Grounding Meshes Performance Evaluation in Sand Soil due Lightning Surges

Daniel S. Gazzana, Arturo S. Bretas, Marcos Telló, Guilherme A. D. Dias, Vanderlei Dienstmann

Abstract-- **This paper presents a study related to the Lightning Protection System (LPS). The work includes practical aspects and computational simulation in order to evaluate the performance of a proper LPS with focus on the grounding system in sand soil. The Alternative Transients Program (ATP) is used to model the whole protection scheme including air termination system, down conductor system and earth termination system. An electric model representing a human body is considered to verify the step and touch potentials generated due a lightning surge. Initially, an introduction is made emphasizing the security problem constantly present in sentry boxes located in beaches. In the following, the proposed LPS is presented with discussion about modeling in ATP. Finally, simulation results are presented and conclusions are made.**

Keywords – Impulsive grounding, grounding meshes, sand soil, lightning protection system.

I. Introduction

Grounding systems are one of the main resources capable of keeping the population security and physical integrity of an installation in the event of a lightning discharge [1]-[3].

In a lightning surge occurrence, grounding systems are responsible for electric current conduction to ground. In this phenomenon, the grounding mesh impedance must be small enough to ensure the integrity of the remaining electrical equipments connected to the ground and in a most important aspect, grounding must guarantee step and touch potentials in the soil surface in tolerable values by human beings [4].

Usually, step and touch potentials are considered as reference parameters on the steady-state/low frequency ground analysis, however, such potentials can be exceeded in the transitory period of an electric impulse as lightning surges. In this way, impulsive analysis during the transient period must be evaluated.

In the case of sand soils, the current dissipation and the potentials generated in soil surfaces are critical points that must be evaluated for the construction of more efficient and security grounding meshes.

This study case is related to the sentry box used to surveillance of swimmers in beaches, which usually is not provided of Lightning Protection System (LPS). In recent years several accidents involving lightning have been evidenced in Brazilian beaches reaching these structures, also causing people death. Fig. 1 shows the mentioned sentry box.

Fig.1: Sentry box where the life guard was hurt

To reduce the effect of a lightning bolt in people in open areas like a beach, a LPS was proposed with base on IEC 62305 Standards Series [3],[5]. In order to evaluate the grounding meshes behaviour some simulations were performed in Alternative Transients Program (ATP) and Matlab.

In this context, the proposed study presents ATP modeling aspects considering the air termination system, down conductors system and earth termination system comparing results in terms of generated potentials scattering in a grounding mesh with and without rod. The simulations of human step and contact voltages, in a simplified way were considered and adopted as stated in [6].

II. Basic Aspects of the LPS

The proposed Lightning Protection System was basically divided in three blocks: air termination system that is responsible for attracting the lightning; down conductors system having the purpose of conducting the surge to the earth termination system that will finally dissipate the electrical discharge.

The air termination system is an arrester composed by a small pole, placed in the top center of the sentry box.

In order to obtain a LPS with appropriate cost efficiency, two topologies of down conductors were taken into account.

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The first one consider four down conductors connected near the apex of the grounding, and the second one regards only one down conductor connected to the center of the earth termination system.

As ground system, a 4 m square pre molded steel mat with meshes of 20 cm x 20 cm was used. To avoid corrosion problems, the earth termination system is encased in concrete, named *UFER Type*.

Fig. 2 shows an illustration of the grounding mesh with the connection points of the down conductors for the two cases. Red squares represent the first set considering four down conductors and the green square represents set two, related to the one down conductor topology.

