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Analysis of Grounding Resistance Value Improvement on 150 kV Glang-Namorambe High Voltage Air Line Tower (SUTT) using three Measurement Points (Three Point Method)

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ABSTRACT

Low grounding resistance is an important factor in ensuring the safety and reliability of electric power systems, especially on High Voltage Overhead Lines (SUTT). This study aims to analyze and improve the grounding resistance values on 150 kV SUTT towers on the Glang–Namorambe line using the three-point measurement method. Measurements were conducted to determine the actual condition of the grounding system and evaluate the effectiveness of the improvements made. Initial measurements showed that several towers had resistance values exceeding the maximum PLN standard limit of 10 ohms. To address this, improvements were made by installing additional electrodes, adding conductors, and using ground enhancement materials. After the improvements, remeasurements were conducted for each tower. The analysis results showed that the applied improvement method succeeded in reducing the grounding resistance value significantly, with an average reduction of 40–60%. The final resistance values of all towers were below the specified threshold, so that the grounding system can function properly in protecting equipment and personnel safety from overvoltage disturbances caused by lightning and ground faults.

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INTRODUCTION

High Voltage Overhead Lines (SUTT) are a vital component of the power transmission system, transferring electrical energy from power plants to load centers over long distances. A critical aspect in ensuring the safety and reliability of SUTT operations is the grounding system. A good grounding system must have a low resistance value to ensure that fault currents, such as lightning or ground faults, can be safely channeled to the ground without damaging equipment or endangering human safety. However, in practice, grounding resistance values often do not meet established standards, particularly in areas with high-resistivity soils. This risks causing protection failure, increased touch and step voltages, and potential damage to power system equipment. Therefore, corrective action is required to bring the grounding resistance value within the permitted limits, according to PLN standards, which generally set a maximum of 10 ohms for transmission installations.

This research focuses on analyzing the improvement of grounding resistance values on 150 kV SUTT towers on the Glang–Namorambe line. Grounding resistance measurements were conducted using the three-point method, a standard method commonly used in field grounding resistance measurements. Based on the initial measurement results, towers with resistance values above the threshold were identified, and improvements were made by adding electrodes, widening the grounding system, and using materials to increase soil conductivity. Through this research, it is hoped that a comprehensive picture can be obtained regarding the effectiveness of the applied repair methods, as well as contributing to increasing the reliability of the grounding system in high-voltage electricity transmission installations.Grounding of the electric power system, both neutral point grounding and equipment grounding, has an impact on the smoothness and safety of the system, especially when a grounding-related disturbance occurs. Therefore, the grounding resistance must be made as low as possible, and its value must meet the guidelines set out in the specified standards and regulations. The grounding resistance value of High Voltage Overhead Line (SUTT) Towers has different values at each tower leg.

Differences in grounding resistance values are caused by several factors, such as soil type, the type of grounding rod used, and humidity conditions around the tower base. The most prominent influence on the resistance value is the water content in the soil. The configuration of the electrode embedded rod can reduce the magnitude of the grounding resistance. If the soil structure is considered homogeneous, then the resistance of the grounding electrode for one rod will be smaller if the electrode is planted further from the ground surface. To maintain the stability of the grounding value on the tower, routine maintenance or measurements are required. If there is a soil grounding value that is not appropriate, improvements will be made to the grounding system by adding new electrodes using the three-point measurement method and three auxiliary electrode branching points to obtain a good value.

Literature Review

Previous Research

Various previous studies in the field of electrical engineering have shown that grounding systems play a crucial role in maintaining the reliability and safety of electric power systems, particularly in transmission infrastructure such as High Voltage Overhead Lines (SUTT). One widely used protection method to address internal and external electrical disturbances is through an effective grounding system. Disturbances such as lightning strikes can cause dangerous voltage surges, especially if the grounding resistance at the tower base is too high. This condition can trigger voltage surges in insulators and cause damage to transmission equipment.

To prevent this, a grounding system with the lowest possible resistance value is required, capable of quickly and safely discharging fault current to the ground. This value can be analyzed and evaluated by comparing theoretical calculations with field measurements using standard methods, one of which is the three-point method.

On the other hand, when a fault occurs at a substation, the fault current can flow through the human body near the grounded area, causing dangerous touch and step voltages. A poor grounding system can exacerbate this risk. Therefore, careful planning and calculation of the grounding system are crucial to protect equipment and personnel safety. In the context of an electric power system, the grounding system also serves to direct fault currents to prevent them from spreading dangerously to other areas. The potential difference between equipment and the ground, as well as between various points on the ground surface, creates voltage gradients that must be controlled. To reduce these gradients, a grounding system with low ground resistance is required.

