Article **Journal of Technologies in Industrial Processes**
June, 2023 Vol.7 No.16 19-27

Grounding System Design of the main Electrical Substation of stones and minerals breaker plant in Campeche State to comply with the NOM-001- SEDE-2012, IEEE-Std-80-2000, and the Código de Red

Diseño del Sistema de Puesta a Tierra de la Subestación Eléctrica principal de una Planta Quebradora de piedra y minerales en el Estado de Campeche para cumplir con la NOM-001-SEDE-2012, IEEE-Std-80-2000 y el Código de Red

LEZAMA-ZÁRRAGA, Francisco Román†, SHIH, Meng Yen, CHAN-GONZALEZ, Jorge de Jesús* and SALAZAR-UITZ, Ricardo Rubén

Universidad Autónoma de Campeche, Campus V, Predio s/n por Av. Humberto Lanz Cárdenas y Unidad Habitacional Ecológica Ambiental, Col. Ex-Hacienda Kala, CP 24085, San Francisco de Campeche, Cam., México.

ID 1st Author: *Francisco Román, Lezama-Zárraga* / **ORC ID**: 0000-0003-3397-7881, **Researcher ID Thomson**: U-1229-2018, **CVU CONAHCYT ID**: 205493

ID 1st Co-author: *Meng Yen, Shih* / **ORC ID**: 0000-0001-7475-6458, **CVU CONAHCYT ID**: 408617

ID 2nd Co-author: *Jorge De Jesús*, *Chan-Gonzalez* **/ ORC ID**: 0000-0002-8638-1646, **CVU CONAHCYT ID**: 84196

ID 3rd Co-author: *Ricardo Rubén, Salazar-Uitz* / **ORC ID**: 0000-0003-2307-737X, **CVU CONAHCYT ID**: 416277

DOI: 10.35429/JTIP.2023.16.7.19.27 Received March 30, 2023; Accepted June 30, 2023

Abstract

This article proposes the design of a grounding mesh for the main electrical substation of 150 kVA in the Breaker Plant in order to obtain a good path to drain overcurrents due to faults and prevent electrical installations from being a danger to connected equipment and users who use electrical installations, allowing voltage control to reduce the risk of shock to people who may come into contact with energized conductors; complying with current regulations NOM-001-SEDE-2012, IEEE-Std-80-2000 and the Código de Red and does not represent a danger of failure for the electrical network supplying CFE. There is a grounding system based on a delta of electrodes already many years after its installation and without maintenance and ineffective that has allowed the passage of overcurrents that have damaged motors. It is intended that the new design of the grounding system be reliable and safe and that, in addition, when an electrical installation verification unit (UVIE) arrives, it provides the Load Center with the Electrical Installation Verification Opinion, signing in agreement that it is complying with the applicable provisions of NOM-001-SEDE-2012, Electrical Installations (use), based on IEEE-Std-80-2000.

Grounding mesh, Substation, Overcurrent, Verification unit

Resumen

En este artículo se plantea el diseño de una malla de puesta a tierra para la subestación eléctrica principal de 150 kVA en la Planta Quebradora con el fin obtener un buen camino para drenar las sobrecorrientes debidas a fallas y evitar que las instalaciones eléctricas sean un peligro para los equipos conectados y los usuarios que usan las instalaciones eléctricas, permitiendo el control de voltaje para la reducción de peligro de descarga a personas que puedan entrar en contacto con conductores vivos; cumpliendo con la normatividad vigente NOM-001-SEDE-2012, IEEE-Std-80-2000 y el Código de Red y no represente un peligro de falla para la red eléctrica suministradora de CFE. Existe un sistema de puesta a tierra basado en una delta de electrodos ya con muchos años de su instalación y sin mantenimiento e ineficaz que ha permitido el paso de sobrecorrientes que han dañado motores. Se pretende que el nuevo diseño del sistema de puesta a tierra sea confiable y seguro y que además cuando llegue una unidad verificadora de instalaciones eléctricas (UVIE) proporcione al Centro de Carga el Dictamen de Verificación de Instalaciones Eléctricas firmando de conformidad que está cumpliendo con las disposiciones aplicables de la NOM-001-SEDE-2012, Instalaciones Eléctricas (utilización), basados en la IEEE-Std-80-2000.

