Modelling and Touch Voltage Simulation of Various Earth Grid Configuration Against Lightning

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Abstract: - Workers in an oil and gas refinery plant are exposed to the danger of touch voltage that occurs due to lightning strike. Horizontal grounding grid with minimum mesh size is the best precaution to eliminate this risk. However, this prevention method requires a lot of money. Henceforth, a series of calculations and simulations have been conveyed in order to obtain the most advantageous and proper grounding grid mesh size. Simulations were carried out by using CDEGS software. In this study, the mesh sizes were varied from 6.5m x 6.5m to 20m x 20m. The simulation results indicate that the peak value of maximum transient touch voltage rose for when the mesh size increases. Moreover, when the mesh size smaller, the injected current dispersed and flowed towards the earth faster, making the safety perimeter radius shorter. Nevertheless, grounding grid with smaller mesh size had more total conductor length. As a result, the cost would also increase. The results conclusively show that 10m x 10m is the most optimum grounding grid mesh size.

Key-Words: - Grounding grid, mesh size, safety parameter, touch voltages

1 Introduction

In oil and gas refinery plant, the personnel are exposed to the danger of hazardous voltages.

During an event of lightning strike, a person might get electrocuted through indirect contact. As defined by IEEE P3003.2 standard, the indirect contact might occur from touching an exposed conductive part (ECP), which become live part when its basic insulation broke down [1]. This phenomenon is known as touch voltage hazard. Since a person’s hand and feet are in contact with different voltage level, current will circulate through body, initiating ventricular fibrillation which causes cardiac arrest [2].

A few published articles have discussed about the danger of touch voltage as well as the mitigation methods [3-7]. One of the most common way to reduce the risk is by installing grounding grid around the electrical installation. On top of that, this article explain about the optimum configuration of the grounding grid that should be installed inside the oil and gas refinery plant.

2 Problem Formulation

2.1 Touch Voltage on Grounding Grid

Dalziel with the support of United States government, has conducted an experiment to discover the human body behavior towards electrical current.

Through this experiment, Dalziel formed an equation as in equation (1) to define the current limit that may circulate inside human body for a specific period of time [8]. If the current surpasses this threshold limit, ventricular fibrillation will happen to the human body.

$$I_B = \frac{k}{\sqrt{t}} \qquad (1)$$

Where I_B is the current limit before ventricular fibrillation, k is a constant depend on the mass of the human and t is the time period of the current circulation inside human body.

There are two values of k that has been calculated by Dalziel, each for people weighing 50kg and 70kg body mass. Moreover, IEEE Std 80-2013 contains the equation to calculate the touch voltage limit, which is shown in equation (2) [9].

$$E_{touch} = I_B\left(R_B + \frac{3}{2}C_s\rho_s\right) \quad (2)$$

E_{touch} is the maximum touch voltage human body can withstand, I_B is body shock current at the threshold of fibrillation, R_B is human body resistivity, C_s is derating factor to surface layer thickness and resistivity and ρ_s is resistivity of the layer of gravel.

Derating factor of the surface layer can be defined by equation (3).

$$C_s = 1 - \frac{0.09\left(\frac{\rho}{\rho_s}\right)}{0.09+2h_s} \quad (3)$$

ñ is top layer natural soil resistivity and h_s is gravel thickness.

For different types of soil, the maximum touch voltage will varies based on the equation in (3). Furthermore, through the derating factor, the characteristic of the surface layer would most likely determine the touch voltage threshold value [10].

The value of tolerable touch voltage is directly affected by four parameters. The maximum allowable current would rise if h_s and/or ρ_s are increased. Oppositely, the touch voltage limit will decrease if ρ and/or t are lower. In most occasions, gravel of about 15 cm thickness covers the surface layer in the grounding. Gravel is known to have high resistivity, about 9 kΩ-m, and the application of gravel may improve the step voltage and touch voltage tolerance in grounding grid system. According to IEC 62305-3, a perimeter of 3 meters from a down conductor should be made, so that there should be no worker in that area [11].