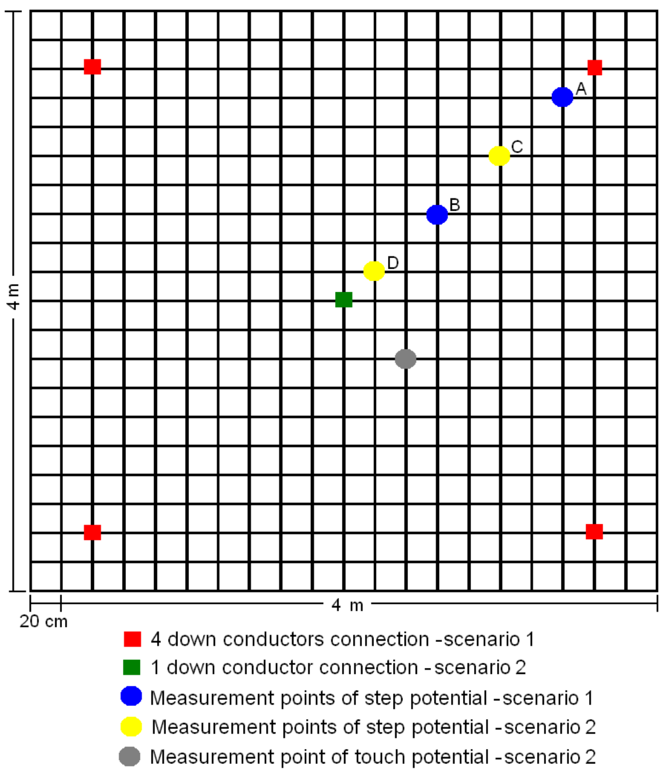

Fig. 2. Illustration of the grounding mesh with down conductors connection points and measuring points of step and touch potentials

In the set one (4 down conductors) only a mesh was used as a grounding system without rods, on the other hand, in the set two (1 down conductor) a rod with 8.5 m long was coupled in the center of the grounding mesh, coinciding with the down conductor connection.

The soil resistivity was measured by the Wenner Method [7]. The resulting soil model with two layers is characterized by a $\rho_1 = 5.41\Omega$◌m and $\rho_2 = 43.34\ \Omega$m with the depth of top layer equal to 3.46 m where ρ_1 and ρ_2 stand for resistivity of top and bottom layer respectively.

The sand soil containing seawater was modeled as a uniform medium with resistivity of 90 Ωm. As stated in [8] "*Concrete, being hygroscopic, attracts moisture. Buried in soil, a concrete block behaves as a semiconducting medium with a resistivity of 30–90 Ωm.*" Then, in a simplified way the soil was considered to be uniform and the resistivity used in computer simulations was 90 Ωm for sand with moisture and concrete.

So, to verify which LPS configuration presents the best response in terms of the generated potential due a lightning surge, several simulations were performed using ATP.

III. Modeling the LPS Using ATP

The Alternative Transients Program was used to model the entire LPS including air termination, down conductors and grounding. Additionally, a human body represented by a set of resistive and capacitive elements was considered in the simulation in order to evaluate voltages on the mesh, and both step and touch potentials generated by a lightning reaching the sentry box.

It is important to note that the focus of the paper is not to establish an analysis related with the tolerable potentials by the human beings. The main purpose is to define witch LPS configuration produces the smallest potentials.

In the following subsections aspects related to the ATP models will be presented.

A. *Air Termination System*

The air termination system was modeled as an RL series circuit with L = 0.0024 mH and R = 1.1 mΩ representing an arrester with 2 m high and section of 35 mm^2.

B. *Down Conductor System*

As commented previously, two configurations of down conductors were taken into account in the model. The first configuration considers four cables connecting the arrester to the grounding and the second only one, as can be seen in Fig. 2. In both cases the 6 m long down conductor with 35 mm^2 of diameter was represented again by a RL series circuit. Aiming to improve the computational resolution, the cable was divided into four sections with 1.5 m long, with L = 0.0018 mH and R = 0.82 mΩ. Fig. 3a and Fig. 3b show the air termination system and the two down conductors topologies considered in the ATP model.

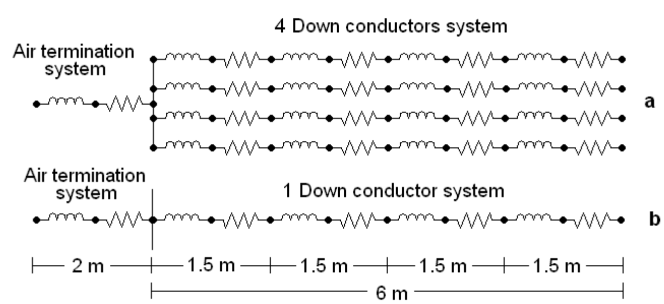

Fig. 3. Air termination and down conductor systems modeled in ATP: (a) four down conductors configuration; (b) one down conductor configuration

C. *Earth Termination System*

To model the earth termination system, a transmission line in π configuration characterized by a set of lumped circuit was considered [9]. According with the transmission line theory, the circuit must be divided in several small sections (segments). Each segment is represented by lumped components (R, L, G and C) as presented in the Fig. 4.

