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Grounding system for a hospital

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--------------------ABSTRACT--------------------

This work describes the essential steps to calculate a grounding system in a hospital, according to the current regulations, the design of the grounding system will be made to dissipate the atmospheric discharges in an efficient way, protecting the medical personnel, patients and medical equipment.

KEYWORDS;- *Current, conductor gauge, electrical discharge, network length, standards, resistivity, grounding system, step voltage, grid voltage.*

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I. INTRODUCTION

The absence of an adequate grounding system in a hospital represents a great risk for the personnel working inside the hospital as well as for the patients, since there is a risk of electrocution, which could result in death. This situation is due to the fact that the current induced by an atmospheric discharge is not dissipated correctly, which can cause damage to the hospital's medical equipment and even affect the end users. These incidents generate considerable economic losses, as the damaged equipment needs to be replaced or repaired.

According to [1], in his article entitled “Prevention of occupational hazards caused by lightning strikes”, he mentions in his section on lightning effects, risks and risk factors that atmospheric discharges can seriously affect sensitive electronic equipment, which can result in its malfunction or even in its total inoperability, due to the inadequate dispersion of atmospheric discharges by the grounding system connected to the building.

This design will be based on data obtained from the terrain where the hospital is located and the pertinent calculations will be made in accordance with current standards: NOM-001-SEDE-2012 and IEEE 80 in order to size and select the materials to be used and thus safeguard the lives of both patients and medical personnel working in the hospital. It also seeks to protect medical equipment, especially in the intensive care area, in order to reduce the cost of acquiring new devices and guarantee a safe medical environment for all those involved.

II. GROUNDING SYSTEM

Definition of a grounding system

A set of buried vertical and horizontal grounding electrodes that drains atmospheric discharge and fault currents to ground and is a safe grounding connection point for personnel during maneuvers [2].

According to [3], the objectives of a grounding system are the following: to limit the potential difference that can occur between metallic structures and ground, to enable the detection of ground faults and ensure the performance and coordination of the protections, thus eliminating or reducing the risk of a fault for the equipment used and people, to limit internal over voltages that may appear in the electrical network under certain operating conditions and to prevent the steep front voltages caused by lightning discharges from causing “reverse priming”, in the case of outdoor installations and particularly in overhead lines.

Types of Grounding Systems

Grounding systems can be classified according to their application into: electrical system grounding, electrical equipment grounding, electronic signal grounding, electronic protective grounding and atmospheric protective grounding [4].

Grounding for electrical systems: The purpose of grounding electrical systems is to limit any high voltages that may result from lightning, induction phenomena or unintentional contact with wires of higher voltages. This is done by means of a conductor appropriate to the total ground fault current of the system, as part of the electrical system connected to planet earth.

Grounding of electrical equipment: its purpose is to eliminate touch potentials that could endanger life and property, so that equipment overcurrent protections operate. Used to ground all the elements of the installation that under normal operating conditions are not subject to voltages, but that may have potential difference with respect to ground because of accidental faults in the electrical circuits, as well as the points of the electrical installation where it is necessary to establish a ground connection to provide greater safety, better performance and regularity of operation, all elements subject to significant electrical short circuit current and over voltages under fault conditions.

Grounding of electronic signals: to avoid contamination with signals at frequencies different from the desired frequency. It is achieved by means of shields of all types connected to a zero reference or to ground.

Electronic protective grounding: to avoid the destruction of semiconductor elements by overvoltages, protective devices are placed to limit the overvoltage peaks connected between the active conductors and ground. The grounding of electronic and control equipment consists of a series of electrodes installed remotely from the building. An electrolytic copper bar of suitable dimensions is installed inside, with an indicative legend, which is for the exclusive use of the electronics system.

Atmospheric protection grounding: as its name indicates, it is intended to drain to ground the currents produced by atmospheric discharges (lightning) without major damage to people and property.

III. CALCULATION AND GROUNDING SYSTEM DESIGN

To make the calculations and design of a grounding system, certain data is needed according to the Norma Oficial Mexicana (NOM-001- SEDE 2012) and the Norm of the Institute of Electrical and Electronics Engineers (IEEE 80-2013) [5] y [6].