3 Method and simulation parameters

3.1 Touch Voltage Threshold Level

In this article, lightning simulation were conducted based on characteristics presented by the IEC [12]. As depicted in Fig. 1, the rise time of the lightning is 10 μs, while the fraction time is 350 μs. The peak current of the lightning reached up to 200 kA.

Meanwhile, the k constant was chosen for 70kg human mass. By substituting those parameters as well as the soil profile to (1), (2), and (3), the maximum touch voltage level was calculated. The obtained value was 12,557 V.

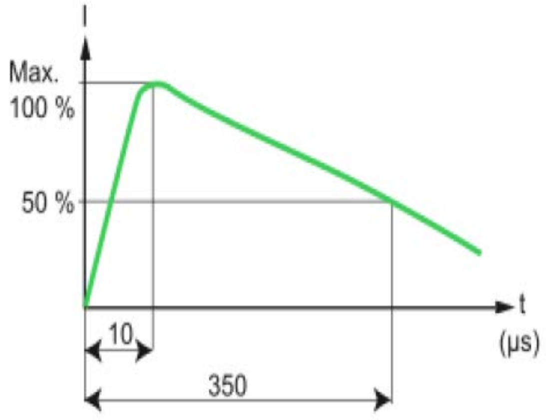

Fig. 1. Lightning characteristic based on IEC Std. 61643-11

3.2 Grounding grid modelling and variations

The horizontal grounding grid was modeled and simulated using COMSOL computer software. The layout of the grounding grid was in square shape with 200m by 200m sides, as shown in Fig.2. Furthermore, the lightning striking point was projected to be in the center of the grounding grid. The parameters for the lightning model was described in Table 1.

In order to determine the most optimum grounding grid configuration, the simulations were done by varying the mesh size. Meanwhile, the other parameters such as grounding area, number of rods, and lightning model parameters were kept constant.

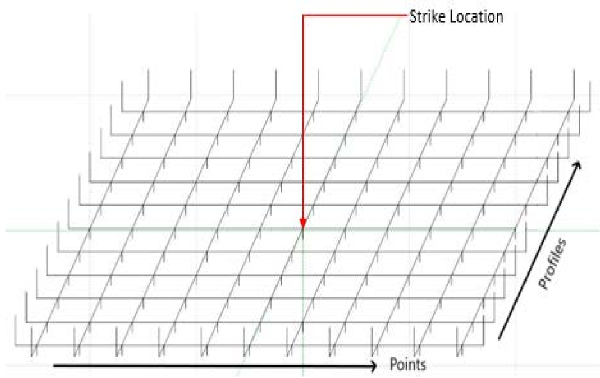

Fig. 2. Diagram of grounding grid of oil and gas refinery plant (represented by 200m x 200m area)

Table 1. Lightning strike model parameters

Parameter	Value
Type	Standard
Rise Time (µs)	10
Maximum Magnitude (A)	200,000
Fraction of Maximum Magnitude (p.u.)	0.5
Fraction Time (µs)	350

Overall, there were five variations of simulation cases. After several calculations as well as trial and error, the grounding mesh size was decided to vary from 6.5x6.5 to 20x20. Table 2 shows all the different mesh sizes that were simulated in this study.

Table 2. Grounding mesh size variation

Simulated grounding area (m^2)	Mesh size (m^2)	Number of ground rods
200 x 200	20 x 20	36
	15 x 15	36
	10 x 10	36
	7.5 x 7.5	36
	6.5 x 6.5	36

4 Problem solution

4.1 Touch Voltage Threshold Level

After the lightning stroke the center of the grounding grid, the current would immediately disperse throughout conductors and into the ground.

Fig. 3 to 7 depict the maximum transient touch voltage that were generated all over the grounding grid, based on time. For all mesh size, the maximum transient touch voltage reached around 700kV. However, this voltage only appeared for a very short period and in a certain point where the lightning stroke directly.

