

REDUCING GROUNDING RESISTANCE BY THE METHOD OF ADDING AND WELDING GROUNDING ELECTRODES AT DISTRIBUTION SUBSTATIONS

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Abstract

The reliability of the electric power distribution system is greatly influenced by the performance of the grounding system at the distribution substation. Operational data in the work area of the Customer Service Unit in (ULP) the Pendopo area shows that 94% of the 529 transformer units have a grounding resistance above 10 Ω , exceeding the safe limit of PUIL 2011 ($\leq 5 \Omega$), thus increasing vulnerability to disturbances due to lightning strikes. This study aims to test the effectiveness of the method of adding and welding grounding electrodes in a relay using galvanized pipes in reducing grounding resistance. The field experimental method was applied to five 20 kV distribution substations with a pretest-posttest design. The measurement results showed a significant decrease in resistance from an initial average of 30.53 Ω to a final average of 2.99 Ω , with all samples meeting the standard below 5 Ω . Statistical analysis confirmed a highly significant difference ($p < 0.001$) before and after the intervention. Besides being effective, this method is also more economical (40% lower cost than chemical grounding systems) and efficient in terms of implementation time. Therefore, this method can be a sustainable technical solution to improve the reliability of lightning protection systems at distribution substations in lightning-prone areas.

Keywords: *grounding resistance, electrode welding, distribution substation, lightning protection, relay grounding system .*

1. INTRODUCTION

The reliability of the electric power distribution system is highly dependent on the performance of distribution transformers as the main component that distributes energy from the transmission network to consumers (Lin et al., 2023) . As a high-value asset, the optimal performance of these transformers must be maintained to ensure continuity of electricity supply (Vita et al., 2023) . Disturbances in distribution transformers not only cause electrical energy not to be distributed or blackouts (Gheorghe & Burlică, 2024) , but also cause economic losses and decreased service quality (Obinna Okeke et al., 2024) . Globally, transformer disturbances can be caused by internal factors such as overload , load imbalance, insulation damage, and protection failure (Huang et al., 2025) , as well as external factors such as lightning strikes, physical accidents, and natural disasters (Tajdinian & Samet, 2022) . In the work area of the customer service unit in the Pendopo area, Operational data

from 2023 shows that lightning strikes were the dominant cause of disruptions, contributing 37.5% of total incidents. This correlates with the geographic characteristics of the area, which is prone to lightning activity.

Standard mitigation efforts through the installation of arresters often not optimal without adequate grounding system support (Putra, Yani, et al., 2023). Measurement results in 2023 revealed that 94% of the 529 distribution transformer units in the region had grounding resistance values above $10\ \Omega$, exceeding the 2011 PUIL safety threshold which requires a maximum of $5\ \Omega$ (Putra et al., 2024). This phenomenon indicates the ineffectiveness of conventional grounding methods (parallel systems) in achieving the required performance, especially on soils with high resistivity (Putra, Pardede, et al., 2023), thus leaving systemic vulnerability to damage due to lightning surges (Yani et al., 2024).

Based on these problems, effective, economical, and sustainable technical innovations are needed. This study proposes and tests the implementation of a grounding method for a relay circuit welded with pipes, a modification of the grounding system that utilizes chain welded joints on galvanized pipes to deepen the electrodes to reach soil layers with better conductivity. The objectives of this study include analyzing the effectiveness of the method in reducing grounding resistance below $5\ \Omega$ and evaluating the consistency of implementation results in the field and examining its technical implications for increasing the reliability of lightning protection systems in distribution substations.

2. RESEARCH METHODS

This study uses a field experimental approach to test the effectiveness of the method of adding and welding grounding electrodes in reducing grounding resistance in distribution substations. The research design adopted a one-group pretest-posttest pattern, where resistance measurements were carried out before and after the implementation of the intervention on the same sample. The research location is located at five 20 kV distribution substations in the Pluto Feeder, ULP Pendopo working area, which were selected purposively based on the criteria of initial resistance value $>10\ \Omega$ and a history of locations prone to lightning strikes. Data collection was carried out through direct measurements using a digital earth tester, systematic observation of the implementation process, and study of historical disturbance data documentation.

The implementation procedure consists of:

1. Initial resistance measurements at the arrester, neutral and body points;
2. Planting additional electrodes in a relay manner using galvanized pipe welding techniques;
3. Periodic measurements until the resistance reaches below $5\ \Omega$; and
4. Post-intervention final measurements.

Data were analyzed quantitatively using descriptive statistics and paired sample t-tests to compare significant differences between pre- and post-treatment conditions, with a 95% confidence level. Data validity was ensured through instrument calibration, standardization of measurement procedures, and triangulation of data sources.

