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Gravel in the Switchyard Area of a Main Substation on Sandy Clay Soil

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Abstract

The thickness of the gravel laid in the switchyard area of a main substation impacts the touch and step voltage values. The gravel thickness generally varies from 0.08 meters to 0.15 meters, tailored to the soil texture at the substation site. This study aimed to determine the optimal gravel thickness in the switchyard equipment area of a main substation on sandy clay soil. A descriptive quantitative analysis method was used. The results revealed that increasing the gravel thickness from 0.08 meters to 0.17 meters resulted in decreased step and touch voltage values. Gravel thicknesses from 0.08 meters to 0.14 meters maintained safe step voltage levels, while thicknesses from 0.15 meters to 0.17 meters achieved the best outcomes, under both wet and dry conditions of the sandy clay soil.

Keywords: Grounding; Gravel Thickness; Sandy Clay Soil.

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1. Introduction

Indonesia's diverse geography presents a variety of soil textures, each with different soil resistivity values, necessitating distinct grounding types and resulting in varying step and touch voltages. Gravel is spread over the surface of switchyard areas to enhance the contact resistance between the soil and human feet at the main substations [1,3,4,5]. The required thickness of the gravel spread at the switchyard locations of main substations varies with each type of soil texture. This study reflects the challenges faced in developing a grounding system for main substations across the different soil textures found in Indonesia. Given the variety of soil textures, it is necessary to investigate the optimal gravel thickness for each texture. This research specifically examines the impact of gravel thicknesses ranging from 0.08 meters to 0.17 meters on step and touch voltages in sandy clay soil.

2. Materials and Methods

2.1 Literature Study

2.1.1 Use of Gravel Rocks

Gravel was spread over the switchyard area with the following objectives [2,6,7,8]:

1. Gravel was spread over the entire surface of the switchyard area at the main substation to provide a high resistance layer between personnel stepping on it and the soil beneath. This layer of gravel serves as insulation between the feet of personnel working in the area and the ground.
2. The gravel layer on the switchyard surface acts as a conduit for fault currents to flow directly into the ground rather than along the surface. This can reduce the magnitude of voltage in both Touch Potential and Step Potential scenarios.
3. In the event of oil spills from transformer leaks, the spread of gravel is intended to prevent fire spread, thus avoiding interference with other equipment in the area.
4. It inhibits the growth of grass and shrubs in the switchyard area.
5. The primary function of the gravel is to reduce the magnitude of touch and step voltages.

2.2 Research Design

The design of the study to be used as a reference in conducting the research is illustrated in Figure 1 below.

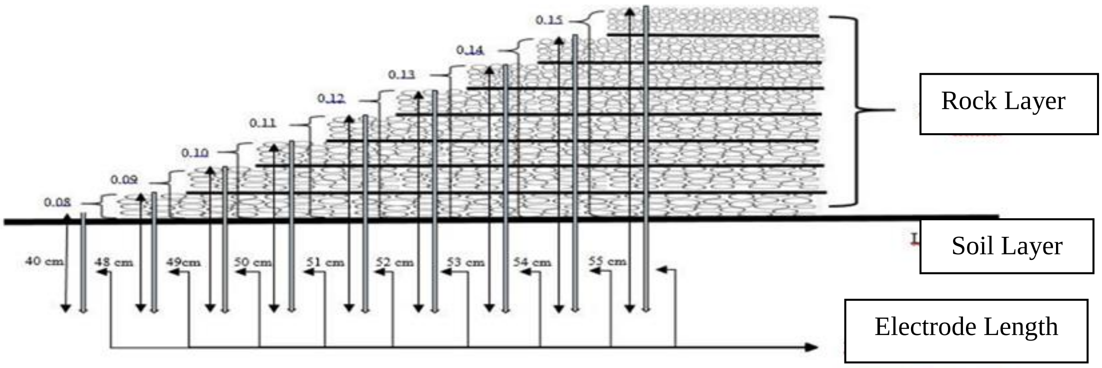

Figure 1: Gravel Thickness from 0.08 m to 0.17 m, Electrode Length from 0.4 m to 0.57 m