Malla de puesta a tierra, Subestación, Sobrecorriente, Unidad verificadora

Citation: LEZAMA-ZÁRRAGA, Francisco Román, SHIH, Meng Yen, CHAN-GONZALEZ, Jorge de Jesús and SALAZAR-UITZ, Ricardo Rubén. Grounding System Design of the main Electrical Substation of stones and minerals breaker plant in Campeche State to comply with the NOM-001- SEDE-2012, IEEE-Std-80-2000, and the Código de Red. Journal of Technologies in Industrial Processes. 2023. 7-16: 19-27

---

*Correspondence to Author (e-mail: jorjchan@uacam.mx)
† Researcher contributing as first author.

Introduction

This article proposes the design of a grounding mesh for the main electrical substation of 150 kVA in the Quebradora Plant in order to obtain a good way to drain the overcurrents due to faults and prevent electrical installations from being a danger to the connected equipment and users who use the electrical installations, allowing voltage control to reduce the danger of shock to people who may come into contact with energized conductors; complying with the current regulations NOM-001-SEDE-2012, IEEE-Std-80-2000 and the Network Code and does not represent a failure hazard for CFE's electrical supply network.

The objectives to be fulfilled by the grounding system of a substation, under normal and fault conditions are:

1. To provide the means to dissipate electric currents to ground without exceeding the operating limits of the network and equipment.
2. To ensure that people inside the substation and in its surroundings are not exposed to the danger of electric shock currents.

The design procedure that is developed corresponds to IEEE-Std-80-2000, allows to obtain safe levels of step and touch voltages inside the substation and in its vicinity. The calculation of the mesh voltage and the maximum step voltage are fundamental to corroborate the efficiency of the mesh.

When the grounding mesh design is square or rectangular, the mesh voltage increases along the mesh from the center to the corners of the grid, depending on its size, the number and location of grounding electrodes, the spacing of parallel conductors, the diameter and depth of the conductors, the soil resistivity and the connections, usually with exothermic welding.

The resistance values of grounding systems, according to current standards are:

a. NOM-001-SEDE-2012 is between 0 and 25 Ω.
b. IEEE-Std-80-2000 is less than 5 Ω.
c. CFE Specification 01J00-01, for the Código de Red, is less than 3 Ω.

Generally the grounding system is composed of a horizontal mesh of buried conductors, supplemented by grounding electrodes connected to the mesh with exothermic welding to penetrate deep layer soils that have lower resistivity. The electrodes are always installed along the perimeter and at the corners of the grid (IEEE, 2000).

Problem Statement

The Breaked Plant addresses the problem of its grounding system based on a delta of electrodes installed 26 years ago and without maintenance, so its operation is ineffective to the passage of overcurrents caused by atmospheric discharges or faults in the supply network, which has caused damage to motors and equipment connected to the low voltage electrical installation.

The grounding system in general is in poor condition; the anomalies found are listed below.

1. The grounding system with delta connected electrodes does not comply with the minimum electrode spacing. According to IEEE-STD-80-2000, a minimum spacing of 2 m is recommended. The electrodes or rods should be copper or copper coated, in our case the rods are very corroded and have a distance between them of 60 cm. See figure 1.

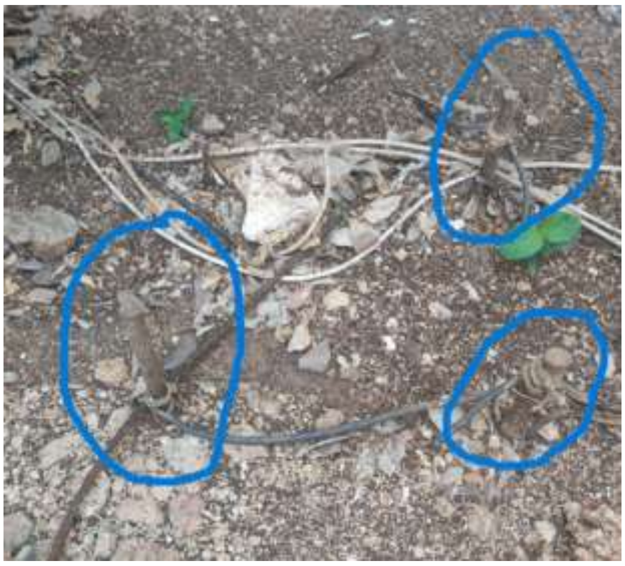


Figure 1 Delta grounding system
Own Elaboration

2. In the Delta system, the connections between electrodes with the conductor must be made with exothermic welding. Here they are only tied together, only one electrode has a mechanical connector. This prevents optimum contact between electrode and conductor, which means that this is not a good way to drain overcurrents due to faults and is a danger for the connected equipment and the users of the electrical installations. See figure 2.

