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Lightning Strike Effect for Potential Difference to Interconnecting Grounding System 150kV Substation

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A B S T R A C T

The grounding system at a 150 kV substation is designed according to IEEE 80-2000 taking into account the event of a lightning strike. Lightning strikes have high currents of 120 kA. The grounding system must be able to normalize the potential difference in the event of a direct or indirect lightning strike. A high potential difference will damage the electrical equipment and more people in the 150 kV substation. The grounding system must be able to normalize the potential difference spikes in a fast time and with a normal limit below 1 volt. The overall area of the grounding system used is 150 × 170m, where there are 5 transmission lines connected to several areas. In the grounding system there are 2 parameters, namely grid and rod. The duration speed in normalizing the potential difference spike is a factor in determining the reliability of the grounding system against lightning strikes. Simulation to measurement peak potential difference based on time duration going to normalize. The interconnecting grounding system to reduce lightning strike effect occur in substation area. Lightning strikes will be forwarded ground to eliminate potential difference spikes generated in the substation. High potential difference spikes in the absence of a grounded system will unsafe electrical equipment and people in area. The potential difference will result step voltage and touch voltage in the lightning strike area which makes an impact on electrical equipment in that area. The effective performance of the grounding system must be able to eliminate the effects of lightning strikes that produce a large potential difference with a very short duration.

INTRODUTION

A substation is a building that contains a lot of electrical equipment that is used to support the process of the electric power system, so it really needs a grounding system to avoid damage to electrical equipment caused by lightning or short circuits.[1]. Design of the grounding system is most important to reduce the potential difference in the effect of lightning strikes. The grounding system is an effective protection system to protect the substation area due to lightning strikes. Fault currents cause a voltage gradient between equipment ground surfaces. Soil type resistance affects the magnitude of the stress gradient [2]. Electrical equipment at 150 kV substations needs to be protected from lightning strikes, because high potential differences can cause component damage. The earthing system for substations is very important for the stability of the electric power system to avoid system failures that can cause blackouts [3]. Two of the most critical parameters that influence the design of the grounding system at an electrical substation are the soil resistivity and the area available for laying the grounding system [4]. Lightning strikes in the grounding system are the effect of resistivity and ground permittivity based on frequency on the performance of the transmission line [5]. The grounding system factor depends on the soil material and soil resistivity of the proposed site and the earthing has a hold-off valve of less than 1. The potential difference caused by lightning surges or short circuit currents must be reduced to protect people and electrical equipment from damage [6]. The frequency response of the grounding system of a generator that is hit by a lightning current has a short duration to deliver a large amount of current in the grounding system of a substation so that it disappears in the ground. The electric and magnetic fields generated by these high voltages and currents can cause equipment damage and can endanger power plant personnel [7]. High soil resistance with rocky soil conditions can be grounded using vertical rods [8]. The distance between the electrodes must be at least twice the length [9]. Rods should be spread through the earthing grid and corners to ensure proper current dispersion into deeper soil layers away from the surface as possible [10]. The resistance value of the grounding electrode will be experience an increase depending on the age of the earthing installation because it is caused by a decrease in the quality of the electrode caused by corrosion [11].

The network impedance, which is within a satisfactory range for power frequency conditions, may not be sufficient for a safe working environment under lightning fault conditions. Substation boundaries should be located at a safe distance from the grounding network as transients can be disastrous for small grids and high ground resistivity media due to the high ground potential rise [12]. The grounding system has a great impact in reducing system disturbances and the occurrence of lightning strikes. protection against overcurrent provides high safety for electrical equipment and people in the substation area. The simulation will measure the high peak potential caused by lightning directly or indirectly. The level of potential voltage drop will mostly enter at the earth electrode closest to the lightning strike because the ground points must be close together thereby reducing potential gradient [13]. Due to lightning strikes that can cause high potential, the grounding system must be able to provide a very fast duration for normalization again.