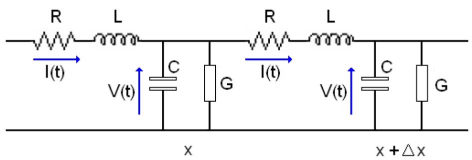

Fig. 4. π configuration characterized by a set of lumped R, L, G and components

In the case of the grounding mesh composed by horizontal conductors buried in a homogeneous soil, the following well-known formulas can be used to establish the line parameters per unit length of the conductors. These parameters are given by (1) to (4) [10].

$$R_d = \frac{\rho_{conductor}}{\pi a^2} \qquad (\Omega/\text{m}) \tag{1}$$

$$L_d = \frac{\mu_{airl}}{2\pi} \cdot \left[\ln\left(\frac{2l}{\sqrt{2ha}} \right) - 1 \right] \qquad (\text{H/m}) \tag{2}$$

$$G_d = \frac{2\pi}{\rho_{soil} \cdot \left[\ln\left(\frac{2l}{\sqrt{2ha}} \right) - 1 \right]} \qquad (\text{S/m}) \tag{3}$$

$$C_d = \frac{2\pi \varepsilon_{air} \varepsilon_{soil}}{\ln\left(\frac{2l}{\sqrt{2ha}} \right) - 1} \qquad (\text{F/m}) \tag{4}$$

In the equations: a is the electrode radius; l is the electrode length; h is the buried deep of the conductor; ρ, ε and μ represent respectively the electric resistivity, electric permittivity and magnetic permeability and finally R_d, L_d, G_d, C_d are respectively the resistance, inductance, conductance and capacitance per unit length.

With the line parameters per unit length, the R, L, G and C can be obtained accordingly with the equations (5) to (8), where Δx is the segment length.

$$R = R_d \cdot \Delta x \qquad (\Omega) \tag{5}$$

$$L = L_d \cdot \Delta x \qquad (\text{H}) \tag{6}$$

$$G = G_d \cdot \Delta x \qquad (\text{S}) \tag{7}$$

$$C = C_d \cdot \Delta x \qquad (\text{F}) \tag{8}$$

In a similar manner, the line parameters per unit length of a vertical electrode or a rod can be determined using the proper equations described in [11].

The conductance (G) presented in the previously formulations is represented by a resistance (R) in the ATP model, so $R = 1/G$.

As mentioned earlier, for the simulations the soil was considered as uniform with ρ_{soil} = 90 Ωm, ε_{soil} = 80 F/m and μ_{soil} = 1 H/m. The air permittivity (ε_{air}) and permeability (μ_{air}) were considered as 8.8419e^{-12} F/m and 1.256e^{-6} H/m respectively. For all electrodes, both in the mesh and in the rod, $\rho_{conductor}$ = 1.7241e^{-8} Ωm.

The grounding mesh is composed by a 4 m x 4 m long conductors (l = 4 m) with Δx = 0.2 m with radius = 0.0017 m buried at h = 0.5 m depth. Consequently the conductors were divided in 20 sections.

The central rod is composed by a vertical electrode with length l = 8.5 m, radius = 0.0108 m and it was divided in 40 segments with Δx = 0.2125 m.

Having been established the circuit parameters, the earth termination system can be modeled in ATP. Fig 5a and Fig 5b show a compact ATP model representing the grounding mesh and the rod respectively.