The data obtained from the hospital where the design will be carried out are as follows:

- Resistivity of the upper soil layer: 25.30 Ohm_meters.
- Resistivity of the lower soil layer: 30.33 Ohm_meters.
- Thickness of the topsoil: 0.2 meters.
- Resistivity of the surface material layer (gravel): 40.5 Ohm_meters.
- Thickness of the superficial material layer: 0.3 meters.
- Short circuit current: 5.1 kA, this short circuit value is obtained from the tables of short circuit values according to the place where the design will be made (north of the CDMX) provided by the company Comisión Federal de Eléctricidad (CFE).

Thus, to obtain the maximum current value of the network, equation 1 is used, for this, a factor of decrease of the asymmetrical short circuit current from phase to ground D_f de 0.9 and a short circuit current I_{cc}de 5 180 Amperes is taken.

$$\mathrm{I_g} = sf * I_{cc} \qquad (1)$$

$$\mathrm{I_g} = 0.9 * 5100 = 4\ 590 \text{ Amperes}$$

Once the symmetrical current is determined, using equation 2, the maximum value of the network current I_G is calculated, defining that there is no system growth, a fault duration time of 0.5 seconds and for a value X/R=10 according to table 1, the decrement factor has a value of 1.026.

$$I_G = D_f I_g \qquad (2)$$

$$\mathrm{I_G} = 1 * 1.026 * 4\ 590 = 4\ 831.78 \text{ Amperes}$$

Failure time (Tf)		Decrement factor (Df)			
Seconds	Cycles	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
0.1	6	1.125	1.232	1.316	1.378
0.2	12	1.064	1.125	1.181	1.232
0.3	18	1.043	1.085	1.125	1.163
0.4	24	1.033	1.064	1.095	1.125
0.5	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 1 Failure time and decrement factor values. Retrieved from: IEE80-2013.

Grid conductor size.

The selection of the minimum size of a conductor required as a function of the current it will transmit, as well as the time it takes to present a sudden change in temperature can be calculated with equation 3.

$$\mathrm{Amm}^2 = 1\frac{1}{\sqrt{\frac{\mathrm{TCAPx10^{-4}}}{t_c\alpha_r\rho_r}\ln\frac{K_o+T_m}{K_o+T_a}}}\ \mathrm{Akcmil} \qquad (3)$$

Where:

I is the rms current [kA]

A_{mm^2} is the cross section [mm^2]

A_{kcmil} is the cross section [kcmil], $\mathrm{Akcmil} = I * K_f * \sqrt{t_c}$

K_o is $^1/_{\alpha_0}$ o $(^1/_{\alpha_0}) - T_r$ [°C]

T_m is the maximum permissible temperature [°C]

T_α is the ambient temperature [°C]

T_r is the reference temperature for the material constant [°C]

α_0 is the thermal coefficient of resistivity a 0 °C $\left[\frac{1}{°C}\right]$

α_r is the thermal coefficient of resistivity at the reference temperature T_r $\left[\frac{1}{°C}\right]$

ρ_r is the resistivity of the earth conductor at the reference temperature T_r [$\mu\Omega * cm$]

t_c is the duration of the current [s]

TCAP is the thermal capacity per unit volume $[\frac{J}{cm^3 * °C}]$

With the calculated data and using equation 3, the conductor gauge required for the grounding network is calculated.

$$\mathrm{Acmil} = \frac{4\,831.78\ \mathrm{A}}{\sqrt{\frac{\log\left(\frac{250°-40°}{234°+40°}+1\right)}{33*0.5}}} = 39\,507.60\ \mathrm{cmil}$$

To obtain this gauge in mm2, multiply the cmil by 5.0671x10-4 mm2 as shown below:

$$A_{mm^2} = (39\,507.60)(5.0671\mathrm{x}10^{-4}) = 20.0188\ [mm^2]$$

Looking up this value in the table provided by the NOM-001 SEDE 2012, in its section 250-122 the value is 2 AWG but for practical and normative recommendations we will use a 4/0 AWG gauge, with a diameter of 107.2 mm2 due to its mechanical resistance.