METHOD

Parameters used in this simulation are the grid and rod in the design of the grounding system. The design of the grounding system in terms of the structure of the grounding system is assumed to use a combination of R, C and L in this simulation. The parameter grid in grounding system uses a combination of R and L for the grid section and a combination of RLC for the rod section. Grounding electrodes are characterized by a series resistance R, capacitance C, a series inductance L. This method is very simple and easy to apply to simulation calculations on ground systems with frequency response, wide frequency range, high precision and computational speed [14].The following equations are used to determine the RL that will be used for the grid arrangement system [15], namely:

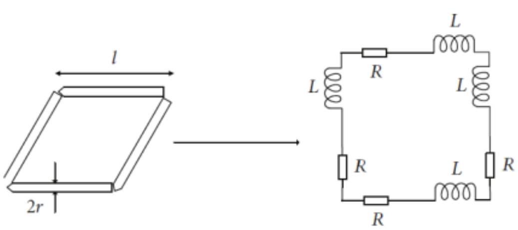

Figure 1. Grid Parameter [15]

Equation (1) is,

$$R = \frac{1}{\pi r^2} \cdot \rho_{cu}$$

Equation (2) is,

$$L = \frac{\mu_o . l}{2\pi}\left[\ln\left(\frac{2l}{\sqrt{2rh}}\right) - 1\right]$$

Where, in the calculation of R, r is the distance between the grids and ρcu the material resistance of the grid conductors. Whereas at L, l is the length of the conductor used. μo has a vacuum permeability value of $4.\pi.10^{-7}$ and h is the depth of the grid. Rod parameter using RLC equation is [15]:

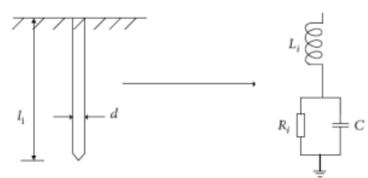

Figure 2. Rod Parameter [15]

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Equation (3) is,

$$Ri = \frac{\rho}{l_i}\left(ln\frac{8l_i}{d} - 1\right)$$

Equation (4) is,

$$Li = 2l_i\left(ln\frac{4l_i}{d} \cdot 10^{-7}\right)$$

Equation (5) is,

$$C = \frac{\varepsilon_r l_i}{8\ln(4l_i d)} \cdot 10^{-9}$$

Where, ρ is the resistivity of the conductor (Ω-m), li is the total length of the rod used, d is the diameter of the rod, εr is the permittivity of the conductor. From the results of the above equation it will be possible to design a grounding system using software and simulate direct or indirect lightning strikes based on the specified point.

RESULT AND DISCUSSION

Reliability analysis of grounding system design was used to find out the parameters that comply with IEEE std 80-2000 hit lightning strike. This investigation is used to analyse potential differences when subjected to a direct or indirect lightning strike. The sampling area at the time of a lightning strike is an area of electrical equipment which is an important point located at the 150 kV substation. Impulse current waves generated by lightning directly or indirectly must be able to lower the voltage level at the safest point around the substation area [16].

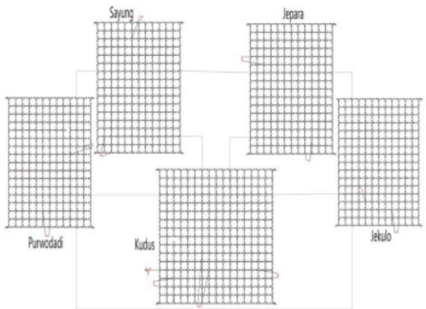

Figure 3. Grounding System Circuit Design

The simulation uses a component that acts as a lightning strike with a lightning current of 120 kA. The first simulation will optimal perform a direct lightning strike at the edge of the grounding system and the second will be carried out after passing through the arrester. Definition of optimal perform is where there is a quality that does not exceed the technical tolerance threshold to maintain equipment in substation [17]. The duration of time on the wavefront and the duration of the stroke on the impulse voltage that affect the current that occurs in the arrester [18].

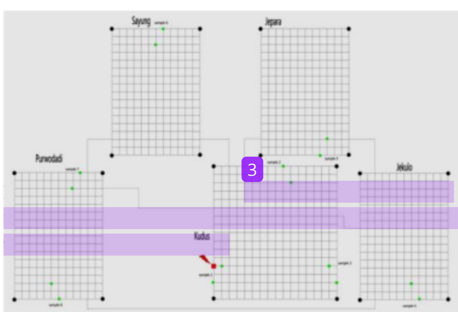

Figure 4. Sample Point Calculating Potential Difference

Direct Lightning Strike

A direct lightning strike is a lightning strike without passing through the arrester or a direct lightning strike that strikes the ground. In the first simulation, the location of the lightning strike was at edge of the grounding system area.