Ground conditions such as hard rock, dry soil, or soil with high resistivity significantly affect the grounding resistance value and require a special approach in its design. Grounding methods such as driven grounding (plugging electrodes) and counterpoise grounding are frequently used in transmission systems. Driven grounding is suitable for soft or clayey soils, while counterpoise is effective in hard soils with radial or parallel conductor installation. To maintain system reliability, grounding resistance measurements must be performed periodically. If the resistance value increases, improvements can be made by adding additional grounding electrodes.

Grounding

Grounding is the process of connecting an electrical system to the earth, with the aim of safely discharging fault currents such as lightning or ground faults. A good grounding system will minimize touch voltages and step voltages that are dangerous to humans and electrical equipment. According to IEEE Std. 142-2007, an ideal grounding system should have the smallest possible resistance value, generally <10 ohms for distribution and transmission systems.

Grounding resistance is the resistance between a grounding electrode and the surrounding soil. This value is greatly influenced by several factors, such as soil type, humidity, temperature, electrode depth, and the electrode's contact surface area with the soil. High grounding resistance will slow the discharge of fault current to the ground and potentially cause damage and safety risks. According to PLN and IEEE standards, the maximum grounding resistance for electrical transmission installations should typically not exceed 10 ohms. This value ensures that the protection system can effectively protect equipment and personnel from electrical disturbances.

Three Point Method

The three-point method, or fall of potential method, is a standard technique for measuring ground resistance. It works by passing current from a current probe to the ground electrode being tested, then measuring the potential difference between the test electrode and the voltage probe. This method is recommended by IEEE Std. 81-2012 because it is considered more accurate in measuring ground resistance. Several methods can be used to reduce ground resistance, including:

a. Adding electrodes, namely adding ground rods to increase the contact area with the ground.
b. Increasing soil conductivity, namely using additives such as bentonite, salt, or ground enhancement material (GEM).
c. Increasing the area of the grounding system, namely creating a grounding grid or expanding the grounding conductor.

These methods are selected based on soil conditions and initial resistivity values measured at the tower location.

SUTT (High Voltage Overhead Line)

A structure called a High Voltage Overhead Line (SUTT) is used to connect the Power List from the Power Plant to the Substation (GI) or to the GI. This is done by connecting wires or condensers to insulators in high systems (30 kV, 70 kV, and 150 kV). The main component in the construction and foundation of the SUTT and SUTET transmission systems is the pole. In addition to functioning as an insulator, this structure can also be used to connect condensers at different heights and distances.
necessary for both humans and machines.
Here is an example of SUTT:

1. Tower or transmission
2. Insulator
3. Strong conductor
4. Wire ground

Transmission Towers or Poles

Transmission pylons, also known as transmission towers, are essential components that support transmission lines. There are four different types of pylons based on their shape or construction.

1. Steel construction poles, which are made from profile steel arranged in such a way as to form a tower with the strength calculated according to requirements.
2. Manesman poles, which are made from steel pipes with lengths, diameters and thicknesses adjusted to requirements.
3. Reinforced concrete pillars, which are made of reinforced concrete and made according to requirements.
4. Wooden poles, which are less durable such as damar laut, rasamala, and kruing must go through a preservation process first so that they can last longer at temperatures of 40 minutes.
5. Poles: Concrete or steel poles can be used to construct overhead power lines (SUTT) built in densely populated urban areas and requiring relatively small land areas. Poles are divided into two types: steel poles and concrete poles.

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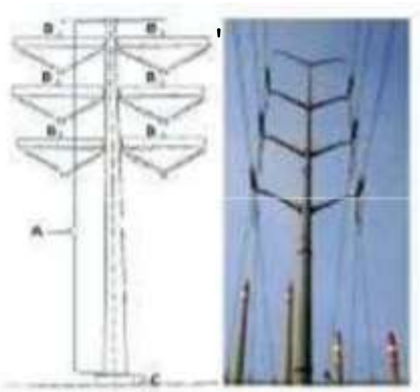

