode (C), and the potential electrode (P).

In the initial phase, the grounding system of the 250 kVA distribution transformer utilized only a single grounding rod electrode. Subsequently, an additional electrode was installed in parallel with the main electrode. During the measurement process, the distance between the main electrode and the additional electrode was maintained consistently so that the measurement results before and after the electrode addition could be evaluated objectively.

The grounding system configuration before and after the installation of the additional electrode is clearly illustrated and supported by field documentation of the grounding system structure that became the focus of this study. From a technical perspective, the installation of an additional parallel electrode expands the surface contact area between the electrodes and the surrounding soil, creating additional paths for fault current to flow more effectively into the ground. This condition causes a significant reduction in grounding resistance, thereby improving the effectiveness of the grounding system in distributing fault current more optimally.

The fall-of-potential method is widely used to measure grounding resistance because it can determine the resistance value of grounding electrodes through the placement of current and potential electrodes [10]. The reliability of grounding resistance measurements is strongly influenced by the measurement method, electrode configuration, and soil resistivity conditions during testing [11]. Differences between calculated and measured grounding resistance may occur due to electrode dimensions, installation procedures, and soil disturbances during field installation [12]. Grounding resistance measurements should also consider environmental conditions because temperature and soil moisture can cause variations in the measured resistance values [13].



Picture 1. Flowchart Research

Study This started with observation direct for dig condition beginning system *grounding* on the transformer 250 kVA distribution. After that, stage selection and assessment location measurement *resistance grounding* implemented based on criteria technical that has been developed in studies this. If the selected location it turns out Not yet fulfil standard, then location the will replaced in accordance needs. However, if location Already in accordance with requirements, steps next is do measurement resistance *grounding* on the transformer body. Result data measurement the Then collected and analyzed with carefully, until Finally study This completed with compilation report as well as formulation conclusion.

Data analyzed through comparison mark resistance land before and after placement electrode in a way parallel, in order to assess level repair in system grounding Measurement process This refers to various indicators, including mark resistance initial value resistance after addition electrode parallel, percentage decline resistance, as well as suitability results measurement with standard security applicable electricity.

Percentage subtraction resistance counted from ratio mark before and after repair done. The decrease more resistance big show that configuration parallel the more effective in repair quality system grounding. Measurement results furthermore compared to with the 2011 PUIL norms which stipulate mark maximum ≤ 5 Ω[14]. If mark resistance be under threshold and shows significant reduction, then system grounding considered more can reliable in distribute current disturbance as well as more safe for devices and power Work.

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2.3 Type of Grounding

Grounding systems are generally classified into system grounding, lightning protection grounding, and equipment grounding according to their respective protection functions [15]. he selection of grounding configuration is influenced by soil conditions, electrode depth, and the required protection objectives [16]. Grounding systems can be implemented using rod, plate, ring, grid, or combined electrode configurations depending on site conditions and protection requirements[17].

A grounding electrode provides a conductive path for fault current to flow into the earth. Electrode dimensions, soil characteristics, and installation techniques significantly affect the resulting grounding resistance [18]. Increasing electrode length or using multiple electrodes can reduce grounding resistance by increasing the effective contact area and providing additional current paths [19]. However, grounding electrode performance may decrease over time because corrosion is influenced by soil moisture, resistivity, pH, and salt content [20].

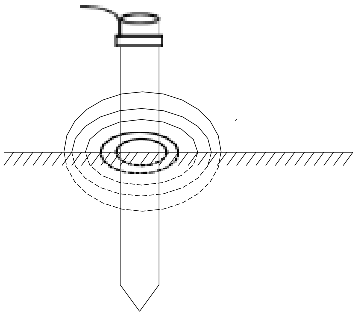

Figure 2. Component stem electrode

$$R\frac{\rho L}{A} \qquad (1)$$

Where:
R = Grounding Resistance (Ω)
ρ = Soil Resistivity (Ωm)
L = Length of current path in the soil (m)
A = Cross-sectional area of the current path in the soil (m²)

2.4 Rod Electrodes and Parallel Configuration

Rod electrodes are conductive rods installed vertically in the soil and are commonly used because they require relatively little installation space. Increasing the installation depth can reduce grounding resistance by extending the electrode into deeper soil layers [21].