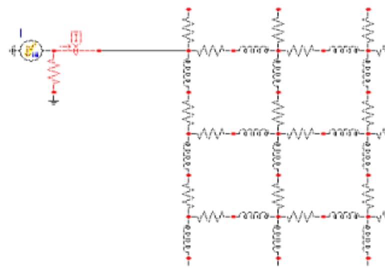

Figure 5. Direct Lightning Strike

- Sample 1

The first sample measures the value of the potential difference closest to the lightning strike. The location of the area to be measured can be seen in Figure 17, where there are several samples which are reinforcement systems at the 150kV. Here are some simulation results of potential differences from several samples that have been determined based on the location closest to the electrical equipment, namely:

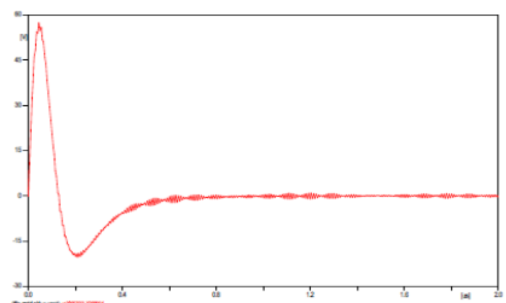

Figure 6. Potential Difference Sample 1

The graph in Figure 6 shows that, the highest voltage spike is 57.42V with a duration of 0.045 µs and after reaching the maximum the voltage has the lowest decrease to -20.2 V for a duration of 0.21 µs. The voltage increases and does not exceed 1 V for a duration of 2µs. The grounding system has worked optimally in reducing the voltage caused by a direct lightning strike in a few µs according to the simulation.

- **Sample 2**

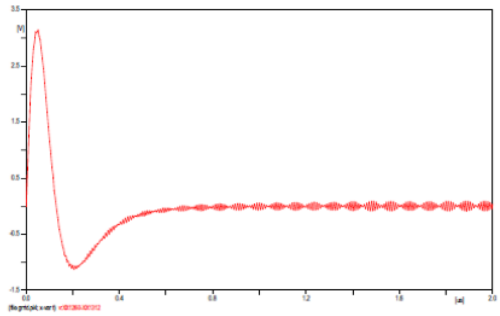

Figure.7 Potential Difference Sample 2

There was an increase in direct voltage at the initial duration of the simulation with the highest voltage of 25.49 V with a duration of 0.05 µs and a maximum voltage drop of -9.13V for a duration of 0.205 µs. The direct voltage increases and does not exceed 1 V for 2 µs.

- **Sample 3**

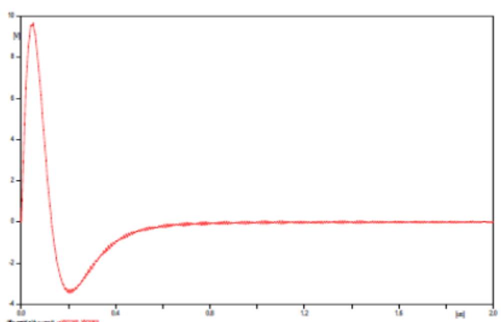

Figure.8 Potential Difference Sample 3

The graph in Figure 8. the voltage spike has decreased because the distance between the direct lightning strikes is some distance from the voltage measurement. In areas where there is a transformer at a 150 kV substation, the measurement area is smaller, the potential difference is 16.80V in a duration of 0.05 µs and immediately drops to the lowest voltage point of -6.63V for a duration of 0.205 µs. After that it increases but the voltage does not exceed 1 volt for a duration of 2 µs.

- **Sample 4**

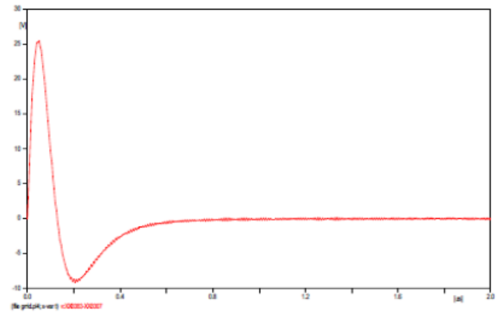

Figure.9 Potential Difference Sample 4

The effect of the current from the lightning strike reaching the grounding system in this area is smaller than in the transformer area. The peak potential difference at the initial surge was only 11.22V at a duration of 0.05 µs with the lowest voltage of -4.02V for a duration of 0.205 µs. After experiencing the lowest voltage point, the voltage increases not to exceed 1V.