Figure 2. Connection between the electrode and the grounding conductor; it can be seen that only one of the three electrodes has its mechanical connector
Own Elaboration

3. The grounding conductor that is connected to the electrodes must be completely bare in order to make contact with the surface of the earth to have a real zero potential. In this system the conductor is sheathed.

4. The conductor must be a minimum 2 AWG gauge to ensure that the resistance to ground is less than 3 Ω; the conductor it has is 10 AWG gauge.

The ground resistance of the existing Delta system was measured; it was 26.4 Ω, which is a value not accepted by the NOM-001-SEDE-2012 and IEEE-Std-80-2000 standards. Therefore, the proposal is to design a grounding system based on a copper conductor mesh and electrodes in the corners.

In addition to complying with the provisions of NOM-001-SEDE-2012 and IEEE-Std-80-2000, the optimal design of the mesh is essential for compliance with the provisions of the Grid Code (DOF, 2020).

Methodology

For the design of the grounding grid, a methodology consisting of the following steps was used:

1. Preparation of tools, measuring equipment and personnel who will perform the measurements and field survey.

2. Physical survey in the low voltage installations and in the substation with the help of the electrical plans and one-line diagram, identifying each of the existing grounding systems.

3. Install the ground Megger equipment to obtain the soil resistivity and ground resistance levels of the existing grounding systems.

4. Analyze the information obtained from the survey and measurements to verify if these values comply with current regulations.

5. Define the anomalies found and give proposals for improvement, through a technical report.

6. If anomalies exist, define the efficient design of the grounding system of the main substation of the Quebradora Plant that complies with NOM-001-SEDE, the Código de Red and IEEE-Std-80-2000.

Single-line diagram

The single-line diagram was previously defined by Lezama et al (ECORFAN, Journal Electrical Engineering, 2022). Figure 3 illustrates only the Medium Voltage utility source to the 150 kVA main substation.

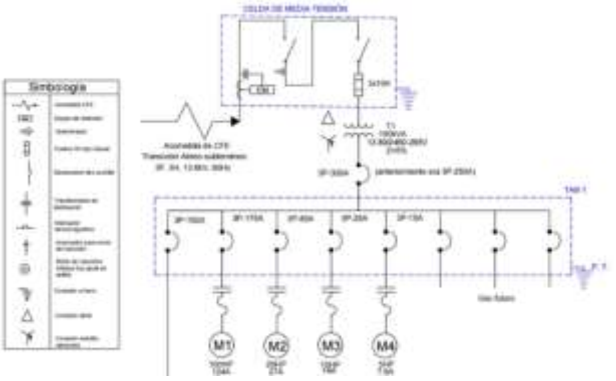


Figure 3 Updated single-line diagram showing the main substation
Own Elaboration

It is essential to keep the single-line diagram updated and to have it always at hand for any revision that may occur.

The following is the methodology for the design of the grounding mesh according to IEEE-Std-80-2000.

Soil resistivity

Soil resistivity measurements were performed in the area where the grounding mesh will be installed, determining the resistivity of the uniform layer by the four-point Wenner method (see figure 4).

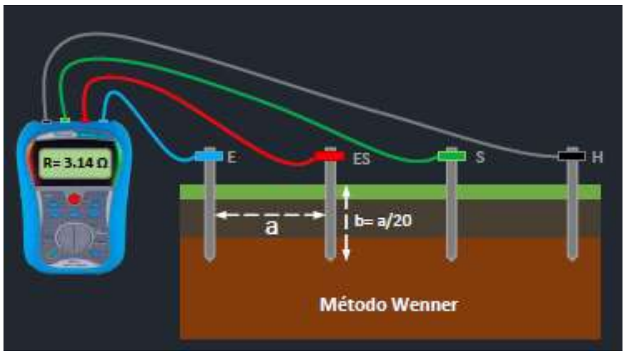


Figure 4 Soil resistivity measurement
Source: Mendoza García, Alan. Blue Energy Ingeniería. 2023

The four electrodes are driven into the ground in a straight line at a depth "b", separated at a distance "a".