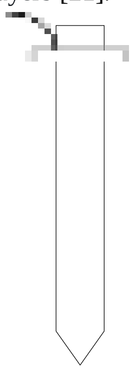

Figure 3. electrode stem single

When two or more electrodes are installed in parallel, fault current can flow through multiple paths to the earth. The resulting grounding resistance is affected by electrode length, diameter, spacing, and soil resistivity[22]. Adequate electrode spacing is required to reduce the influence of overlapping current-dispersion areas. Therefore, parallel electrode configurations generally provide lower grounding resistance than a single-electrode configuration.

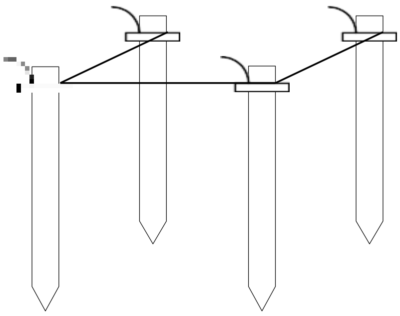

Figure 4. Electrode stem in group

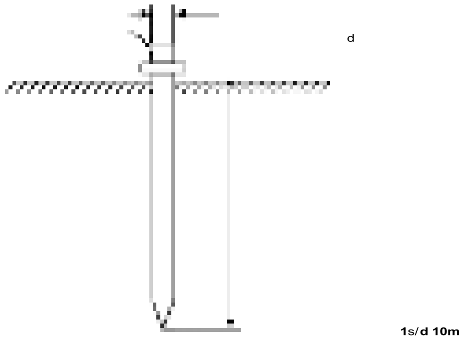

Figure 5. Depth stem electrode

2.5 Soil Resistivitiy

Soil resistivity represents the ability of soil to oppose the flow of electric current and is an important factor in determining grounding-system performance. Its value is influenced by soil depth and environmental conditions [23]. Reliable soil-resistivity evaluation requires measurements over an appropriate period to account for variations in soil conditions [24].

The electrical characteristics of soil-enhancement materials can also affect grounding performance through changes in soil resistivity and permittivity [22]. Seasonal variations in moisture and temperature can cause changes in soil conductivity and consequently affect grounding resistance [25]. Dry and rocky soil conditions generally produce higher grounding resistance because limited moisture reduces the ability of the soil to conduct electric current [26]. Accurate soil-resistivity modeling is important for designing reliable grounding systems, particularly in high-voltage substations [27]. Grounding resistance can also vary according to the type and characteristics of the soil surrounding the electrode [28].

$$R_{bt^2}=\frac{\rho}{4\pi L}\left(1n\frac{4L}{d}-1\right)+\frac{\rho}{4\pi s}\left(1n\frac{L^2}{3s^2}+\frac{2L^2}{5s^4}\right) for\ s>L \qquad (2)$$

$$R_{bt^2}=\frac{\rho}{4\pi L}\left(1n\frac{4L}{d}+1n\frac{4L}{s}-2+\frac{s}{2L}-\frac{s^2}{16L^2}+\frac{s^4}{512L^2}\right) for\ s<L \qquad (3)$$

Where s = Distance k between the two rod electrodes (meters)

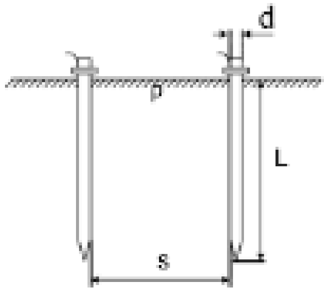

Figure 6. Two rods electrode planted

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Table 1. Soil Resistivity Values

Soil Type	Soil Resistance (Ω.m)
Marshland	10 – 40
Clay and Farmland	20 – 100
Wet Sand	50 – 200
Wet Gravel	200 – 3000
Dry Sand / Gravel	< 10000
Rocky Land	2000 – 3000
Sea Water and Fresh Water	10 - 100

2.6 Evaluation of Grounding-Resistance Reduction

A low grounding resistance is important to provide an effective path for fault current and reduce the risk of touch and step voltages to personnel and electrical equipment [28]. Therefore, the effectiveness of grounding-system improvement can be evaluated by comparing the resistance values before and after the installation of parallel electrodes.