- **Sample 5**

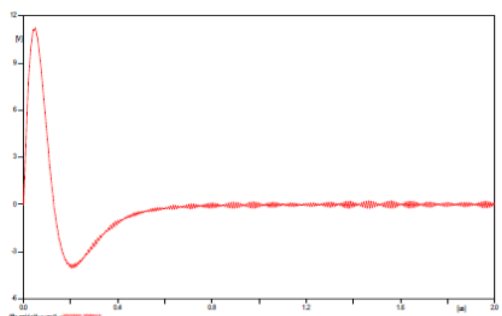

Figure.10 Potential Difference Sample 5

The effect of a lightning strike in the area with a magnitude of 9.65V at the initial surge in duration to reach a peak is 0.05 µs and after that it experiences the lowest voltage point which is -3.45 for a duration of 0.205 µs. After hitting the lowest point, it will increase to around below 1V (not exceeding).

- **Sample 6**

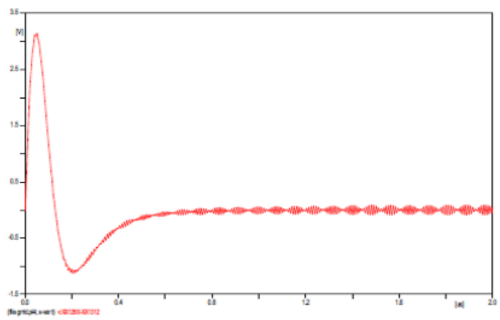

Figure.11 Potential Difference Sample 6

The distance between lightning strikes that occur in the transformer area greatly affects the initial spike during the lightning strike. The voltage obtained in the simulation only monitors the voltage to 3.14 V in a duration of 0.05µs and after reaching the peak point the voltage will drop. The decrease reaches the lowest voltage point of -1.24V and rises again until the value is below 1 V to 2 µs.

- **Sample 7**

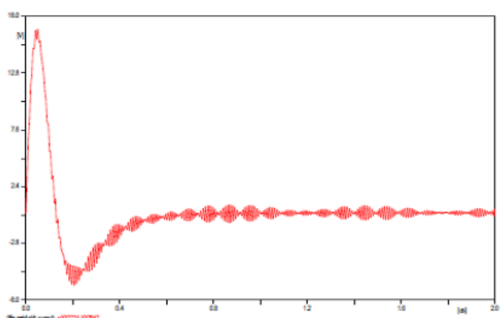

Figure.12 Potential Difference Sample 7

The maximum potential value generated is 9.56V with a duration of 0.05µs and the lowest point of the voltage is -3.4V for a duration of 0.205µs. After that, there is an increase in the potential difference not exceeding 1 V to 2 µs.

- **Sample 8**

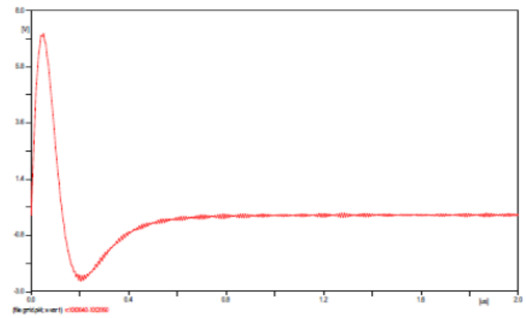

Figure.13 Potential Difference Sample 8

The measurement point was carried out in the area under the grounding system which obtained the maximum potential value of 7.11V with a duration of 0.05µs and the lowest voltage point of - 2.58V for a duration of 0.205. The voltage increases after reaching the lowest point but does not exceed 1 V. All samples subjected to a direct lightning strike will have a stable potential difference not exceeding 1 volt for a time span of 0.2 µs. The overall simulation results from the interconnected grounding system have a high level of safety, because there is a stable potential difference of less than 1s at voltages below 1 V. Only sample 1 or the closest has faster time to peak potential difference of 0.045 µs than the other samples. So, to reach the lowest point faster, namely 0.2 µs. In the graph above the nearest measuring point takes longer to rise to reach normal voltage than the other samples. A lightning strike will cause a wave that will affect electrical equipment connected to a transmission line in a nearby lightning strike area, resulting in the generation of a potential difference [19].