According to the graphs, it took less than 100 µs for the touch voltage to be depleted into less than 1/8 of its maximum value. In Fig. 3 with 6.5x6.5 mesh size, the peak value was the smallest among other mesh size, with less than 700kV transient voltage. When the lightning stroke grounding grid with higher conductor density, the current flowed towards the ground faster because there were more conductors that were in contact with the soil. Table 3 summarized the maximum step voltage for various mesh size.

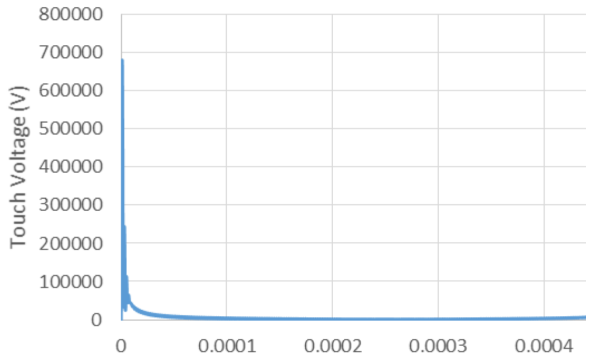

Fig. 3. Maximum transient touch voltage for 6.5 x 6.5 mesh size

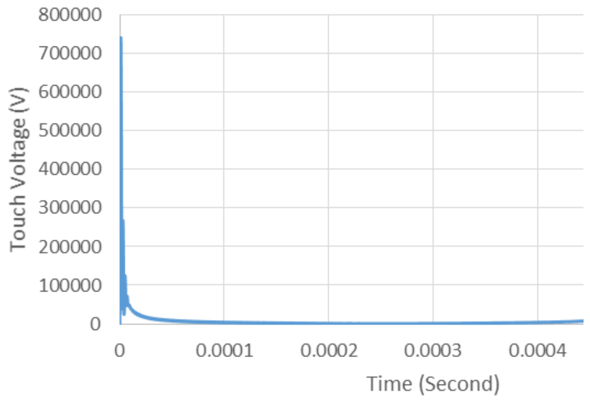

Fig. 4. Maximum transient touch voltage for 7.5 x 7.5 mesh size

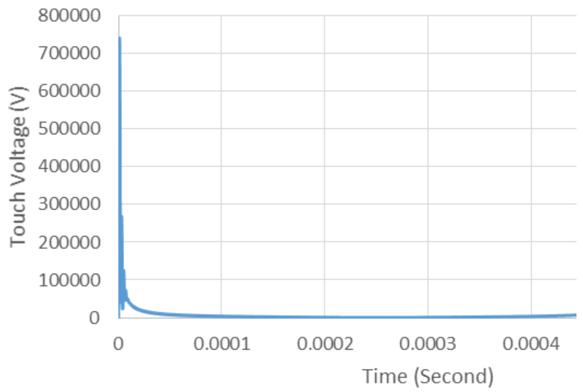

Fig. 5. Maximum transient touch voltage for 10 x 10 mesh size

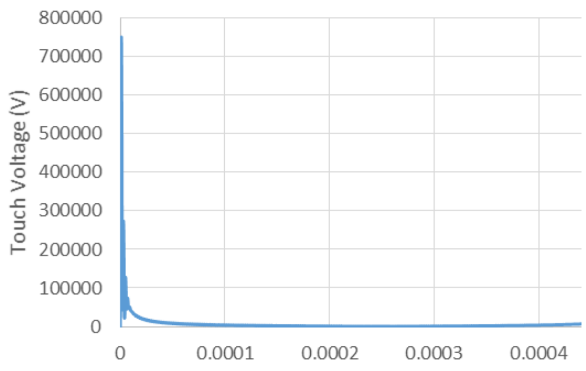

Fig. 6. Maximum transient touch voltage for 15 x 15 mesh size

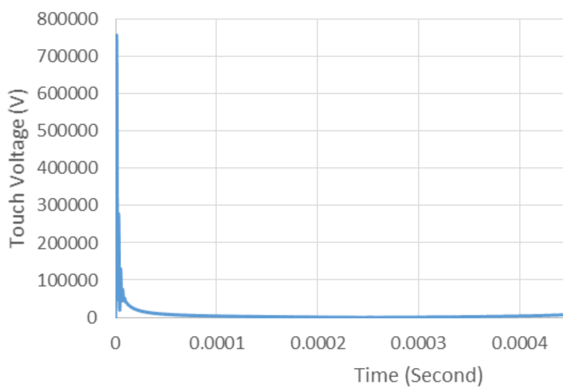

Fig. 7. Maximum transient touch voltage for 20 x 20 mesh size

As shown in Table 3, the peak value of the transient touch voltage decreases as the mesh size reduces. However, the reduction was not linear. Decreasing the mesh size from 10x10 to 7.5x7.5 shown insignificant decline on the maximum voltage. Oppositely, significant incline was indicated when the mesh size increased to 15x15.

Table 3. Maximum step voltage for various mesh size

Mesh size	Area (m^2)	Maximum voltage (V)
6.5x6.5	200x200	680,790
7.5x7.5	200x200	741,450
10x10	200x200	741,640
15x15	200x200	751,308
20x20	200x200	758,227

4.2 Grounding grid modelling and variations

In order to determine how much the grounding grid implication was, a safety perimeter was created for each simulation case.