Length of the network

Equation 4 is used to calculate the required conductor length.

$$L = \frac{K_m * K_i * \rho * I_g * \sqrt{t_f}}{(116 + 0.174C_s(h_s * k)\rho_s)} \quad [\mathrm{meters}] \qquad (4)$$

$$L = \frac{0.977 * 1.384 * 25 * 4\,831.78 * \sqrt{0.5}}{(116 + (0.174 * 0.87 * 2000))} = 275.8021 = 275\ \mathrm{meters}$$

Where:

P is the soil resistivity in Ω-m.

ρ_s is the resistivity of the surface soil in Ω-m.

I_G is the maximum value of phase to ground short circuit current in amperes.

K_m is the coefficient that takes into account the effect of the number of conductors “n”, spacing between conductors “D”, conductor diameter “d” and the burial depth of the grounding network “h”.

K_i is the correction factor for ground irregularities, to take into account the non-uniform current flow in different parts of the network.

The geometric factor K_m is calculated based on equation (5).

$$K_m = \frac{1}{2\pi}\left[\mathrm{Ln}\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_{ii}}{K_h}\mathrm{Ln}\left[\frac{8}{\pi(2n-1)}\right]\right] \qquad (5)$$

Since the electrodes will be located around the perimeter of the network, it is necessary that $K_{ii} = 1$, $h_0 = 1$, thus, the geometric factor can be calculated:

$$K_m = \frac{1}{2\pi}\left[\ln\left(\frac{10^2}{(16)(0.5)(11.67\mathrm{x}10^{-3})} + \frac{(10+(2*0.5))^2}{8(10)(11.67\mathrm{x}10^{-3})} - \frac{0.5}{4(11.67\mathrm{x}10^{-3})}\right) + \frac{1}{1.22}\ln\left[\frac{8}{\pi(2*5-1)}\right]\right]$$

$$K_m = 0.977$$

Calculating the terrain irregularity factor K_i,

$$K_{ii} = 0.644 + (0.148 * 5) = 1.384$$

Where:
D is the spacing between conductors.
h is the network burial depth in meters.
d is the diameter of the bare conductor already selected.
K_{ii} is the correction factor that takes into account the effect of the electrodes on the perimeter of the network $K_{ii} = 1$ for networks with electrodes on the perimeter.
K_h is the correction factor that takes into account the effect of the depth of the network.

To calculate K_{ii} equation 6 is used.

$$K_{ii} = \frac{1}{(2n)^{\frac{2}{n}}} \qquad (6)$$

In the same way, equation 7 is used to calculate K_h,

$$K_h = \sqrt{1 + \frac{h}{h_0}} \qquad (7)$$

Where:
h_0 is the reference depth of burial of the network m = 1.0 meters.
n is the number of parallel conductors in one direction.
h_s is the thickness of the crushed gravel layer in meters.
K is the reflection factor between the resistivities of the different materials.

Equation 8 is used to calculate the bending factor.

$$K = \frac{\rho - \rho_s}{\rho + \rho_s} \qquad (8)$$

$$K = \frac{25 - 2000}{25 + 2000} = -0.97$$

Therefore, the reduction factor is calculated as follows: $C_s = 0.87$.

To calculate the value of n, equation 9 is used.

$$n = n_a * n_b * n_c * n_d \qquad (9)$$

$$n = 3.4 * 1.38 * 1 * 1 = 4.692 = 5$$

Where:

$$n_a = \frac{2 * L_c}{L_p}$$

$$n_b = \sqrt{\frac{L_p}{4 * \sqrt{A}}}$$

Determination of ground rods

Equation 10 is used to calculate the minimum number of rods.

$$N_v = 1.125 * R_v \qquad (10)$$

Where:

$$R_v = \frac{\rho}{1.915 L_v}\left(\text{Ln}\frac{96 L_v}{dv} - 1\right) \ [\Omega]$$

$$R_v = \frac{25}{1.915(10)}\left(\ln\frac{96(10)}{3/4\,"} - 1\right) = 9.339\ \Omega$$