If b << a, as is the most common case, the resistivity of the soil is determined through

$$\rho_a = 2\pi a R \tag{1}$$

where ρ_a is the apparent resistivity in (Ωm), a is the separation distance between electrodes in (m) and R is the measured resistance in Ω.

The results of the measurements with the ground resistance tester are shown in Table 1.

Distance between electrodes (m)	**Average Resistivity (Ω-m)**
1	3.1
2	5.6
3	7.2
4	12.5
5	22.2
6	26.7
7	27.6
8	29.4
9	31.3
10	32.2

Table 1 Results of soil resistivity measurements of the Breaker Plant
Own Elaboration

The uniform equivalent resistivity ρ_{su} calculated by averaging the data obtained from the above table, *i.e.*, with eq:

$$\rho_{su} = \frac{\rho_1 + \rho_2 + \cdots + \rho_n}{n} \tag{2}$$

in our case study, the $\rho_{su} = 19.78\ \Omega m$

To observe and analyze the measurements, it is presented in the resistivity curve below.

Graph 1 Soil resistivity curve
Own Elaboration

Grounding mesh design

The design of the grounding mesh is suggested empirically. The dimensions are provided in the following table.

Design data	
Length short side of mesh Lx (m)	4.5
Length long side of mesh Ly (m)	6
No. of horizontal cond. in X nLx	5
No. of horizontal cond. in Y nLy	4
Grid size D (m)	1.5
Vertical conductor length Lr (m)	3
Vertical conductor diameter 2b (mm)	16
Number of vertical cond. nR	4
Mesh depth h (m)	0.6
Horizontal conductor diameter 4/0 AWG ***2a*** (mm)	13.4
Mesh area ***A*** (m2)	**27**
Total length cond. Horizontal ***Lc*** (m)	**46.5**
No. of total horizontal cond**. *nLc***	**9**
Total length of horizontal and vertical cond. ***LT*** (m)	**58.5**

Table 2 Data for the design of the grounding grid of the Breaker Plant
Own Elaboration

The last four data in Table 2 were obtained through the set of equations given in (3):

$$\begin{aligned} A &= Lx * Ly \\ Lc &= Lx * nLx + Ly * nLy \\ nLc &= nLx + nLy \\ LT &= Lc + (Lr * nR) \end{aligned} \tag{3}$$

Mesh conductor sizing

IEEE Std 80-2000 states that, the conductor cross-section, as a function of the short time temperature rise, the magnitude and duration time of the fault and when the conductor material constants are known, can be determined with the equation

$$A = \frac{I_f}{\sqrt{[\frac{TCAP*10^{-4}}{t_c \sigma_r \rho_r}]\, ln[\frac{K_0+T_m}{K_0+T_a}]}} \tag{4}$$

where:

A = Conductor cross section [mm^2].
I_f= Maximum short-circuit current [kA]
Tm = Maximum permissible temperature [°C]
Ta = Ambient temperature [°C].
Tr = Reference temperature for material constants [°C].
σ_0 = Thermal coefficient of resistivity at 0°C [1/°C]
σ_r = Thermal coefficient of resistivity at reference temperature Tr [1/°C]
ρ_r = Resistivity of the grounding conductor at reference temperature Ta [μΩ-cm]
$K_0 = 1/\sigma_r$ [°C]
t_c = Current duration [seconds]
$TCAP$ = Thermal capacity per unit volume [J/cm^3/°C].

For copper conductors at a certain reference temperature and with a conductivity of 97%, the following values are obtained (IEEE,2000)

$$\alpha_r = 0.00381\, {}^{1}/_{°C}, conT_r = 20°C$$
$$K_0 = 242°C$$
$$T_m = 480°C$$
$$\rho_r = 1.78\mu\Omega - cm, conT_r = 20°C$$
$$TCAP = 3.42\, {}^{J}/_{(cm^3 °C)}$$
$$T_a = 35°C$$
$$t_c = 0.5 \text{ seg}$$

Short circuit current (I_{cc}) will be calculated from the short circuit power provided by the supplying company, CFE Zona de Distribución Campeche, which is 645 MVA.