Figure 1. Pole Construction

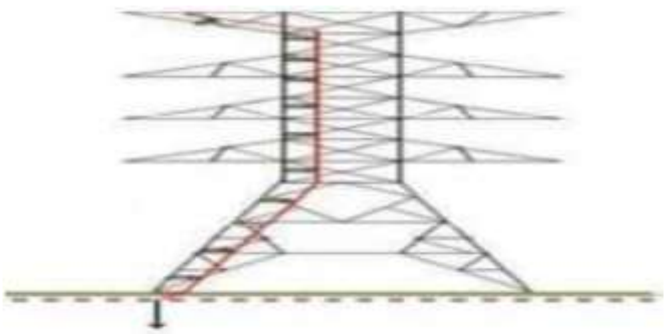

Figure 2. Manesman Pole Grounding

METHOD

This research is an experimental quantitative research with a field study approach. The focus of the research is to analyze the grounding resistance value on a 150 kV SUTT tower and evaluate the effectiveness of improvements using appropriate grounding methods. The research was conducted on the 150 kV SUTT transmission line connecting the Glang Substation with the Namorambe Substation, which consists of a number of transmission towers that are the objects of grounding resistance measurement. This method is used to measure the grounding resistance value of an electrode with the principle of measuring the voltage drop (fall of potential). Three electrodes are used:

1. Electrode E: Electrodes being tested (at the foot of the tower)
2. P electrode: Potential probe, placed at a certain distance
3. Electrode C: Current probe, placed further away from electrodes E and P

Steps

1. Connect the Earth Tester with three electrodes (E, P, and C).
2. Take measurements at several distance points to obtain a graph of resistance variation.
3. Determine the average resistance value as the actual soil resistance value.

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If the resistance value exceeds the standard limit (for example >10 ohms), then corrective action is taken, such as:

1. Adding additional grounding electrodes in parallel.
2. Use of soil resistance reducing materials (GEM, bentonite, salt, etc.).
3. Expansion of the contact area with the ground (e.g. with a grid or radial system).

After the repair, repeat measurements were performed using the same method. The measurement results were compared with the initial values to determine the effectiveness of the repair. The measurement data before and after the repair were analyzed quantitatively. The comparison was made using:

1. Maximum standard grounding resistance (e.g. <10 ohms according to PLN/IEEE)
2. Percentage reduction in value of detainee
3. Evaluation of the effectiveness of improvements based on the type of method used

Before a grounding system is implemented in an electrical installation, measuring the ground resistance value is a crucial step. This measurement is carried out using a measuring instrument called an Earth Tester, which functions to determine the resistance of the grounding system. This tool is generally equipped with a segment-based digital display, making it easier to read and record the measurement data. The measurement process is carried out using three electrodes: electrode E (ground electrode), electrode P (potential), and electrode C (current), each of which is planted in the ground at a certain distance according to the three-point method procedure.

In the process of collecting research data, several methods are used:

1. Interview and discussion method: This method involves interviews and discussions with PLN GLANG-NAMORAMBE employees regarding the results of grounding resistance measurements at the foot of towers 46, 47, and 48.
2. Literature and internet study methods: To obtain the necessary information and data, the author read books and trusted internet sources that are relevant to the research.
3. Field data collection: The author conducted direct measurements in the field for 4 days to obtain accurate data.

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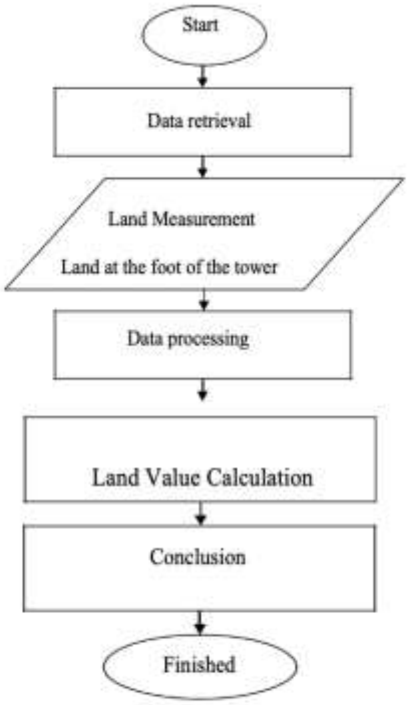

Figure 3. Research Flow Diagram

ANALYSIS AND RESULTS

Research Systematics

Based on the research results, the implementation methodology is demonstrated through a flowchart that systematically depicts the process. The data required for this grounding system analysis includes:

1. Soil resistance data on the 150 kV tower on the Glang–Namorambe line.This information is used to calculate the soil resistivity value using a basic formula. The resulting soil resistivity value then becomes an important parameter in calculating other ground resistance values.
2. Data related to the configuration of rod and grid electrodes embedded in the ground.Parameters such as the length of the ground rod (LT), the length of the grid conductor (LC), the grid installation depth (h), and the conductor diameter (a), will be used in the available formula to obtain the total resistance value of the grounding system (Rg).