The percentage reduction in grounding resistance is calculated using:

$$\eta(\%) = \frac{R_{before} - R_{after}}{R_{before}} \times 100\% \tag{4}$$

Where is the percentage reduction, is the grounding resistance before improvement, and is the grounding resistance after improvement.

For parallel grounding paths, the equivalent resistance can be expressed as:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} \tag{5}$$

Where Req is the equivalent grounding resistance and R1,R2,…,Rn are the individual grounding-path resistances. The equation indicates that adding parallel grounding paths reduces the equivalent resistance of the system. However, actual field measurements may differ from theoretical calculations because of electrode spacing, mutual resistance, soil nonuniformity, moisture conditions, and installation conditions.

3. RESULTS AND DISCUSSION

Referring to PUIL 2011, the optimal ground resistance is recommended to be below 5 Ohms; the smaller the resistance, the superior the performance of the grounding system, while strengthening protection against the danger of leakage currents that threaten safety.

3.1. Grounding Resistance Calculation

Using equation 3 to calculate the grounding resistance of two electro rods installed in parallel, namely:

$$R_{bt^2} = \frac{\rho}{4\pi L}\left(1n\frac{4L}{d} + 1n\frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^2}\right) for\ s < L$$

Calculation of grounding resistance for two electrode rods connected in parallel. Based on survey data at the BJPH distribution substation with a 250 KVA transformer, the following variables were obtained:

Soil Resistivity (ρ)	: 100 Ωm
Diameter (D)	: 0.35 cm
π	: 3.14
Electrode Length (L)	: 140 cm
Electrode Spacing (A)	: 100 cm

$$R_{bt^2} = \frac{\rho}{4\pi L}\left(1n\frac{4L}{d} + 1n\frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^2}\right) for\ s < L$$

$$1n\frac{4L}{d} = \frac{4 \times 140}{0{,}35} = \frac{560}{0{,}35} = 1600$$

$$\text{In}(1600) \approx 7{,}377$$

$$1n\frac{4L}{s}=\frac{560}{0,35}=5,6$$
$$\text{In}(5,6)\approx 1,722$$

$$\frac{s}{2L}=\frac{100}{2\times 140}=\frac{100}{280}=0,357$$

$$\frac{s^2}{16L^2}=\frac{100^2}{16\times 140^2}=\frac{10000}{16\times 19600}=\frac{10000}{313600}\approx 0,0319$$

$$\frac{s^4}{512L^2}=\frac{100^4}{512\times 140^4}\approx 0,0005$$
$$=7,377+1,722-2+0,357-0,0319+0,0005$$
$$=7,4256$$

$$\frac{\rho}{4\pi L}=\frac{100}{4\times 3,14\times 140}$$
$$=\frac{100}{1758,4}\approx 0,0569$$

$$R_{bt^2}=0,0569\times 7,4256\approx 0,422\Omega$$

From this data, using equation 3, resistance of three rods parallel electrodes counted of 0.42 Ω.

3.2. Measurement Result

Based on the results of grounding resistance measurements on the 250 kVA distribution transformer of the BJPH Main Substation of PT PLN (Persero) ULP Cirebon City which was carried out for 10 days from January 1 to 10, 2026, grounding value data was obtained before and after the installation of parallel electrodes as shown in tabel 2 and 3:

Table 2. Grounding Measurement Results

Day	Grounding Value Before Paralleling (Ω) Time			
	09.00 (Ω)	12.00 (Ω)	16.00 (Ω)	Average
1	2,54	2,44	2,41	2,46
2	2,88	3,18	3,31	3,12
3	2,72	2,89	2,80	2,80
4	2,81	2,87	2,88	2,85
5	2,87	2,84	2,89	2,87
6	2,96	2,93	2,89	2,93
7	2,93	2,88	2,90	2,90
8	2,96	3,01	3,03	3,00
9	2,96	3,03	3,04	3,01
10	3,03	3,12	3,13	3,09

Table 2 shows significant variations in grounding resistance values prior to parallel connection. On the first day, the grounding resistance ranged from 2.41 Ω to 2.54 Ω, followed by an increase on the second day to a range of 2.88 Ω to 3.31 Ω. From the third to the sixth day, grounding resistance value is relatively stable in the range of 2.72 Ω to 2.96 Ω. Subsequently, from the seventh to the tenth day, the grounding resistance increased again and remained relatively stable within the 2.88 Ω to 3.13 Ω range. These fluctuations in grounding resistance were influenced by soil moisture levels, ambient temperature, and the soil characteristics surrounding the grounding electrode.