The area outside this safety perimeter would be harmless for human when a lightning strike. As calculated and mentioned before, the maximum tolerable touch voltage is 12,557 V. Fig. 8 to 12 illustrate the area where the touch voltage did not surpass the tolerable value. All graphs were colorized based on their touch voltage level. Blue area indicated that the touch voltage varied from 0 to 12,557 V. Meanwhile, for the red area, the touch voltage was between 12,557 and 25,114 V. Lastly, the points where the touch voltage more than 25,114 V was colored as green.

As depicted in Fig. 8 through 12, the blue-colored area were considered safe, where the touch voltage did not surpass 12,557 V. From each of those figures, a longest distance was measured from the lightning striking point to the border between red and blue colored area. The obtained distances stood as the safety perimeter radius. Table 4 summarized the measurements taken.

As predicted, the safety perimeter radius increases by increasing the mesh size. The grounding grid with smaller mesh size had more total conductor length. Therefore, the total area that made contact with the earth also increases. Consequently, the lightning current spread, dispersed, and depleted faster.

However, the safety perimeter radius did not increase linearly. Instead, there was certain point where the mesh size was the most optimum. Fig. 13 shows how the safety perimeter radius made insignificant decline when the mesh size was decreased from 10x10 to 7.5x7.5 and made a sharp increment when the mesh size change to 15x15. However, when the mesh size increases to 20x20, there is slightly increment of safety radius with difference only 2m.

In comparison to Fig. 13, Fig. 14 shows how the total conductor length, which is linear to the total cost, made insignificant decline when the mesh size was changed to 15x15. Henceforth, either decreasing or increasing the mesh size from 10x10 were rather ineffective.

From all of the simulation results show that the 10x10 m mesh size is considered to be the most optimum configuration against the lightning strike.