Since the most critical short-circuit current condition in the substation is produced by a phase-to-ground fault in the Medium Voltage connection of the 13.8 kV, of the Break Plant, the I_{cc} is calculated with the following equation

$$I_{cc} = \frac{MVA_{cc}}{\sqrt{3}(kV)} \; [kA] \tag{5}$$

substituting the data, we have

$$I_{cc} = \frac{645\; MVA}{\sqrt{3}(13.8kV)} = 26.98kA$$

Considering a forward growth factor of the system, *i.e.* f_c=1.3, the effective symmetrical fault current (rms) for the grounding grid design is

$$I_f = f_c * I_{cc} \tag{6}$$

For our system, I_f is

$$I_f = 1.3 * 26.98 = 35.074kA$$

Substituting the data in equation (4), we have the area A of the conductor cross-section

$$A = \frac{35.074}{\sqrt{[\frac{3.42x10^{-4}}{0.5*0.00381*1.78}]\, ln[\frac{242+480}{242+35}]}} = \frac{35.074}{\sqrt{0.1008*0.958}} =$$

$$112.86mm^2$$

Therefore, for this conductor cross-section area, we have a 4/0 AWG gauge.

This conductor is the one empirically taken in the design section of the grounding mesh.

Resistance of the mesh

It is obtained based on the resistivity of the soil equivalent to a layer by means of Sverak's equation (IEEE Std 837-1989, Appendix B).

$$R_{g2} = \rho_{su}\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}}\right)\right] \tag{7}$$

Substituting the values obtained above, we have:

$$R_{g2} = 19.78\left[\frac{1}{57} + \frac{1}{\sqrt{20*18}}\left(1 + \frac{1}{1+0.6\sqrt{\frac{20}{18}}}\right)\right]$$

$$R_{g2} = 2.43\Omega$$

Table 3 shows the grounding resistance values of different types of substations provided by the IEEE-Std-80-2000, in our case it is a substation of an industrial plant and it is observed that the value of R_{g2} calculated is acceptable.

Type of electrical installation	Grounding resistance [Ω]
Subestaciones de gran tamaño (20,000 m^2) y de Transmisión	1 or less
Substations for industrial plants, large commercial buildings and facilities and small substations	Range 1 to 5
Individual electrodes (residential)	25
Individual transmission towers	10

Table 3 Grounding resistance values.
Source: IEEE-Std-80-2000

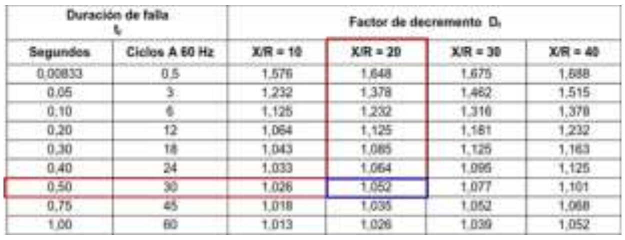
Mesh current

We will determine the maximum current to be dissipated by the ground mesh to avoid oversizing, according to the following equations:

$$\begin{aligned} I_G &= D_f * I_g \\ I_g &= S_f * I_f \\ S_f &= \left|\frac{Z_{eq}}{Z_{eq}+R_{g2}}\right| \end{aligned} \tag{8}$$

where:
I_G is the peak current in the mesh [A],
D_f is the decrement factor of the conductor,
I_g is the symmetrical mesh current [A],
S_f is the fault current division factor.
I_f is the ground fault current [A],
Z_{eq} is the equivalent impedance [Ω].
R_{g2} is the equivalent impedance [Ω].

According to our industrial installation, IEEE-Std-80-2000 recommends an *X/R* = 20. Thus, using Table 4 intercepting the column *X/R* equal to 20 with the row of fault duration time *tc* = 0.5 seconds, we obtain the decrement factor *Df* = 1.052. In the stone crusher substation, only one neutral of the CFE distribution circuit and no transmission lines are considered. Applying table 5 we obtain the $Z_{eq} = 1.29 + j0.967\ \Omega$.



