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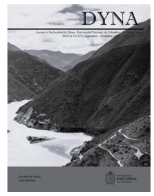

UNIVERSIDAD NACIONAL DE COLOMBIA

Effectiveness of 2-Layered grounding grids in high voltage GIS substations and new design considerations using FEM

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Abstract
With the rising demand for electricity and the expansion of power generation facilities, grounding systems have become critical for ensuring human safety and equipment protection. This study employs the finite element method to model single- and double-layer grounding networks, evaluating their effectiveness in mitigating step and touch voltages. Findings reveal that, despite increased complexity and cost, the double-layer configuration does not significantly enhance ground resistance reduction or voltage distribution, indicating that the single-layer network remains a reliable and efficient solution.

Keywords: grounding systems; protection of equipment; high voltage; finite element method; step and touch voltage.

Eficacia de redes de puesta a tierra de dos capas en subestaciones GIS de alta tensión y consideraciones de diseño mediante FEM

Resumen
Con el aumento de la demanda eléctrica y la expansión de las instalaciones de generación, los sistemas de puesta a tierra se han vuelto esenciales para garantizar la seguridad humana y la protección del equipo. Este estudio emplea el método de elementos finitos para modelar redes de puesta a tierra de una y dos capas, evaluando su eficacia en la mitigación de las tensiones de paso y de contacto. Los resultados muestran que, pese a su mayor complejidad y costo, la configuración de doble capa no mejora significativamente la reducción de la resistencia de tierra ni la distribución de voltaje, indicando que la red de capa única sigue siendo una solución confiable y eficiente.

Palabras clave: sistemas de puesta a tierra; protección de los equipos; alto voltaje; método de los elementos finitos; tensión de paso y de contacto.

1. Introduction

Grounding (earthing) systems play a key role in the safety and efficiency of electrical networks. These systems help protect individuals and equipment from voltages caused by electrical faults, lightning, and over voltages [1-5]. Proper grounding network design reduces step and touch voltages, preventing serious damage (Fig. 1). This research aims to examine the performance and effectiveness of single-layer and double-layer grounding networks, comparing them in terms of ground resistance and safety. The finite element method has been employed as an effective approach for the simulation and analysis of these networks [6-8].

In this study, the finite element method was used to model and simulate single-layer and double-layer grounding networks. First, data related to soil and environmental conditions were collected. Then, the network geometries were designed in COMSOL Multiphysics software, and ground resistance, as well as step and touch voltages, were calculated for each network. Boundary conditions and loading were configured according to industry standards. Simulations were conducted for both types of networks under various conditions to examine their performance in dissipating fault currents and reducing hazardous voltages [9-11].

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Figure 1. A view of high voltage switchgear
Source: Wang, 2020.

2. Single-Layer Network simulation

The single-layer grounding network was simulated by designing its geometry in COMSOL Multiphysics. Soil parameters and environmental conditions were incorporated to ensure realistic modeling. Boundary conditions and loading were set according to relevant standards to assess ground resistance and the distribution of step and touch voltages. The simulation aimed to analyze the network's effectiveness in fault current dissipation and hazardous voltage reduction. The results provided insights into the safety and efficiency of the single-layer design in electrical systems (Figs. 2 and 3).