2.3 Research Flowchart

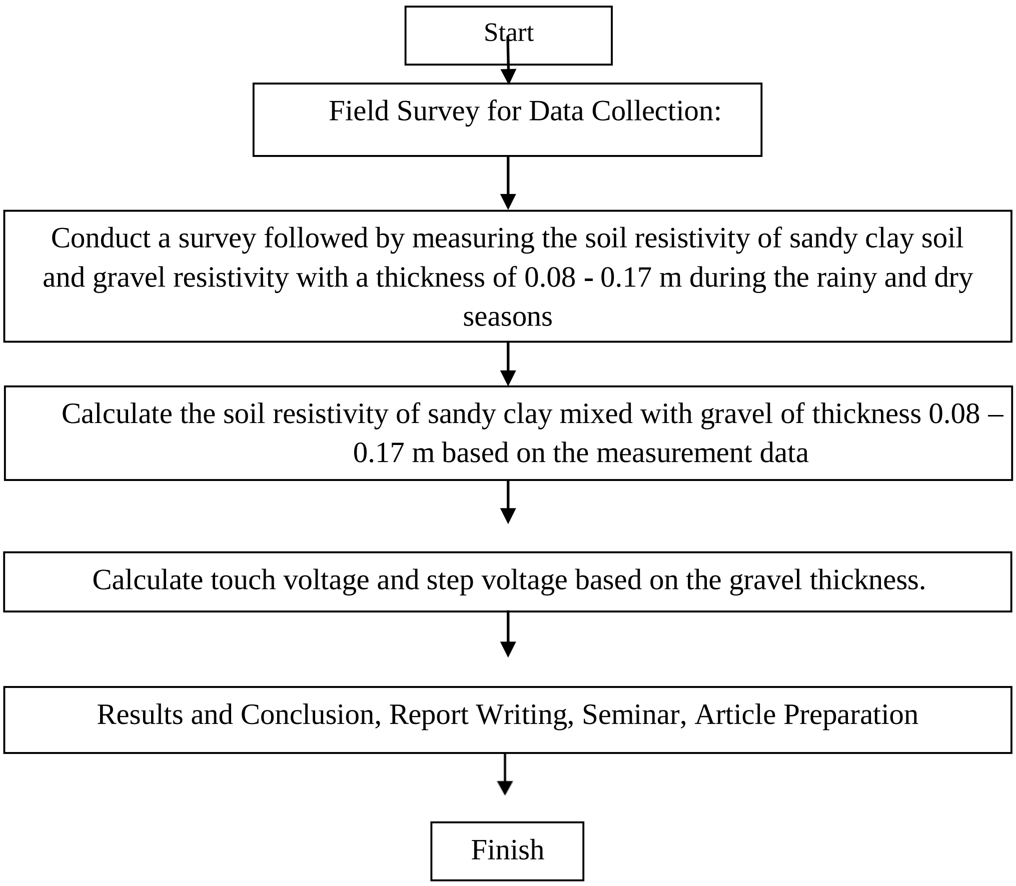

Figure 2: Research Process Flowchart

2.4 Data Analysis

The collected measurement data were analyzed to determine the touch and step voltages at gravel thicknesses ranging from 0.08 meters to 0.17 meters. The analysis was based on relevant equations under both wet and dry conditions of the soil and gravel.

3. Results and Discussion

The results of the soil resistivity measurements under dry and wet conditions are presented in Table 1.

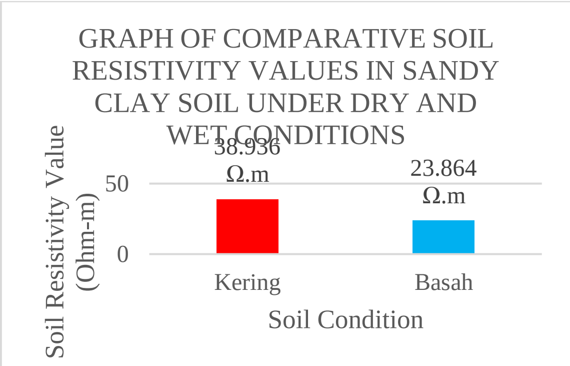

Figure 3: Graph of Soil Resistivity Values for Sandy Clay Soil under Dry and Wet Conditions

