Evaluation of Grounding System Values with Grid Type on 150 Kv in Batu Besar Substation, Batam

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Abstract. Generally, electrical fault occurs in substations, such as phase-to-ground short circuit. The fault currents flowing in Grounding System with Grid-Type can cause voltage gradient different on ground points around substation. The purpose of this study is to evaluate the Grounding System Values with Grid-Type whether meets standard, and protect somebody who is walking around substation or touching equipment stung of 150Kv electric in Batu-Besar Substation, Batam. Grounding System with Grid-Type needs to be evaluated every certain period to get Touch Voltage and Step Voltage that meet safety and security standard of IEEE Std 80-2013. The research method is to collect parameters $\rho, \rho_s, h, A, LT, h$, which calculated using formula of Resistance Value, Touch Voltage, Step Voltage of Grounding System with Grid-Type. Then, analyzing and comparing of these data are performed based on results of calculation using the IEEE Std 80-2013. From results of this research, Resistance Value is 0.62\,\Omega, 737.65\,V and 2,458.43\,V are Touch Voltage and Step Voltage of Grounding System Values with Grid-Type respectively, based on 0.5second interruption duration with somebody’s body weight of 50kg. The Evaluation results show that Grounding System Values with Grid-Type, meet the standard of IEEE Std 80-2013 for somebody who has weight 50kg in Batu-Besar Substation, Batam.

1. Introduction

Substation is the most important part in the electrical power system. It is also a part of the link between the transmission and distribution lines. In addition, the substation contains an electrical power system equipment such as transformers, protection equipment and control equipment.

In substation, there is an electrical fault current of short circuit. It is dangerous. This interference current can damage equipment and also endanger someone in the area of substation because it can cause a voltage gradient on the equipment and the ground surface. The voltage gradient can cause Touch Voltage for someone who touches equipment and Step Voltage to someone who is walking in the area of substation.

To overcome this problem, the substation must have a good and safe grounding system for equipment and especially for someone who is in the area of the substation during normal conditions or in the time of disruption. The grounding system used must be able to prevent danger when the electrical disturbance occurs, so it can not cause a potential different at many points around the disturbance area. There are several parameters that determine whether the grounding system meets safety and security requirements, namely Grounding Resistance, Touch Voltage and Step Voltage. [1] For Grounding System in the substations, there are several standards that used to obtain a good and safe Grounding System. It also can minimize hazards during interruptions. One of the standards used is IEEE Std 80-
2013. In IEEE Std 80-2013, there is a basic concept of the Grounding System for substations until step by step in design and calculation Grounding System for substations are explained clearly and detail. [2]. Based on this standard, the research conduct an evaluation of the 150/20 kV Grounding System to meet the IEEE Std 80-2013 in Batu Besar Substation, Batam. The purpose of this study is to evaluate the Grounding System Values with Grid Type whether meets standard, and can protect somebody who is walking around substation or can protect somebody who is touching equipment stung of 150 Kv electric in Batu Besar Substation, Batam.

2. Theoretical Basic

2.1. Previous study

Reference [3] was Analysis of Grounding System for Substation of Bagan Batu with Grid Construction to plan the grounding system in the form of a grid and to find out the ratio of the amount of touch stress and step voltage in the field with touch voltage and allowable step voltages based on the IEEE 80-2000 Electrical Standards. The results of each Touch Voltage are 154.1 volts from the Touch Voltage permitted 186.7 volts and step voltage of 209.6 volts from permitted step voltage of 214.4 volts.

Reference [4] was Study of Substation Grounding System 150/20 KV Design at Garuda Sakti Substation by taking data in the field and processed to calculate the formulas. Then, compare the results with the IEEE Std 80-2000. Based on the design results, it was obtained 626.38 V mesh voltage, 344.46 V step voltage, 2300 m length of the grid conductor used along with 0.55 Ω resistance and 2/0 AWG (86.59 mm²) conductor with 0.0105 m or 0.414 inch diameter.

Reference [5] was Safety Evaluation on 150 KV Ngawi Substation Grounding System, Surakarta. The results of this study in 150 KV grounding resistance in Ngawi Substation during 2017 period is ≤1. It meets the quality of safety criteria for grounding resistance. The difference of allowable Touch Voltage is 1,430 volts, whereas Touch Voltage of research is 134 volts. The allowable Step Voltage is 4,940 volts, whereas Step Voltage of research is 153 volts and the Transfer Voltage is 3,833.5 volts.

Further Reference [6] was IEEE Guide for Safety in AC Substation Grounding. In this research, it was discussed the importance of the Grounding System at the substation. Disturbances rise in the substation will give hazardous result that can cause accidents to human. So, a proper and safe design of Grounding System that meets the standards for humans is obtained.