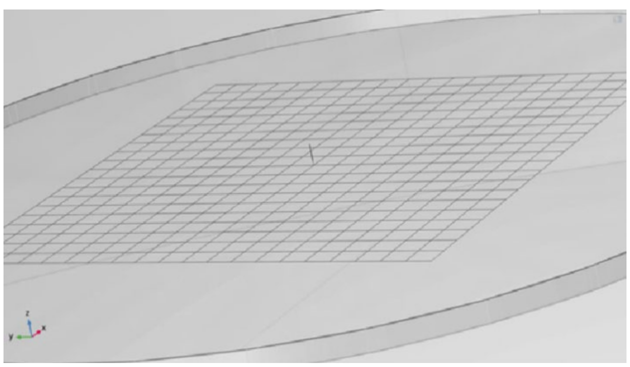

Figure 2. Close-up illustration of the single-layer
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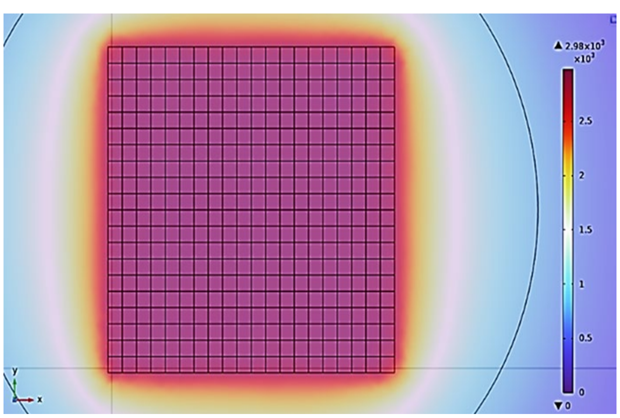

Figure 3. Finite Element Modeling of a Single-Layer Grounding System Using COMSOL Software
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2.1 Step voltage for the Single-Layer Network

Step voltage is the potential difference a person may experience between two points on the ground, typically one step apart, while a fault current is flowing through the grounding system. For the single-layer grounding network, step voltage is calculated based on the current dispersal pattern through the soil and the resistance profile around the grounding electrodes.

In this simulation, step voltage for the single-layer network is measured by analyzing the voltage gradient in the soil around the grounding grid. The aim is to ensure the step voltage stays within safe limits defined by industry standards, minimizing the risk of electrical shock to personnel near the fault location. This analysis helps verify that the single-layer network provides adequate safety during fault conditions by keeping step voltages within acceptable thresholds (Fig. 4).

2.2 Touch voltage for the Single-Layer Network

Touch voltage is the potential difference a person might experience between a point on the ground and a conductive structure or equipment in contact with the grounding network during a fault condition. In a single-layer grounding network, touch voltage is a crucial safety parameter that indicates the level of potential hazard near equipment or structures connected to the ground.

For this network, touch voltage can be evaluated by measuring the voltage difference between the grounding network's metal parts and nearby ground surface points. The goal is to ensure that the touch voltage remains within safe limits as defined by industry standards to prevent electric shock. (Fig. 5).

Through simulation, touch voltage values are analyzed across various points around the network to confirm that the single-layer design effectively reduces potential hazards, keeping touch voltage at safe levels for personnel working near grounded equipment.

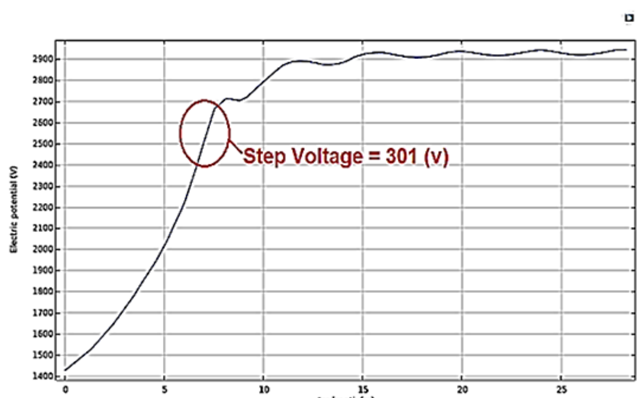

Figure 4. Voltage step diagram for a single-layer network
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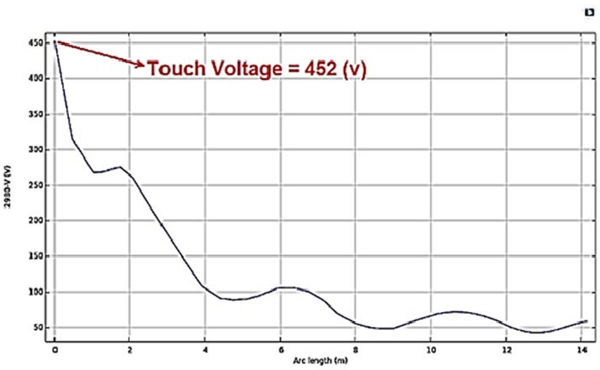