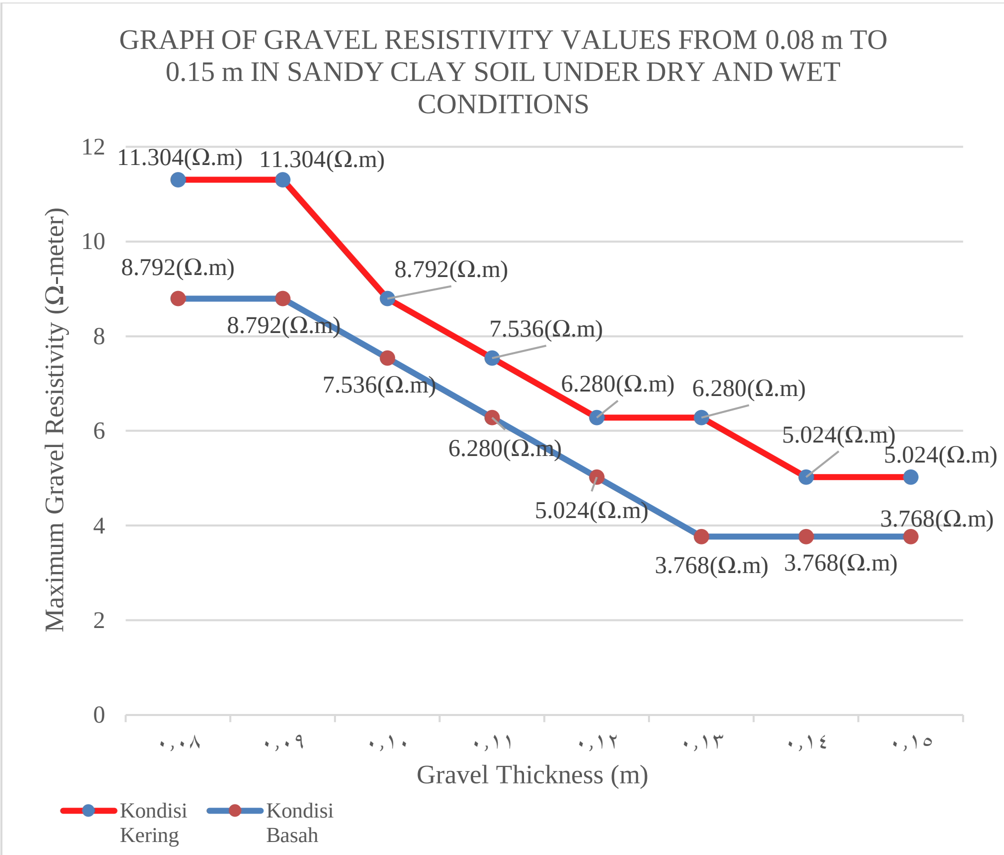

Figure 4: Graph of Gravel Resistivity Values from 0.08 m to 0.17 m Thickness under Wet and Dry Conditions

3.1 Touch Voltage Analysis

The reduction factor based on the gravel thickness from 0.08 meters to 0.17 meters is calculated using the following equation:

$$C_{s\,0.08} = 1 - \frac{0.09\left(1-\frac{\rho}{\rho_S}\right)}{2h_s+0.09}$$

Therefore, for a gravel thickness of 0.08 meters, the calculation is:

$$C_{s\,0.08} = 1 - \frac{0.09(1-\frac{38.936}{11.304})}{2x0.08+0.09}$$

$$C_{s\,0.08} = 1.8784$$

Thus, the touch voltage calculation based on a gravel thickness of 0.08 meters on sandy clay soil in dry condition is as follows:

$$E_{t\,70} = [1000 + 1.5\rho_s\, C_s]\, \frac{0.147}{\sqrt{t}}$$

$$E_{t\,70} = [1000 + 1.5\, x\, 11.304\, x\, 1.8784]\, \frac{0.147}{\sqrt{1}}$$

$$E_{t\,70} = 151.68 \text{ Volts}$$

The results of the touch voltage calculations for dry soil and gravel conditions with varying gravel thicknesses from 0.08 meters to 0.17 meters are shown in Table 1.

Table 1: Calculation of Touch Voltage under Dry Soil and Gravel Conditions with Varying Gravel Thickness from 0.08 meters to 0.17 meters

No	**Sandy Clay Soil Resistivity Dry $\rho = 2\,.\,\pi\,.\,\alpha\,.\,R$ (Ohm – m)**	**Dry Gravel Resistivity (Ohm-m)**	**Gravel Thickness (m)**	**Reduction Factor**	**Touch Voltage (V)**
1	38.936	11.304	0.08	1.878	151.680
2	38.936	11.304	0.09	1.813	151.518
3	38.936	8.792	0.10	2.063	150.999
4	38.936	7.536	0.11	2.210	150.672
5	38.936	6.280	0.12	2.418	150.348
6	38.936	6.280	0.13	2.337	150.236
7	38.936	5.024	0.14	2.642	149.926
8	38.936	5.024	0.15	2.557	149.832
9	38.936	5.024	0.16	2.562	149.819
10	38.936	5.024	0.17	2.581	149.801

While the calculations of touch voltage under wet soil and gravel conditions with varying gravel thickness from 0.08 meters to 0.17 meters are as shown in Table 2.