Duración de falla t_f		Factor de decremento D_f			
Segundos	Ciclos A 60 Hz	X/R = 10	X/R = 20	X/R = 30	X/R = 40
0,00833	0,5	1,576	1,648	1,675	1,688
0,05	3	1,232	1,378	1,462	1,515
0,10	6	1,125	1,232	1,316	1,378
0,20	12	1,064	1,125	1,181	1,232
0,30	18	1,043	1,085	1,125	1,163
0,40	24	1,033	1,064	1,095	1,125
0,50	30	1,026	1,052	1,077	1,101
0,75	45	1,018	1,035	1,052	1,068
1,00	60	1,013	1,026	1,039	1,052

Table 4 Driver decrement factor
Source: IEEE-Std-80-2000

Table 5 Some approximate equivalent impedances of transmission line guard cables and distribution neutrals (feeders). *Source: IEEE-Std-80-2000.*

Number of transmission lines	Neutral distribution numbers	Zeq. Rtg=15, Rdg=25
1	1	0.91+j0.485
1	2	0.54+j0.33
16	0	0.163+j0.037
0	1	1.29+j0.967
0	2	0.643+j0.484
0	4	0.322+j0.242
0	8	0.161+j121

Table 5 Some approximate equivalent impedances of transmission line guard cables and distribution neutrals
Source: IEEE-Std-80-2000

We apply eq. (8) and obtain our design values:

$$S_f = \left|\frac{1.29 + j0.967}{1{,}29 + j0.967 + 2.43}\right| = 0.42$$

$$I_g = 0.42 * 35{,}074\,A = 14{,}731.08\,A$$

$$I_G = 1.052 * 14{,}731.08\,A = 15{,}497.096\,A$$

Tolerable touch and step stresses

We start with the touch stress for a 50 kg person, which is given by

$$E_{\text{contacto}} = (1000\Omega + (1.5C_s * \rho_s)\frac{F_p}{\sqrt{t_s}} \tag{9}$$

Similarly, the touch stress for a person weighing 50 kg is calculated with the equation

$$E_{\text{paso}} = (1000\Omega + (6C_s * \rho_s)\frac{F_p}{\sqrt{t_s}} \tag{10}$$

The equation of the surface layer shrinkage factor (C_s), is introduced here, which is considered as a correction factor to calculate the effective resistance of a person's foot in the presence of a surface material of finite thickness; it is given by

$$C_s = 1 - \frac{0.09\left(1 - \frac{\rho_{su}}{\rho_s}\right)}{2h_s + 0.09} \tag{11}$$

where:
C_s is the surface layer shrinkage factor,
ρ_{su} is the soil resistivity [Ω-m],
ρ_s is the resistivity of the surface layer [Ω-m],
h_s is the thickness of the surface layer [m],
t_s is the maximum failure release time [s],
F_p is the maximum failure release time.

Calculating the surface layer shrinkage factor, we have:

$$C_s = 1 - \frac{0.09\left(1 - \frac{2.43}{1000}\right)}{2(0.8) + 0.09} = 0.946$$

The contact voltage is now determined:

$$E_{contacto} = \big(1000 + (1.5 * 0.946 * 10{,}000)\big) * \left(\frac{0.116}{\sqrt{0.5}}\right)$$

$$E_{contacto} = 2{,}491.9\ V$$

The step voltage is obtained with: $E_{paso} = \big(1000 + (6 * 0.946 * 10{,}000)\big) * \left(\frac{0.116}{\sqrt{0.5}}\right)$

$$E_{paso} = 9{,}475.45\ V$$

Ground potential rise and touch voltage evaluation

When a voltage is transferred from the substation grounding mesh to a remote external point near the grid, the *GPR* ground potential rise must be minimized:

$$GPR = I_G * R_{g2} \tag{12}$$

Substituting the data obtained above, we have:

$$GPR = 15{,}497.096\ A * 2.43\ \Omega = 37{,}657.94\ V$$

When comparing GPR with the $E_{contacto}$ obtained previously, it is observed that GPR is very excessive so we must perform some additional calculations.

Mesh tension and maximum step tension.