Figure 5. Touch voltage diagram for a single-layer network
Source: Created by the authors

3. Double-Layer grid simulation

The double-layer grounding grid simulation involved creating a detailed geometry in COMSOL Multiphysics, taking into account layered soil characteristics and environmental factors for accurate modeling. Boundary conditions and load settings were applied following industrial standards to calculate ground resistance and evaluate step and touch voltage distributions. This simulation focused on assessing the double-layer network's ability to dissipate fault currents and minimize dangerous voltages. The results helped to determine the added value, if any, of the double-layer configuration in enhancing electrical system safety and reliability compared to the single-layer network (Figs. 6 and 7).

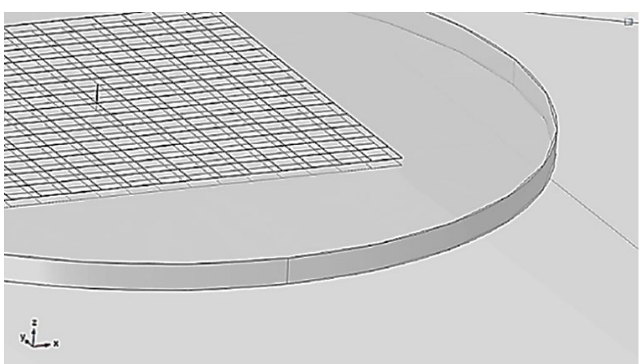

Figure 6. Close-up illustration of the double-layer grounding network
Source: Created by the authors

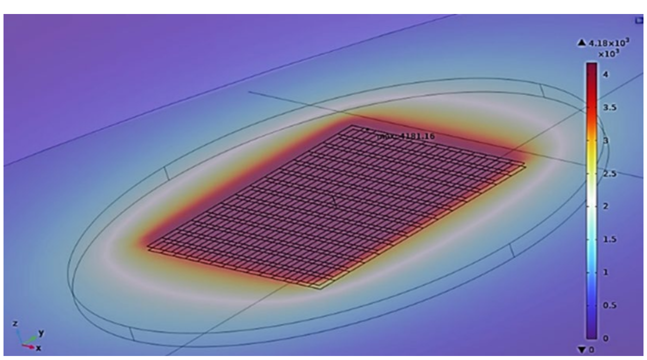

Figure 7. FEM Modeling of a 2-Layer Grounding Grid (COMSOL Software)
Source: Created by the authors

3.1 Step voltage for the Double-Layer Network

Step voltage in a double-layer grounding network refers to the potential difference experienced between two points on the ground surface, typically spaced one step apart, during a fault condition. In this setup, the double-layer design aims to spread fault current more evenly across the soil, potentially reducing step voltages at various points on the surface.

For this network, step voltage is analyzed by simulating voltage gradients around the grounding system (Fig. 8).

The double-layer configuration, with its added complexity, theoretically distributes current over a broader area, potentially achieving lower step voltages compared to a single-layer system. The simulation measures these voltages at various distances from the network to assess compliance with safety standards and to verify the effectiveness of the double-layer design in minimizing step voltage hazards.

3.2 Touch voltage for the Double-Layer Network

In a double-layer grounding network, touch voltage represents the potential difference that a person might experience between a point on the ground and a conductive structure (such as equipment connected to the grounding system) during a fault condition. The double-layer design is intended to distribute fault currents more effectively, which may lower touch voltages in areas surrounding grounded equipment.