2.2. Substation

Substation is a main of electrical power system equipment placed, such as Power Transformers, Control Equipment, Protection Equipment, Current Transformer, Potential Transformer, Conductors and Insulators. Substation functions as a place to increase or decrease high-voltage electric to be low-voltage electric, and viceversa. Substation is used as a place to supervise the equipment operation. Substation in Batu Besar, Batam, can be seen in Figure 1.

![Figure 1. Substation in Batu Besar, Batam](image)

Land in the substation has electrical voltage because Grounding System process occurred in the substation. Disturbance current flows to the ground will cause potential differences on the ground surface.
In addition, soil degradation affects the size of resistivity value of the soil type. It also affects the size of the Touch Voltage and Step Voltage. Soil degradation is caused by three factors, namely Physical, chemical and Biological Degradation.

Touch Voltage Value and Step Voltage Value are various. These values depend on location of someone who is standing in the location of the grounding points of an equipment.

2.3. Grounding System with Grid Type

Grounding System on equipment in the substation using conductors that are injected parallel in the ground and connected between one each other to form grid. This grid system is in depth of 0.3m to 0.8m of ground surface. [7] Grid system configuration can be seen in in Figure 2.

![Figure 2. Grid system configuration [7]](image)

2.4. Soil Resistivity

The condition of soil resistivity, structures and soil layers are different in a substation. So. It causes resistance different of soil types. This is caused by geological factor, soil salinity, soil humidity, soil temperature and soil electrolyte. Group of soil types and their resistivity is shown in Table 1.

| Soil Type              | Resistivity (m) |
|------------------------|-----------------|
| Marshland              | 30              |
| Organic Soil           | 100             |
| Wet Sand               | 200             |
| Wet Gravel             | 500             |
| Dry Sand and Gravel    | 1000            |
| Crushed Rock           | 3000            |

2.5. Grid Grounding Resistance

For most transmission and other large substation, grid grounding resistance value must be 1Ω or less. Grid Grounding resistance can be determined with simplified calculation, using formula is the Equation 1. [9]

\[
R_g = \rho \left( \frac{1}{L_f} + \frac{1}{\sqrt{20A}} \left( 1 + \frac{1}{1 + h \sqrt{\frac{20}{A}}} \right) \right)
\]  

(1)

2.6. Touch Voltage

Touch Voltage is voltage occurs between object touched with a point within 1 meter, whereas the object is connected to the grid grounding. The number of disturbance current flowing to someone is limited by the resistance of that person and the contact resistance of that person’s feet to the ground. Flowing the Touch Voltage can be seen in Figure 3. The Touch Voltage event is formulated in the equivalent circuit and shown in Figure 4.
From Figure 3, when a short circuit disturbance occurs, it flows to an electrical equipment. Intentionally or accidentally, that equipment is touched by someone. Touch voltage is stated in Equation 2 and Equation 3 [9]:

$$E_{\text{touch}50} = (850 + 1.5C_s x \rho_s) \cdot I_b_{50}$$ (2)

$$I_b_{50} = \frac{0.116}{\sqrt{f}}$$ (3)

Resistivity Reduction Factor on the ground surface is stated in Equation 4. [9]:

$$C_s = 1 - \frac{1 - \frac{\rho_s}{\rho}}{2h_s + 0.09}$$ (4)

Shock Duration and Tolerable Touch Voltage can be seen in Table 2.

| Shock Duration (s) | Tolerable of Touch Voltage (Volt) |
|--------------------|----------------------------------|
| 0.1                | 1,980                            |
| 0.2                | 1,400                            |
| 0.3                | 1,140                            |
| 0.4                | 990                              |
| 0.5                | 890                              |
| 1.0                | 626                              |
| 2.0                | 443                              |
| 3.0                | 362                              |

2.7. Step Voltage

Step Voltage is voltage occurs between the two legs of somebody who standing on the ground of substation that flowed of a short circuit fault current to the grid grounding. In this step, assumed voltage distance between two feet of someone is 1 meter and 8 cm of feet diameter. [2] Figure 5 shows the occurrence of Step Voltage caused by the flowing of short-circuit fault current to the grid grounding. At the same time, the same person is standing on the substation area that connected to the grid grounding. Equivalent of Step Voltage is shown in Figure 6.
Step Voltage is stated in Equation 5 and Equation 6 [2]:

$$E_{\text{Step}50} = (1000 + 6C_s \times \rho_s) \times I_{b50}$$  \hspace{1cm} (5)

$$I_{b50} = \frac{0.116}{\sqrt{f}}$$  \hspace{1cm} (6)

Table 3 shows the Shock Duration and the Tolerable of Step Voltage

| Shock Duration (s) | Tolerable of Touch Voltage (Volt) |
|--------------------|----------------------------------|
| 0.1                | 7,000                            |
| 0.2                | 4,950                            |
| 0.3                | 4,040                            |
| 0.4                | 3,500                            |
| 0.5                | 3,140                            |
| 1.0                | 2,216                            |
| 2.0                | 1,560                            |
| 3.0                | 1,280                            |

3. Research Methodology
This research method is to collect parameters of Grounding System with Grid Type, such as $\rho$, $\rho_s$, $h_s$, $A$, $LT$, and $h$. All of these parameters are calculated by using formula of Grid Grounding Resistance, Touch Voltage, and Step Voltage. Then the results of calculations are analyzed and compared with to determine whether all these obtained parameters meet the standard of IEEE Std 80-2013. Procedure of the research can be seen in Figure 7.