Because $GPR \gg E_{contacto}$, the mesh efficiency must be corroborated with the following set of equations:

$$\begin{gathered}
E_m = \frac{\rho_{su} * I_G * k_m * k_i}{L_m} \;;\; E_p = \frac{\rho_{su} * I_G * k_s * k_i}{L_s} \\
L_m = L_c + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + L_y^2}}\right)\right] L_R \\
L_s = 0.75\,L_c + 0.85 L_R \\
k_m = \frac{1}{2\pi}\left[ln\left(\frac{D}{16hd} + \frac{(D+2h)^2}{8Dh} - \frac{h}{4d}\right) + \frac{k_{ii}}{k_h} ln\left(\frac{8}{\pi(2n-1)}\right)\right] L_R \\
k_h = \sqrt{1 + \left(\frac{h}{h_0}\right)} \;;\; k_i = 0.664 + (0.148n) \\
k_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \frac{1}{D}(1 - 0.5^{n-2})\right] \\
n = n_a * n_b \;;\; n_a = \frac{2 * L_c}{L_p}
\end{gathered} \tag{13}$$

where:
ρ_{su} is the soil resistivity [Ω-m],
I_G is the maximum current in the mesh [A],
k_m is the geometrical value of mesh spacing,
k_i is the irregularity factor,
k_s is the geometrical mesh factor,
L_m is the effective buried length [m],
L_s is the length of horizontal and vertical conductors,
L_c is the total length of horizontal conductors [m],
L_r is the vertical conductor length [m],
L_x is the length of the short side of the mesh [m],
L_y is the length of the long side of the mesh [m],
L_R is the total length of vertical conductors [m],
k_{ii} is a correction factor that adjusts for the effects of the conductors on the corner of the mesh,

k_h is a correction factor that takes into account the effects of the depth of the mesh,
k_i is the irregularity factor,
h_0 is the reference depth, it is 1m.
n is the number of parallel conductors of an equivalent rectangular mesh,,
n_a y n_b are the geometrical factors of the mesh,
L_p is the length of the perimeter of the rectangular mesh [m].

We apply equation (13) and obtain:

$$L_m = 46.5 + \left[1.55 + 1.22\left(\frac{3}{\sqrt{4.5^2+6^2}}\right)\right] * 12$$

$$L_m = 70.95\, m.$$

$$k_h = \sqrt{1 + \left(\frac{0.6}{1}\right)} = 1.264$$

$$n_a = \frac{2 * L_c}{L_p} = \frac{2 * 46.5m}{21m.} = 4.429 = 5$$

$$n = n_a * n_b = 5 * 1 = 5$$

$$k_m = \frac{1}{2\pi}\left[ln\left(\frac{1.5}{16 * 0.6 * 0.0134} + \frac{(1.5+(2*0.6))^2}{8 * 1.5 * 0.0134} - \frac{0.6}{4 * 0.0134}\right) + \frac{1}{1.264} ln\left(\frac{8}{\pi * ((2*5)-1)}\right)\right]$$

$$k_m = 0.4985$$

$$k_i = 0.664 + (0.148 * 5) = 1.404$$

The mesh tension is:

$$E_m = \frac{15 * 15{,}497.096 * 0.4985 * 1.404}{70.95}$$

$$E_m = 2{,}293.09\, V$$

In addition, we calculate:

$$L_s = 0.75 * 46.5 + 0.85 * 12 = 45.075m.$$

$$k_s = \frac{1}{\pi}\left[\frac{1}{2 * 0.6} + \frac{1}{1.5+0.6} + \frac{1}{1.5}(1 - 0.5^{5-2})\right]$$
$$k_s = 0.603$$

Then, the maximum step voltage is:

$$E_p = \frac{15 * 15{,}497.096 * 0.603 * 1.404}{45.075}$$

$$E_p = 4{,}366.06\, V$$

According to IEEE-Std-80-2000, to define if the grounding grid design of the 150 kVA electrical substation of the stone crusher plant is optimal, the provisions of Table 6 must be complied with.

$E_m < E_{contacto}$	$E_p < E_{paso}$
2,293.09 V < 2,491.9 V	4,366.06 V < 9,475.95 V

Table 6 Comparison and evaluation of voltajes
Source: Own Elaboration

Therefore, our design complies with the specification. If in one case the limits of the step or touch voltages are exceeded, the grounding system design is required to be modified and can be improved by increasing the mesh area and smaller spacings in horizontal and vertical conductors.

Figure 5 illustrates the design of the grounding mesh that complies with the specifications of the current standards.