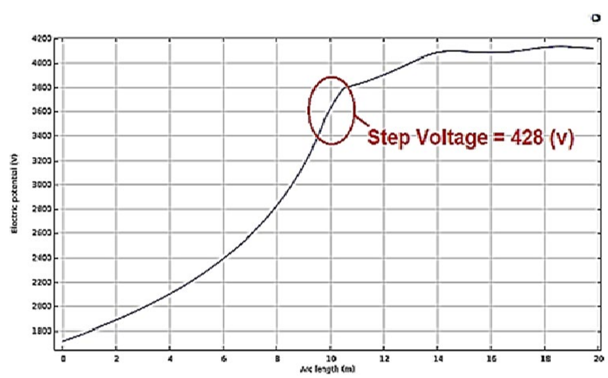

Figure 8. Step Voltage Diagram for the Two-Layer Network
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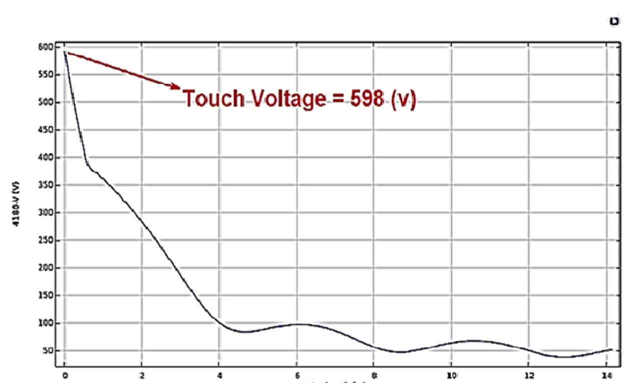

Figure 9. Touch Voltage Diagram for the Two-Layer Network
Source: Created by the authors

To evaluate touch voltage in this network, simulations are conducted to measure the voltage difference between the grounding network components and points on the ground surface nearby (Fig. 9). The double-layer configuration, with its deeper and additional grounding layer, can potentially provide improved voltage distribution and further reduce touch voltage risks.

By analyzing touch voltages at various points, this assessment helps verify that the double-layer network can achieve safer voltage levels, enhancing protection for personnel working near grounded equipment, in line with industry safety standards.

4. Simulations and Results

The simulation results showed that the step and touch voltages in double-layer networks are significantly higher than in single-layer networks. For the single-layer network, the step voltage was measured at 301 volts and the touch voltage at 452 volts, while these values for the double-layer network were 406 volts and 598 volts, respectively. Ground resistance was also higher for the double-layer network compared to the single-layer network (0.418 ohms versus 0.298 ohms).

These results indicate that, despite the increased complexity of the double-layer network, its performance does not significantly improve safety or reduce step and touch voltages.

5. The proposed network

A third network was also modeled, in which the ineffective middle sections of the two-layer configuration were removed (Fig. 10). This modification reduces copper usage, construction delays, and coupling effects, while yielding results comparable to those of the full two-layer network (Figs. 11, 12 and 13).

Comparison among 3 types of investigating grids is briefly obtained as mentioned in Table 1 and Table 2. It can be resulted from this table that in two-layered structure; all technical parameters especially Rg, is increased value and the upper layer is not effectively enough as the commercial designers consider during calculation process.