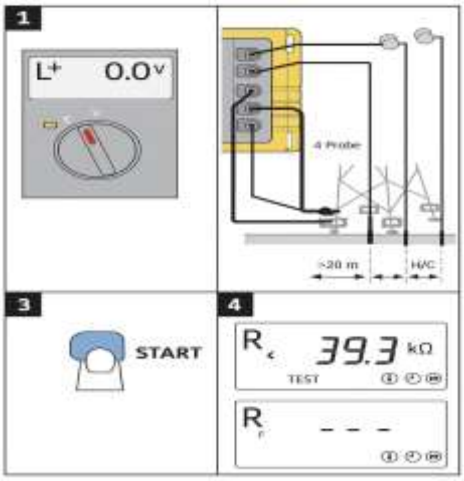

Figure 4. Measurement Analysis

The image above shows the use of an earth tester measurement analysis by PT. PLN (Persero) in the field. The initial step is carried out by connecting probe E to the ground rod or tower foot. Next, probe S is installed 20 meters from the point of probe E, then probe H is placed 40 meters from the same point. In addition, a current test clamp is also installed on the tower foot to complete the measurement series. After all connections are installed, the user adjusts the position of the rotary switch on the device, then presses the START button. The tower grounding resistance value will then appear on the device screen, as shown in Figure 2 (PT. PLN (Persero), 2009).

Table 1. Grounding Resistance Measurement Data on the 150 Kv High Voltage Overhead Line (Sutt) Tower in Glang-Namorambe

No.	Parallel			
Tower	A	B	C	D
	Ω (ohm)			
A01	0.37	0.25	0.27	0.5
A02	1.2	1.53	0.91	1.31
D03	0.39	0.41	0.57	0.46
D04	0.12	0.27	0.22	0.16
D18	0.15	0.03	0.08	0.05

Table 2 .Buried Rod and Grid Specification Data

Type Tower	Amount Rod	Diameter Rod(m)	Long One by one Rod(m)	Conductor Length and Rod who Buried (m)	Long Conductor (m)	Diameter Conductor (m)	Depth Grid(m)
Tension	9	0.038	3	95.14	68.14	0.019	0.25
Suspension	9	0.038	3	80.41	53.41	0.019	0.25

Table 2 displays the specifications of the buried rod and grid system for grounding installation, referring to data obtained from PT. PLN (Persero). One of the important results of this study is the evaluation of the improvement of the grounding system on the 150 kV High Voltage Overhead Line (SUTT) tower. Initial measurements showed that most of the towers had grounding resistance values that exceeded the recommended standard threshold (<10 ohms). This excessively high value has the potential to endanger the protection system and increase the risk of damage due to disturbances such as lightning or ground currents. After the improvement efforts were implemented, re-measurements were conducted at three points on the tower. With resistance values that meet standards, the protection system against external disturbances (such as lightning) can function optimally. This also contributes to increased transmission system reliability and operational safety around the tower.

Data Analysis

The ideal grounding resistance value on a 150 kV SUTT tower should be smaller to support system performance and safety. PT PLN (Persero), as the operator of the 150 kV Glang–Namorambe SUTT transmission line, sets a maximum grounding resistance limit of 10 Ohms. The low resistance value aims to accelerate the discharge of fault currents to the ground, especially due to high potential differences when lightning strikes directly to the ground wire, so that the disturbance does not spread to the transmission system. Because the ground rod is buried in the ground, its condition cannot be inspected visually. Therefore, the only indicator of the condition of the grounding system is through measuring its resistance value.

Based on the measurement data, the analysis of the grounding resistance condition of the 150 kV Glang–Namorambe SUTT tower—which is part of the operational unit of PT PLN (Persero)—is divided into three measurement methods as follows:

1. Combined (Parallel) Grounding Resistance Measurement between Tower Legs
   The measurement results show that all points have resistance values that are still below the maximum limit of 10 Ohms, so they are categorized as being in good condition with a success rate of 100%.
2. Grounding Resistance Measurement on Towers Without Additional Grounding System
   From the test results, 95.83% of the measurement points showed resistance values that met the standard (<10 Ohm), while the remaining 4.17% were above the maximum permitted limit, thus requiring further attention.
3. Measurement of Grounding Resistance on Each Tower Leg Ground
   All measurement points in this method show results that meet the standards with resistance values below 10 Ohms, so that the level of suitability of the individual grounding system at each tower leg reaches 100%.