Thus:

$$N_v = 1.125(9.339) = 10.50 = 11 \text{ rods}$$

Calculation of step tension and grid tension

The step voltage is determined with equation 11.

$$E_{paso} = \frac{\rho I_G K_s K_i}{L_s} \ \text{[Volts]} \qquad (11)$$

Where:
ρ is the average resistivity of soil [Ω-m].
K_s is the geometric factor.
K_i is the irregularity factor.
L_s is the effective length of buried conductors [m].
For grids with or without ground rods, the effective length of buried conductors is determined by Equation 12.

$$L_s = 0.75 L_c + 0.85 L_R \quad [m] \qquad (12)$$

The geometric factor K_s for usual soil grid depths between $0.25<h<2.5$ mm, is determined with equation 13.

$$K_s = \frac{1}{\pi}\left[\frac{1}{2*h} + \frac{1}{D+h} + \frac{1}{D}\left(1 - 0.5^{(n-2)}\right)\right] \qquad (13)$$

Equation 14 is used to calculate the grid tension.

$$E_m = \frac{\rho K_m K_i I_G}{L_m}\ [\text{Volts}] \qquad (14)$$

Where:

ρ is the average soil resistivity in [Ω-m].

K_m is the geometric factor.

K_i is the irregularity factor.

$\frac{I_G}{L_m}$ is the ratio of the average current per unit length of effective buried conductor in the grounding system.

The irregularity factor is calculated with equation 15.

$$K_i = 0.644 + 0.148 * n \qquad (15)$$

Equation 16 is used to calculate the effective conductor length.

$$L_m = L_c + \left(1.55 + 1.22\left(\frac{L_r}{\left({L_x}^2 + {L_y}^2\right)^{1/2}}\right)\right) L_r\ [\text{meters}] \qquad (16)$$

Where:

L_c is the total length of the horizontal conductors in the ground grid [meters].

L_r is the length of a single vertical electrode (ground rod) [meters].

L_R is the total length of the vertical electrodes (ground rods) connected to the grid [meters]

L_x is the maximum length of the ground grid in the 'x' direction [meters].

L_y is the maximum length of the ground grid in the 'y' direction [meters].

Within IEEE 80-2013 it is stated that the step tension and grid tension should be calculated for two different weights, which are 50 kg and 70 kg respectively as shown below:

$$E_{step\ 50\ kg} = \left(1000 + 6(0.871)(2000)\right)\frac{0.116}{\sqrt{0.5}} = 1878.68\ \text{Volts}$$

$$E_{step\ 70\ kg} = \left(1000 + 6(0.871)(2000)\right)\frac{0.157}{\sqrt{0.5}} = 2542.7050\ \text{Volts}$$

$$E_{grid\ 50\ kg} = \left(1000 + 1.5(0.871)(2000)\right)\frac{0.116}{\sqrt{0.5}} = 592.7082\ \text{Volts}$$

$$E_{grid\ 70\ kg} = \left(1000 + 1.5(0.871)(2000)\right)\frac{0.157}{\sqrt{0.5}} = 802.199\ \text{Volts}$$

RECOMMENDED DESIGN

Once the data is obtained, the design of the grounding system can be proposed, as shown in Figure 1. The conductors are shown in red and the electrodes in green. The mesh has 4 conductors of 20 meters, 3 conductors of 30 meters, and has 10 rods of 3 meters.