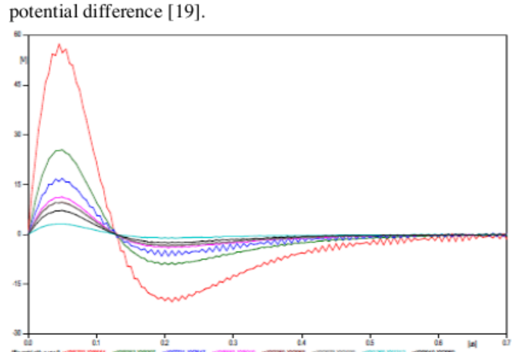

Figure 14. Total Sample Potential Difference Direct Lightning Strike

B. Indirect Lightning Strike

The arrester used has a nominal working voltage of 170 kV at the 150kV substation. Indirect lightning strike simulation with parallel interconnection to the grounding system. The simulation results are obtained from several differences in the maximum potential of each point in the grounding system model. The effect of distance from the lightning strike has the effect of minimizing the lightning strike on the potential difference.

Table 1. Maximum Potential Difference

Sample	**Duration Maximum Potential Difference**	**Maximum Potential Difference**
1	0,012 µs	992,96 V
2	0,06 µs	230,98 V
3	0,039 µs	490,7 V
4	0,06 µs	107,85 V
5	0,06 µs	92,85 V
6	0,06 µs	31,07 V
7	0,06 µs	95,96 V
8	0,06 µs	69,34 V

Fast duration in sample 1 and 3 to reach the maximum potential of other samples. Sample 1 has the fastest time to reach the highest value because the location of the measurement point is very close to the lightning strike area. Likewise in sample 3, although the distance between the lightning strike area and the measuring point is a bit far, the network conducting cable is parallel to the measuring point. The alignment of the conductor with the lightning strike field affects the time duration to the maximum voltage. The closest distance to the lightning strike has more effect on the high-level maximum potential. The farther the distance from the lightning strike area, the smaller the value of the maximum potential difference generated. In samples 2, 4, 5, 6, 7, and 8 the values reached the maximum potential with the same duration but the difference in the maximum potential values was different. Therefore, the closest distance to the lightning strike has more effect on a high maximum potential. The farther the distance from the lightning strike area, the smaller the maximum potential difference value. Lightning parameters affecting on the resultant overvoltage are the peak current magnitude, and the front and tail time of the current waveform [5]. Touch voltage and step voltage in the event of a short circuit caused by a lightning strike in the substation area must be able to be lowered to safe limits [20].

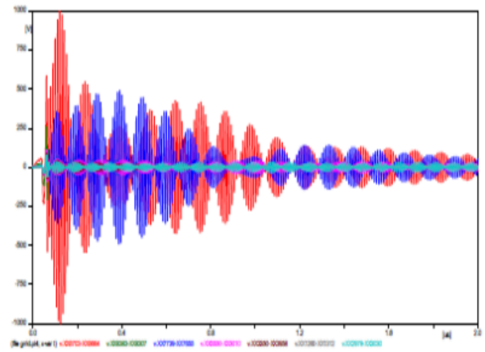

Figure 15. Potential Difference Indirect Lightning Strike

The total samples with indirect lightning strikes decreased every µs until the potential could be achieved and no humans or operators were working. The red graph of sample 1 has the highest value and sample 6 has the lowest value on the potential achieved in measurements using simulation. In sample 1 and 3 which are seen in Table 1., it was found that the maximum stress value was fast to reach the maximum stress, but the duration in potential reduction was slower than the other samples.

CONSCLUSION

The interconnected grounding system performs well against direct lightning strikes, and indirect lightning strikes. In an indirect lightning strike, there is a peak value of potential difference that exceeds the mesh voltage limit, but the duration of the reduction is very fast to get to a stable potential difference below the maximum limit in the next seconds. In the model of the grounding system at the 150kV substation, it has good performance in stabilizing the potential with a fast duration according to the simulation.

ACKNOWLEDGMENT

The author is thanks

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AUTHOR BIOGRAPHY

NUMENCLATURE

ρ	resistivity of the conductor
Li	total length of the rod used
D	diameter rod
εr	permittivity
r	distance between grid
ρcu	material resistance
μo	vacuum permeability value of $4.\pi.10^{-7}$
l	length

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