3. RESULTS AND DISCUSSION

3.1 Results of Implementation and Analysis of Method Effectiveness

The implementation of the method of adding and welding grounding electrodes at five distribution substations resulted in a significant reduction in grounding resistance. Before the intervention, all samples showed resistance values above $10\ \Omega$, with a range of $10.7 - 79.9\ \Omega$ and an average of $30.53\ \Omega$. After the repair, all measurement points (arresters, neutrals, and bodies) successfully achieved values below the standard of $5\ \Omega$, with a new average of $2.99\ \Omega$ (range $1.91 - 4.68\ \Omega$). Statistically, the paired sample t-test showed a highly significant difference ($p < 0.001$) between the conditions before and after the intervention.

Table 3.1 Results of Method Implementation on Five Sample Substations

No. Substation	Location	Average Resistance Before (Ω)	Average Resistance After (Ω)	Decrease (%)	Number of Additional Bars
U 0004	Rami Pasai	79.27	3.51	95.6	4
U 0005	Pagar Dewa	17.04	3.38	80.2	4
U 0006	Pagar Dewa	12.1	3.08	74.5	4
U 0007	Betung	12.8	2.68	79.1	4
U 0008	Betung	13.24	2.16	83.7	4

The data shows that the greatest resistance reduction occurs in the substation with the highest initial value (U 0004: 95.6 %), indicating that this method is particularly effective for locations with very poor grounding conditions. The consistent use of 4 additional electrode rods in all samples indicates that the effective depth of the relay system is in the range of 9–12 meters , in accordance with theoretical predictions.

3.2 Reduction Mechanism and Advantages of the Method

The drastic reduction in grounding resistance can be explained by two main mechanisms optimized by this method. Based on the rod electrode resistance equation:

$$R = \frac{\rho}{2\pi x L} \times \left(\ln \frac{4xL}{a} - 1 \right) \quad (1)$$

Increasing the electrode length (L) significantly reduces the R value, especially in soils with heterogeneous resistivity (ρ). The relay system allows penetration into soil layers with higher water content, which in this study was shown to reduce resistance by up to 86.4 % on average. This result is consistent with previous studies which stated that every 2 meters of additional depth can reduce resistance by 0.5–0.6 Ω in soil with $\rho=30 \Omega\text{m}$.

Conventional mechanical connections (bolts) have additional contact resistance (typically 0.5–2 Ω) that is not accounted for in theoretical models. Welding metallurgically fuses the materials, reducing the interfacial resistance to near zero. This explains why the field results (1.91 Ω at substation U 0008) are better than the theoretical predictions (2.662 Ω for a depth of 12 meters).

By achieving resistance below 5 Ω , the footing voltage (voltage that arises when lightning current flows to the ground) can be suppressed below the transformer's insulation level. Calculations show that for a lightning current of 10 kA, the voltage in the old grounding system (30 Ω) reaches 300 kV, far exceeding the BIL (Basic Impulse Level) of a 20 kV transformer (125 kV). After rectification (3 Ω), the voltage drops to 30 kV, so that the surge energy can be safely dissipated through the arrester.

3.3 Technical and Operational Implications

During the three-month post-implementation monitoring period, no substations experienced repeated lightning-related outages. This confirms that reducing grounding resistance is directly proportional to increasing protection reliability. Based on historical data, where 37.5 % of outages are caused by lightning, this method has the potential to significantly reduce the System Average Interruption Duration Index (SAIDI) .

This method uses local materials (galvanized pipe) and costs 40% less than chemical grounding systems. The average implementation time of 6 hours per substation is also faster than conventional methods that require extensive excavation. ROI calculations show that the investment in improvements can be recovered within 1.2 years through reduced transformer repair costs and reduced energy losses.

Implementing this method requires field welding skills and adequate equipment. Results may also vary in soils with very hard bedrock or very low water content. However, the flexibility of the relay system allows for depth adjustments to suit field conditions.

4. CONCLUSION

Based on the identification of the problem of high distribution transformer disturbances due to lightning strikes in the Pendopo area, which was triggered by an average grounding resistance condition of $>30\ \Omega$ (94% of transformers $>10\ \Omega$) so that it did not meet the 2011 PUIL standard ($<5\ \Omega$), this study successfully proved that the implementation of the grounding method through the addition and welding of galvanized pipe electrodes in a relay manner—can drastically reduce the grounding resistance to an average of $2.99\ \Omega$ (86.4% reduction) while meeting safety standards in all sample substations. This success not only improves the technical performance of the grounding system, but also contributes significantly to reducing the potential for operational disturbances and increasing the reliability of electricity supply, with added value in the form of cost efficiency, use of local materials, and permanent, sustainable solutions to be applied to distribution networks in lightning-prone areas.

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