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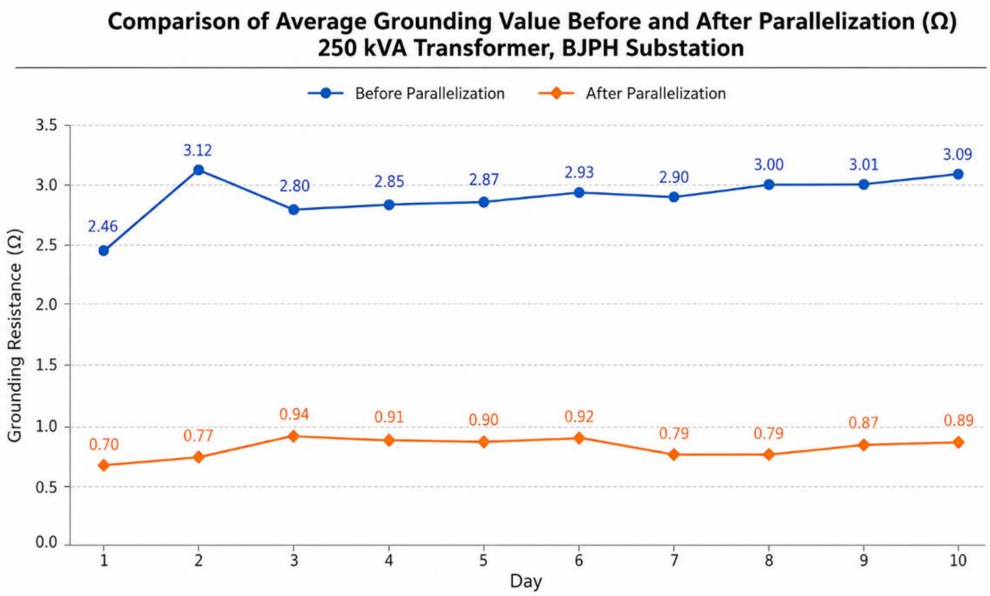
Table 3. Grounding Measurement Results

Day	Grounding Value After Paralleling (Ω) Time			
	09.00 (Ω)	12.00 (Ω)	16.00 (Ω)	Average
1	0,80	0,65	0,65	0,70
2	0,78	0,66	0,88	0,77
3	0,97	0,87	0,98	0,94
4	0,88	0,93	0,91	0,91
5	0,90	0,89	0,91	0,90
6	0,90	0,98	0,88	0,92
7	0,78	0,77	0,82	0,79
8	0,74	0,81	0,82	0,79
9	0,82	0,89	0,90	0,87
10	0,84	0,91	0,92	0,89

Table 3 presents the grounding resistance measurement results following the installation of parallel electrodes. The grounding values obtained ranged from 0.65 Ω to 0.98 Ω over a 10-day measurement period. On the first day, the grounding values were recorded between 0.65 Ω and 0.80 Ω, while subsequent days showed no significant changes. The highest recorded value was 0.98 Ω, and the lowest was 0.65 Ω. The peak value of 0.98 Ω was attributed to drier soil conditions, which increased soil resistivity. Conversely, the lowest value of 0.65 Ω occurred due to moister soil conditions, which enhanced soil conductivity and improved current flow into the ground.

Figure 6. graph repair resistance grounding BJPH substation



During ten days of testing the 250 kVA transformer grounding system at the BJPH substation of PT. PLN (Based on the results of measurements conducted on the 250 kVA transformer grounding system at the BJPH substation of PT. PLN (Persero) ULP Cirebon City for 10 days, grounding resistance values were obtained before and after grounding system optimization. The measurement data are then presented in Tables 4.1 and 4.2 and visualized graphically in Figure 4.1 to facilitate the analysis process.