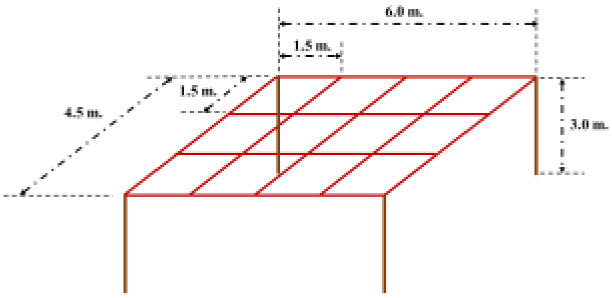


Figure 5 Grounding grid design
Own Elaboration

Acknowledgement

The authors are grateful for the support and effort of the Universidad Autónoma de Campeche for its researchers to disseminate the research projects developed in this CIERMMI 2023 Congress.

Conclusions

The design of the grounding mesh in the stone and mineral crushing plant provides a methodology to obtain a robust grounding system for a distribution substation in the industrial, commercial and service sectors. It complies with NOM-001-SEDE-2012, IEEE-Std-80-2000 and the Código de Red.

Likewise, now there are electrical installations with voltage control, reducing the danger of shock to people who may come into contact with live conductors and avoiding damage to equipment such as motors, since there is a safe way to drain overcurrents.

As future work, the implementation of a lightning rod system against atmospheric discharges is recommended.

References

Comisión Federal de Electricidad. 2016. “*Sistema de Tierra para Plantas y Subestaciones Eléctricas. Especificación CFE 01J000-01”*. México. Recuperado de: https://lapem.cfe.gob.mx/normas/pdfs/u/01J00_01.pdf el día 12 de mayo de 2023.

Diario Oficial de la Federación. 2016. “*Disposiciones Administrativas de carácter general que contienen los criterios de eficiencia, calidad, confiabilidad, continuidad, seguridad y sustentabilidad del Sistema Eléctrico Nacional: Código de Red*”. Recuperado de: https://www.cenace.gob.mx/Docs/16_MARCOREGULATORIO/SENyMEM/(DOF%202016-04-08%20CRE)%20RES-151-2016%20DACG%20C%C3%B3digo%20de%20Red.pdf el día 06 de junio de 2023.

Hussain, GA, Hassan, W., Mahmood, F., Shafiq, M., Rehman, H. y Kay, JA (2023). Revisión sobre Técnicas de Diagnóstico de Descargas Parciales para Equipos de Alta Tensión en Sistemas de Potencia. Acceso IEEE.

Diario Oficial de la Federación. 2017. “*Procedimiento para la Evaluación de la Conformidad de la Norma Oficial Mexicana NOM-001-SEDE-2012, Instalaciones Eléctricas (utilización)*”. Recuperado de: https://verielec.com/assets/pec-nom-001-sede-2012-nov-2017.pdf el día 01 de junio de 2023.

IEEE. 1991.” *Especificaciones para Tierra de Sistemas de Energía Comercial e Industrial, IEEE-Std-42-1991”.* Recuperado de: https://protergia.com/descargas/IEEE%20142%201991%20Definicion%20tierras.pdf el día 07 de junio de 2023.

IEEE. 2000. *“IEEE Guide for Safety in AC Substation Grounding, IEEE-Std-80-2000”.* Recuperado de: https://standards.ieee.org/ieee/80/225/ el día 07 de junio de 2023.

Juárez Torres, Alfredo. 2001. “Sistemas de puesta a tierra”. Editorial Alfredo Juárez Torres. México.

Lee, KY, Bühs, F., Göhlich, D. y Park, S. 2023. Hacia un diseño y operación confiables de sistemas de carreteras eléctricas para vehículos pesados en escenarios de tráfico realistas. Transacciones IEEE en Sistemas de Transporte Inteligentes.

Lezama Zárraga, Francisco; Shih, Meng Yen; Chan González, Jorge de Jesús; y Salazar Uitz, Ricardo Rubén. 2022. *“Eficiencia energética en una Quebradora de piedra y minerales en el Estado de Campeche para cumplir con el Procedimiento de Evaluación de Conformidad (PEC) de la NOM-001-SEDE-2012”.* Journal Electrical Engineering; Volume 6, Isuue 16: Editorial Ecorfan. DOI: 10.35429/JEE.2022.16.6.24.32

SEGOB, Diario Oficial de la Federación. 2020. “*ACUERDO por el que se emite la Política de Confiabilidad, Seguridad, Continuidad y Calidad en el Sistema Eléctrico Nacional*”. 15 de mayo de 2020. Recuperado de: https://dof.gob.mx/nota_detalle.php?codigo=5593425&fecha=15/05/2020 el día 28 de junio de 2022.