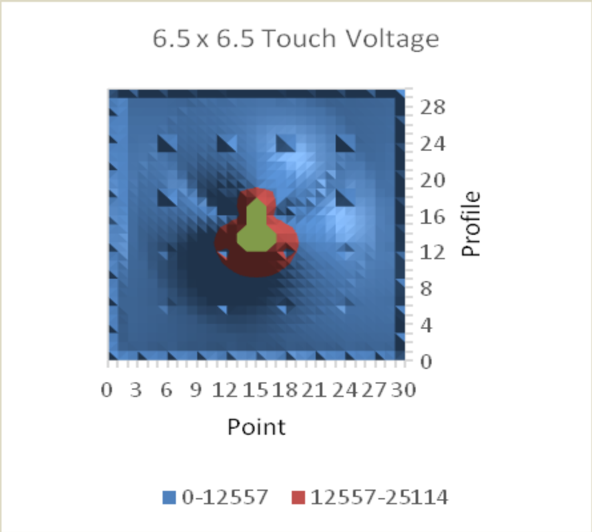

Fig. 8. 6.5 x 6.5 mesh step voltage distribution

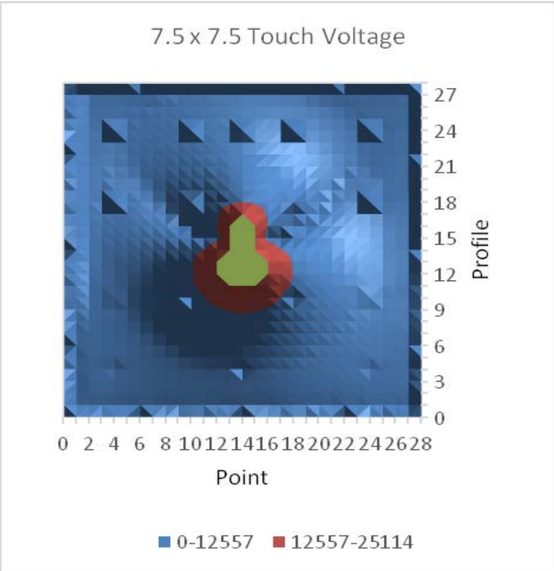

Fig. 9. 7.5 x 7.5 mesh touch step distribution

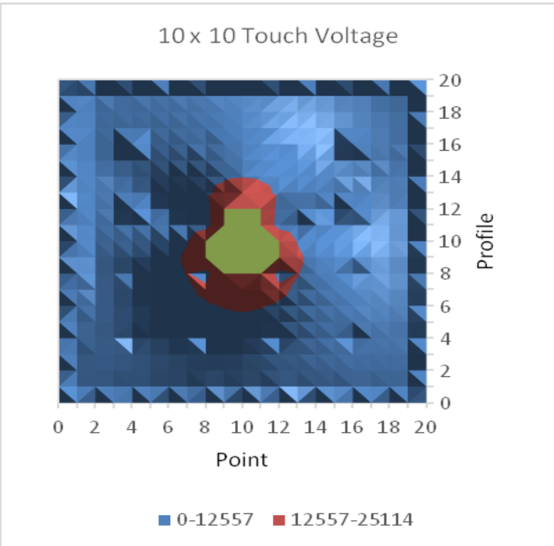

Fig. 10. 10 x 10 mesh touch step distribution

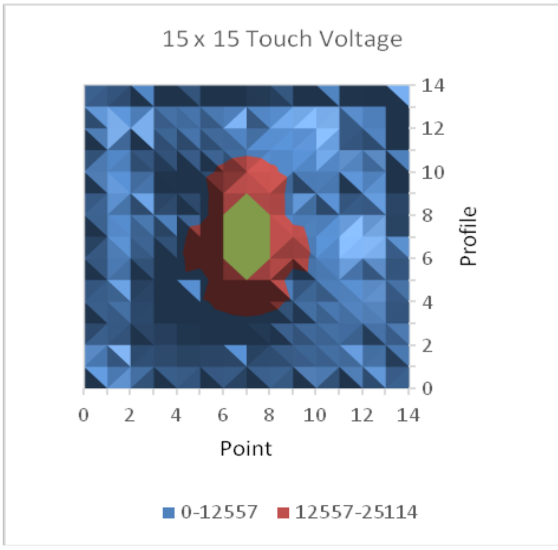

Fig. 11. 15 x 15 mesh touch step distribution

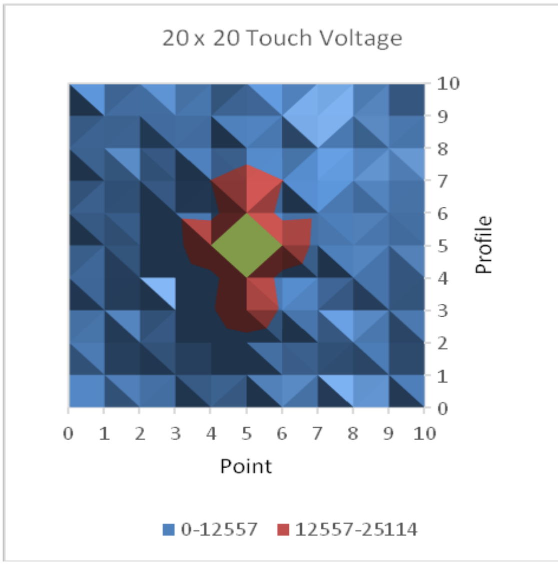

Fig. 12. 20 x 20 mesh touch step distribution

Table 4. Safety perimeter radius on grounding grid without gravel

Grounding area (m^2)	**Mesh Size (m)**	**Safety Perimeter Radius (m)**
200x200	6.5	39.0
	7.5	41.3
	10.0	43.0
	15.0	52.0
	20.0	54.0

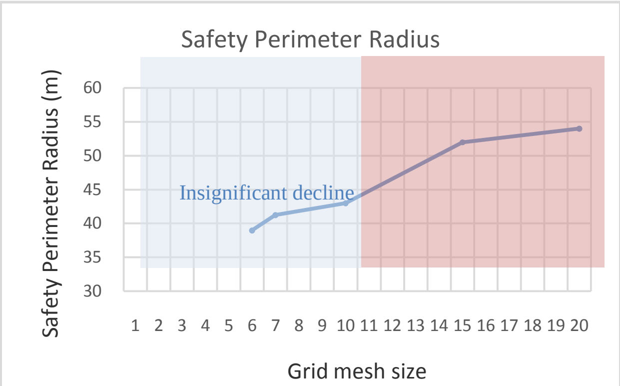

Fig. 13. Safety perimeter radius compared to the corresponding grounding grid mesh size

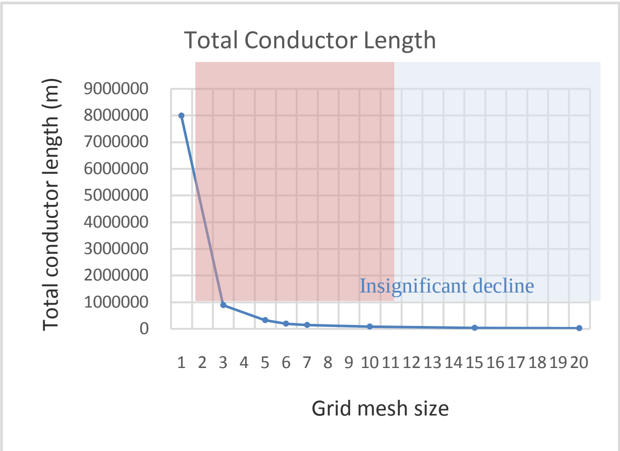

Fig. 14. Total conductor length compared to grid mesh size

5 Conclusion

The horizontal grounding grid in oil and gas refinery plan has been modeled with various mesh sizes in order to evaluate the touch voltage caused by a direct lightning strike. By using Dazlier's equations, the touch voltage threshold level obtained is 12,557 V. Meanwhile, the simulation results indicated that for mesh sizes of 6.5x6.5, 7.5x7.5, 10x10, 15x15, and 20x20 m, they required a safety perimeter area with radius of 39, 41.3, 43, 52, and 54 respectively.

In the meantime, the cost for the grounding grid rose exponentially when the mesh size was decreased from 10x10 to 1x1 m, and made insignificant decline when the mesh size was increased from 10x10 to 20x20 m.

When the mesh size is smaller, the touch voltage dissipated faster, because there were more conductors that were in contact with the earth. Henceforth, the safety perimeter radius was also smaller.

Thus, this study conclusively suggests 10x10 m grounding grid mesh size as the most optimum and advantageous option to be installed in the oil and gas refinery plant.

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