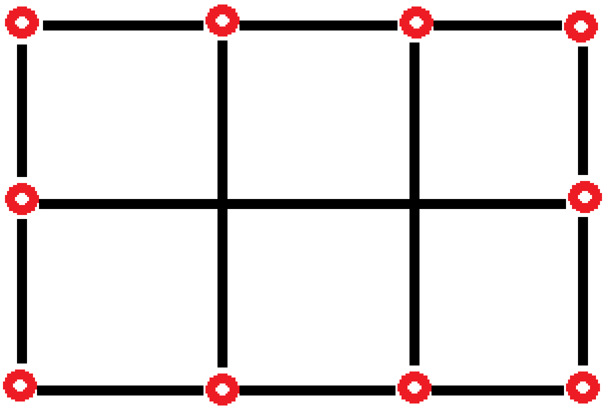

Figure 1 Design of the proposed grounding system

Resistance of the grounding grid

Using Equation 17 and the above data, the resistance of the grounding grid configuration can be calculated.

$$R_g = \rho\left[\frac{1}{L_r} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right]\ [\Omega] \qquad (17)$$

$$R_g = 25\left[\frac{1}{170} + \frac{1}{\sqrt{20 * 600}}\left(1 + \frac{1}{1 + 0.5\sqrt{20/600}}\right)\right] = 0.5844\ \Omega$$

And to calculate the ground potential rise (GPR), equation 18 is used.

$$GPR = I_G * R_g\ \ [\text{Volts}] \qquad (18)$$

$$GPR = 4\,831.78 * 0.5844 = 2\,823.69\ \text{Volts}$$

If the value of the maximum ground potential rise in the preliminary design is below the touch voltage tolerable by the human body, no further analysis is necessary. Only additional conductors for equipment grounding are required [7].

With the calculated GPR data, a quick comparison is made with respect to the grid tension to determine if further analysis should be performed.

With 50 Kg $\quad 2\,823.69\ \text{v} < 592.7082\ \text{v}$

With 70 Kg $\quad 2\,823.69\,9\ \text{v} < 802.199\ \text{v}$

Finally, the grid tension and step tension are shown below:

$$E_{grid} = \frac{25 * 0.977 * 1.384 * 4\,831.78}{219.5453} = 743.967\ \text{Volts}$$

$$n = \sqrt{3 * 4} = 3.46 = 3$$

$$K_s = \frac{1}{\pi}\left(\frac{1}{2 * 0.5} + \frac{1}{10 + 0.5} + \frac{1}{10}(1 - 0.5^{5-2})\right) = 0.3764$$

$$K_i = 0.644 + 0.148(5) = 1.384$$

$$L_s = 0.75 * 170 + 0.85 * 30 = 153\ \text{metros}$$

$$E_{step} = \frac{25 * 0.3764 * 1.384 * 4\,831.78}{153} = 411.283\ \text{Volts}$$

In order to make sure that the design of the proposed grounding system is correct, a comparison is first made between the mesh voltage and the calculated voltage.

For 50 kg $\quad E_{grid} \quad 743.967\ \text{v} < 592.7082$ Volts

For 70 kg $\quad E_{grid} \quad 743.967\ \text{v} < 802.199$ Volts

As the grid tension is less than the calculated tension for the 50 kg weight it does not meet the requirement, so it is necessary to recalculate the data, in this case the calculation of 70 kg will be used as it is the average weight of an adult person.

For 50 kg $\quad E_{step} \quad 411.283\ \text{v} < 1878.68$ Volts

For 70 kg $\quad E_{step} \quad 411.283\ \text{v} < 2542.7050$ Volts

It is observed that the step voltage is lower compared to the voltage for 50 and 70 kg, as the calculation for 70 kg will be used, it can be concluded that there is no need for a readjustment of calculations, electrodes, conductor and consequently the design is optimal, if it is required to occupy the calculation for a person of 50 kg should make the necessary adjustments for that weight.

IV. CONCLUSION

It can be concluded that in order to obtain a good design of a grounding system, it is necessary to take into account the regulations applicable to the selected site (hospital), in this work the IEEE 80-2013 standard and the NOM 001- SEDE 2012 standard were used.

The proposed design is based on the data obtained from the terrain where the hospital is located in order to perform the necessary calculations with the purpose of sizing and selecting the materials to be used and thus safeguard the lives of both patients and medical personnel working in the hospital. It also seeks to protect medical equipment, especially in the intensive care area, in order to reduce the cost of acquiring new devices and guarantee a safe medical environment for all involved.

Therefore, it is important to address this issue, considering technical and regulatory aspects established for its calculation and design.

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