Table 2: Calculation of Touch Voltage under Wet Soil and Gravel Conditions with Varying Gravel Thickness from 0.08 meters to 0.17 meters

No	Sandy Clay Soil Resistivity Wet $\rho = 2 \,.\, \pi \,.\, \alpha \,.\, R$ (Ohm – m)	Wet Gravel Resistivity (Ohm – m)	Gravel Thickness (m)	Reduction Factor	Touch Voltage (V)
1	23.864	8.792	0.08	1.6171	150.135
2	23.864	8.792	0.09	1.558	150.020
3	23.864	7.536	0.10	1.672	149.778
4	23.864	6.280	0.11	1.813	149.510
5	23.864	5.024	0.12	2.000	149.215
6	23.864	3.768	0.13	2.370	148.969
7	23.864	3.768	0.14	2.300	148.911
8	23.864	3.768	0.15	2.230	148.852
9	23.864	3.768	0.16	2.241	148.806
10	23.864	3.768	0.17	2.251	148.852

3.2 Step Voltage Analysis

The reduction factor for gravel thicknesses ranging from 0.08 meters to 0.17 meters was calculated as follows:

$$C_{s\,0,08} = 1 - \frac{0.09(1 - \frac{38.936}{11.304})}{2x0.08 + 0.09}$$

$$C_{s\,0.08} = 1.878$$

The step voltage calculation based on gravel thickness on sandy clay soil in dry conditions is given by:

$$E_{s\,70} = [1000 + 6\rho_s\, C_s]\,\frac{0.157}{\sqrt{t}}$$

$$E_{s70} = [1000 + 6\,x\;\; x\,1.878]\,\frac{0.157}{\sqrt{1}}$$

$$E_{s70} = 225.880 \text{ Volts}$$

Table 3: Calculation of Step Voltage under Dry Soil and Gravel Conditions with Varying Gravel Thickness from 0.08 meters to 0.17 meters

No	**Sandy Clay Soil Resistivity Dry** $\rho = 2 . \pi . \alpha . R$ **(Ohm – m)**	**Dry Gravel Resistivity (Ohm – m)**	**Gravel Thickness (m)**	**Reduction Factor**	**Step Voltage (V)**
1	38.936	11.304	0.08	1.878	176.997
2	38.936	11.304	0.09	1.813	176.305
3	38.936	8.792	0.10	2.063	174.085
4	38.936	7.536	0.11	2.210	172.688
5	38.936	6.280	0.12	2.418	171.304
6	38.936	6.280	0.13	2.337	170.825
7	38.936	5.024	0.14	2.642	169.503
8	38.936	5.024	0.15	2.557	169.101
9	38.936	5.024	0.16	2.582	168.912
10	38.936	5.020	0.17	2.610	168.896

Table 4: Calculation of Step Voltage under Wet Soil and Gravel Conditions with Varying Gravel Thickness from 0.08 meters to 0.17 meters

No	**Sandy Clay Soil Resistivity Wet** $\rho = 2 . \pi . \alpha . R$ **(Ohm – m)**	**Wet Gravel Resistivity (Ohm – m)**	**Gravel Thickness (m)**	**Reduction Factor**	**Step Voltage (V)**
1	23.864	8.792	0.08	1.617	170.392
2	23.864	8.792	0.09	1.558	169.900
3	23.864	7.536	0.10	1.672	168.869
4	23.864	6.280	0.11	1.813	167.725
5	23.864	5.024	0.12	2.000	166.465
6	23.864	3.768	0.13	2.370	165.412
7	23.864	3.768	0.14	2.300	165.163
8	23.864	3.768	0.15	2.230	164.915
9	23.864	3.760	0.16	2.282	164.251
10	23.864	3.760	0.17	2.306	163.986

4. Conclusion

Gravel thicknesses ranging from 0.08 meters to 0.14 meters have been found to provide safe step voltage levels. However, gravel thicknesses from 0.15 meters to 0.17 meters yield the best results, both in wet and dry conditions of sandy clay soil.

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