![Figure 7. Procedure of the research](image-url)
4. Results and Discussion
The case study presented in this work is extracted of 150 kV in Batu Besar Substation, Batam Island. Parameters used in the research is shown in Table 4.

| Parameter | Symbol | Value |
|-----------|--------|-------|
| Soil resistivity | $S_\rho$ | 1000 $\Omega$-m |
| Surface layer resistivity | $S$ | 3000 $\Omega$-m |
| Total length of grid conductor | $L_T$ | 1692 m |
| Total area enclosed by grid | $A$ | 6230 m² |
| Deep of earth grid conductor | $h$ | 0.3 m |
| Surface layer thickness | $h_s$ | 0.15 m |
| Duration time of allowable short circuit | $t_f$ | 0.5 s |

4.1 Ground Resistance Calculation
Calculation of grid ground resistance is carried out with data and Equation 1 as follows:

$$R_g = \rho \left[ \frac{1}{L_T} + \frac{1}{\sqrt{20A}} \left( 1 + \frac{1}{1 + \frac{20}{h}} \right) \right] = 0.62 \Omega$$

4.2. Touch Voltage
Calculation of Touch Voltage is carried out with data as follow:

$$R_B = 850 \Omega, \quad \rho_s = 3000 \Omega \text{-m} \quad t_f = 0.5 \text{s}$$

To get $C_s$ is used Equation 4:

$$C_s = 1 - \frac{0.09 \left( 1 - \frac{\rho_s}{\rho_B} \right)}{2h + 0.09} = 1 - \frac{0.09 \left( 1 - \frac{3000}{3000} \right)}{2.015 + 0.09} = 0.777F$$

Touch voltage:

$$E_{\text{Touch50}} = (850 + 1.5C_s \times \rho_s) \cdot I_{\text{b50}} = (850 + 1.5 \times 0.777 \times 3000) \frac{0.116}{\sqrt{0.5}} = 713 \text{ Volts}$$

Result of Touch Voltage calculation can be seen in Table 5.

| Someone’s Weight (kg) | Touch Voltage ($E_t$) (V) | Tolerable Touch Voltage by IEEE Std 80-2013(V) |
|-----------------------|---------------------------|---------------------------------------------|
| 50                    | 713                       | 890                                         |

Based on Table 5, the Touch Voltage for somebody with 50 kg weight is 713V. This value meets the standard of allowable Touch Voltage based on IEEE Std 80-2013 of 890 V with a duration of 0.5 second interruption. So, with 0.5 seconds, someone is still quite safe to touch electrical equipment without using safety equipment.

4.3. Step Voltage
Calculation of touch voltage is carried out with data as follows:

$$R_B = 850 \Omega, \quad \rho_s = 3000 \Omega \text{-m} \quad t_f = 0.5 \text{s}$$

To get $C_s$, Equation 4 is used:

$$C_s = 1 - \frac{0.09 \left( 1 - \frac{\rho_s}{\rho_B} \right)}{2h + 0.09} = 1 - \frac{0.09 \left( 1 - \frac{3000}{3000} \right)}{2.015 + 0.09} = 0.777F$$
Step Voltage:

\[ E_{\text{Touch50}} = (1000 + 6C_x \times \rho) \times \frac{0.116}{\sqrt{t}} = (1000 + 6 \times 0.777 \times 3000) \times \frac{0.116}{\sqrt{0.5}} = 2,458.4 \text{ Volts} \]

Result of Step Voltage calculation is shown in Table 6.

| Someone’s Weight (kg) | Touch Voltage (E_t) (V) | Tolerable Touch Voltage by IEEE Std 80-2013(V) |
|-----------------------|-------------------------|-----------------------------------------------|
| 50                    | 2,458.4                 | 3.140                                         |

Based on Table 6, Step Voltage for somebody with weight of 50 kg is 2,458.4 V. This value meets the standard of the allowable Step Voltage based on IEEE 80-2013 at 3,140 V with a duration of 0.5 seconds interference. With this result, it is still safe for somebody to stand on both feet without safety equipment in the substation without exceeding 0.5 seconds.

5. Conclusion

From the results, Resistance Value is 0.62 Ω, 737.65 V and 2,458.43 V are Touch Voltage and Step Voltage, respectively, of Grounding System Values with Grid Type based on the duration of 0.5 second interruption with somebody’s body weight of 50 kg. The results of Grounding System Values with Grid Type, meet the standard of IEEE Std 80-2013 for somebody who has weight 50 kg in Batu Besar Substation, Batam.

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