Grounding Resistance Measurement Characteristics of the 150kV SUTT Tower Glang – Namorambe

The characteristics of the grounding resistance measurement of the 150kV Glang-

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Namorambe SUTT tower during the measurement period are as follows:

a. Good Condition

The condition of the grounding resistance value which is still in good condition is found in the three measurement method techniques, namely as follows:

1. Measurement of parallel/combined grounding resistance values
   A condition where the parallel/combined grounding resistance value is still in good condition throughout, no measurement value is found above the standard used. The factor causing the grounding condition to still be good is the grounding system connected to the 150kV SUTT tower, starting from the tower foot ground with a ground wire connected to the grounding system on all transmission lines and connected to the grounding at the Main Substation (GI). If these two variables are connected for the grounding system on the 150kV SUTT tower, a good grounding resistance measurement value will be obtained.
2. Measurement of grounding resistance of tower legs without grounding
   A condition where the grounding resistance value of the tower foot without using a ground is mostly still in good condition, but there is one result of the tower foot grounding measurement that is bad and exceeds the permitted standard, namely the measurement of the grounding value of tower D23 with a measurement result of 88.6 Ohm. One of the factors in the field is the condition of the land, which is field land.
3. Measurement of the grounding resistance value of the tower leg on each side This condition is where the value of the grounding resistance of the tower leg is mostly still in good condition. The condition where the grounding resistance value of the tower leg is good is possible due to several factors, namely:
   a) The ground rod and clamp contact are still in good condition. This condition occurs because the ground rod has not been affected by corrosion after being buried in the ground for so long, resulting in good contact between the ground rod and the ground. Another possible cause is the contact between the ground rod and the ground conductor and the clamp, which are also in good condition.
   b) Soil conditions that still have high humidity Soil conditions that still have high humidity are one of the variables that determine the value of grounding resistance. The more humid the soil conditions, the more
      The value of the resistivity will be better and the value of the grounding resistance of the soil will also be better.
   c) Constant groundwater conditions
      As we all know, a grounding system in good condition is one that can approach groundwater. If the groundwater level remains stable, this could be due to the increasing rainfall at the time of the measurement, resulting in a relatively stable grounding resistance.

b. Warning Condition

The condition where the grounding resistance value is in the alert position appears in the measurement of the parallel/combined grounding resistance value, the grounding resistance value of the tower leg without grounding and the grounding resistance value on each ground with the opposite side. Towers with this condition occur in 10 towers.

c. Good Condition

The condition of the grounding resistance value which is still in good condition is found in the three measurement method techniques, namely as follows:

a) Measurement of parallel/combined grounding resistance values
A condition where the parallel/combined grounding resistance value is still in good condition throughout, no measurement value is found above the standard used. The factor causing the grounding condition to still be good is the grounding system connected to the 150kV SUTT tower, starting from the tower foot ground with a ground wire connected to the grounding system on all transmission lines and connected to the grounding at the Main Substation (GI). If these two variables are connected for the grounding system on the 150kV SUTT tower, a good grounding resistance measurement value will be obtained.

b) Measurement of grounding resistance of tower legs without grounding
A condition where the grounding resistance value of the tower foot without using a ground is mostly still in good condition, but there is one result of the tower foot grounding measurement that is bad and exceeds the permitted standard, namely in the measurement of the grounding value of tower D23 with a measurement result of 88.6 Ohm. One of the factors in the field is the condition of the soil.

CONCLUSION

Based on the results of the analysis and measurements carried out on the 150 kV Glang-Namorambe SUTT tower using the three-point method, it was found that the grounding resistance values of several towers were still above the required standard (<10 Ohm). After improvements to the grounding system, such as the addition of grounding electrodes, increasing the electrode contact area with the ground, and planting additional conductors, the grounding resistance value was successfully reduced to within safe limits according to SPLN and IEEE standards. The evaluation results showed that the three-point measurement method provided accurate and effective results in mapping the grounding resistance conditions. The improvements made were proven to increase the reliability of the grounding system, which is very important in maintaining the stability of the protection system, reducing the risk of voltage surges due to lightning, and ensuring the safety of equipment and personnel. Therefore, routine maintenance and testing of the grounding system in SUTT installations is highly recommended to ensure the system continues to function optimally in the long term.

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