A parallel circuit in a grounding system can be analogized as several resistance paths operating simultaneously. Therefore, the total resistance value after paralleling will be smaller than before paralleling. Using the equation 5:

Where:

$R1 = 2.8\ \Omega$

$R2 = 2.9\ \Omega$

$R3 = 3.0\ \Omega$

So:

$$\frac{1}{R_{total}} = \frac{1}{2{,}8} + \frac{1}{2{,}9} + \frac{1}{3{,}0}$$
$$\frac{1}{R_{total}} = 0{,}357 + 0{,}345 + 0{,}333 = 1{,}035$$
$$R_{total} = \frac{1}{1{,}035} \approx 0{,}97\ \Omega$$

These results are close to the table value of 0.93 Ω. The small differences may be due to actual field conditions, such as soil moisture, electrode depth, and more even current distribution.

Thus, this calculation shows that the use of several electrodes in parallel can produce resistance values close to the measurement results, which are around 0.93 Ω, thus proving the effectiveness of the parallel method in reducing grounding resistance.

3.3. Analysis

Based on the results of measurements that have been carried out on the distribution transformer grounding system, it was found that the grounding resistance value before repairs was in the range of 2.46 Ω to 3.12 Ω with an average value of 2.90 Ω. This value is actually still within the permissible limits according to the electrical power installation standards PUIL 2011, which is below 5 Ω. However, this value cannot be categorized as optimal, especially for distribution systems that require a high level of reliability and safety.

After optimization by adding parallel grounding electrodes, the resistance value decreased significantly. Based on the measurements, the resistance value after the improvements ranged from 0.70 Ω to 0.94 Ω, with an average value of 0.85 Ω. This decrease indicates an improvement in the quality of the grounding system, particularly in its ability to channel fault currents more effectively to the ground.

The percentage reduction in grounding resistance can be calculated using equation 4, namely:

$$\eta(\%) = \frac{R_{before} - R_{after}}{R_{before}} \times 100\%$$
$$= \frac{2{,}90 - 0{,}85}{2{,}90} \times 100\%$$
$$= \frac{2{,}05}{2{,}90} \times 100\% \approx 70{,}80\%$$

This value shows that the method of adding parallel electrodes has a very significant effect on reducing grounding resistance.

When compared with other methods, such as soil treatment using a mixture of rice husk ash and mangrove charcoal, the resistance decreased from 6.94 Ω to approximately 3.78 Ω, or 43.5%. This indicates that the parallel electrode method is more effective than the soil improvement method.

This difference stems from the working principles of each method. Adding parallel electrodes increases the contact area between the electrode and the soil and provides an additional path for fault currents, thereby directly reducing the total system resistance. Meanwhile, soil treatment methods increase soil conductivity by improving its physical and chemical properties, so resistance reduction tends to depend on environmental conditions.

However, the two methods are essentially complementary. The parallel electrode method focuses on increasing the number of current paths, while the soil treatment method focuses on improving the quality of the soil medium as a conductor. Therefore, when these two methods are combined, the potential for reducing grounding resistance can be optimized. Adding electrodes will expand the current distribution, while improving the soil will increase the conductivity around the electrodes, allowing fault current to flow more easily and evenly into the ground.

The final resistance values in this study, which were below 1 Ω, indicate that the grounding system is in excellent condition. However, the combination of the parallel electrode method and soil treatment has the potential to achieve even better performance, especially in high-resistivity soil conditions.

Thus, it can be concluded that the method of adding parallel electrodes is a very effective solution, and when combined with soil improvement methods, it can provide more optimal, stable and reliable grounding system performance improvements.

4. CONCLUSION

Based on measurements on a 250 kVA distribution transformer at the BJPH Substation of PT. PLN (Persero) ULP Cirebon City, the initial grounding resistance was recorded at an average of around 2.90 Ω, which is still within the maximum limit of PUIL 2011 ($\leq 5\ \Omega$). However, this value is not entirely ideal to ensure fast and effective fault current discharge. However, after additional grounding electrodes were installed in parallel, the resistance dropped drastically to an average of around 0.85 Ω, indicating a reduction of almost 70,8% from the initial value.

This discovery revealed that the parallel electrode arrangement effectively reduces grounding resistance while improving the quality of the grounding system. With the reduced resistance, the reliability of the protection system significantly increases, minimizing the dangers of touch and step voltages, thus maintaining the safety and smooth operation of distribution substations.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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