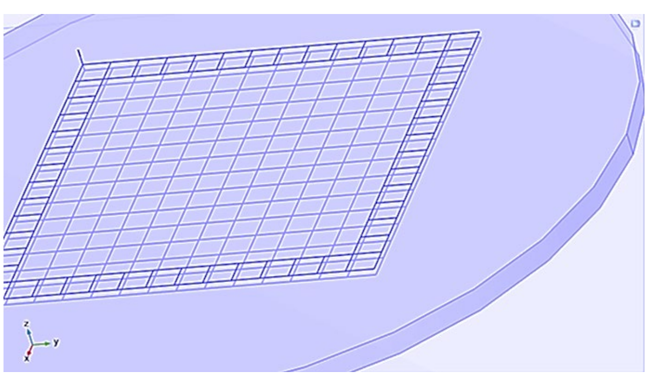

Figure 10. Simulation of the Proposed Network
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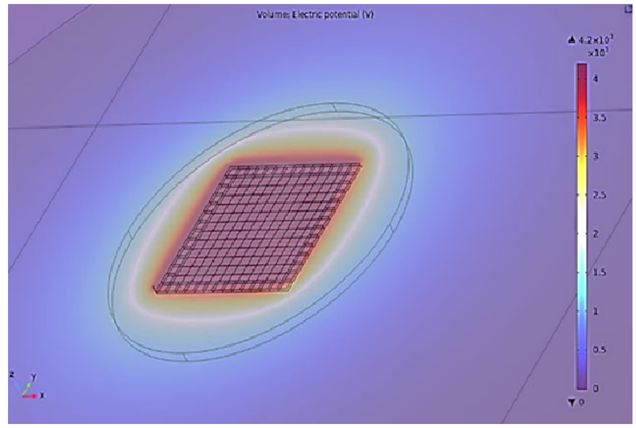

Figure 11. Finite Element Modeling of the Third Proposed Grounding System Using COMSOL Software
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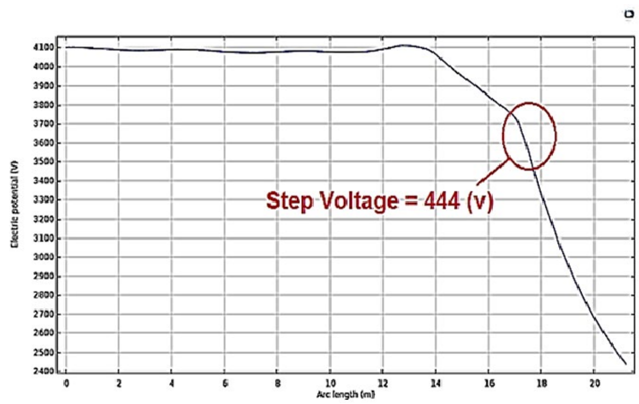

Figure 12. Step Voltage Diagram for the Proposed Network
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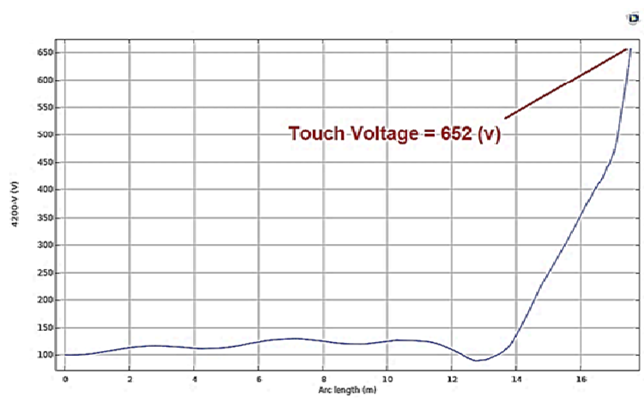

Figure 13. Touch Voltage Diagram for the Proposed Network
Source: Created by the authors

Table.1
Comparison of two-layer and single-layer grounding systems

	Rg	Step-voltage	Touch-voltage	GPR
Single-layer	0.298	492	301	2980
Two-layer	0.418	598	406.4	4180

Source: Created by the authors

Table. 2
Comparison among 3 types of investigating grids

	Rg	Step-voltage	Touch-voltage	GPR
Single-layer	0.298	492	301	2980
Two-layer	0.418	598	406.4	4180
Proposed grounding system	0.42	444	652	4200

Source: Created by the authors

Regarding to proposed grid structure which save about 38% needed copper wire, it is observed that technical parameters variations, especially Rg, are not serious.

6. Discussion and Conclusion

The findings show that two-layer grounding grids, despite their higher complexity and cost, do not outperform single-layer networks in mitigating touch and step voltages. Simulation results confirm that single-layer networks can ensure adequate safety and efficiency, making them the more cost-effective option. Therefore, grounding system designs should prioritize single-layer configurations, optimized according to local and environmental conditions to reduce costs while maintaining safety.

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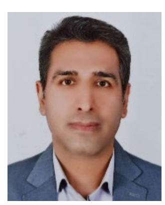

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