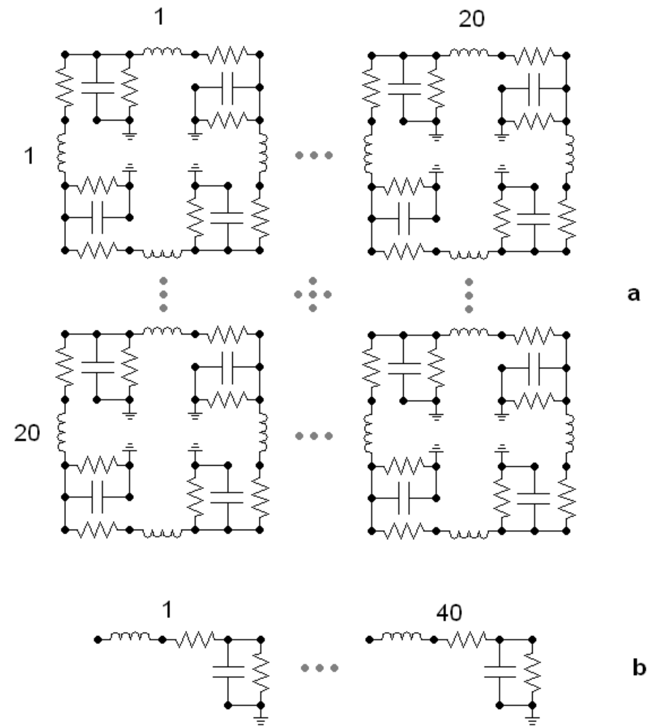

Fig. 5. Earth termination system modeled in ATP: (a) grounding mesh; (b) rod

In the proposed model the soil ionization phenomenon was not taken into account. It is important to note that in the occurrence of this phenomenon, the generated potentials shall have smaller magnitude in comparison with the model without soil ionization. So, the performed simulations are in favor of the safety. Additional information about the soil ionization phenomenon in grounding electrodes can be found in [12]-[13].

The frequency dependence of the soil parameters is not considered in the developed model of the grounding mesh. However, related studies can be found in some state-of-art papers with focus on single grounding electrode as stated in [14].

D. Human Body Model

To evaluate the step and touch potentials generated due lightning reaching the LPS, a simplified model composed by a resistive (R) and capacitive (C) components representing a human body was implemented [6]. Fig. 6a shows a body model picture represented by an equivalent circuit, as can be seen in Fig 6b.

In the model, a current source (Surge Type 15 block) with 20 kA peak value (1 µs x 10 µs) was utilized to simulate the lightning strike.

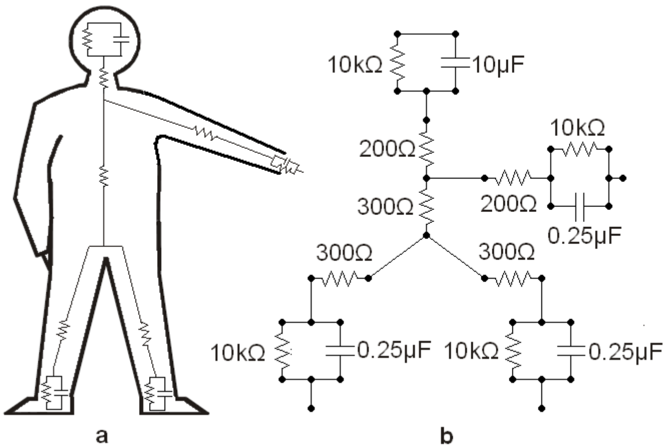

Fig. 6. Human body representation: (a) body model draft; (b) equivalent circuit

IV. Simulation Results

To ascertain a LPS topology that present the smallest potentials generated in the grounding and consequently in the soil surface, two simulation groups were performed.

In the first scenario, the air termination system is connected in four down conductors as presented in Fig. 3a. The down conductors are linked to the grounding mesh, without center rod, as can be seen in Fig. 2 (red square near the corners). Fig 7, Fig. 8 and Fig. 9 show the potential generated on the mesh in different instants of time for the first scenario.

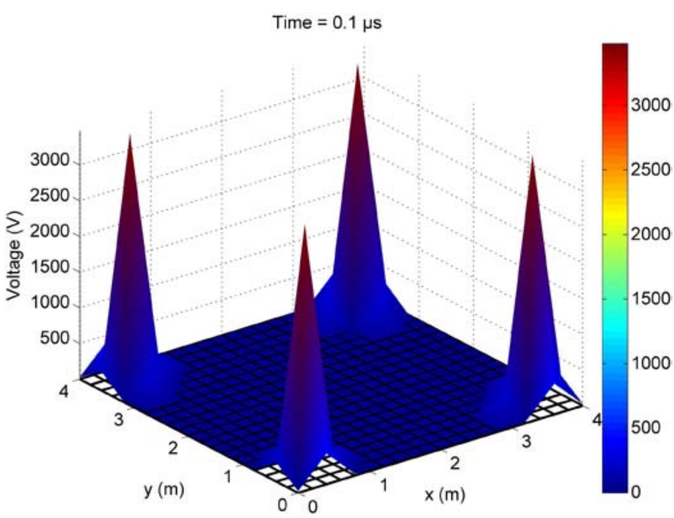

Fig. 7. Surface potential on grounding mesh in 0.1 µs considering a LPS with four down conductors

Fig. 7 shows one of the first time steps after the surge have been injected in the arrester. In this figure can be seen that in 0.1 µs the voltage on the mesh reaches 3480 V. This surface allows the visualization that in the first moments of the transitory period only a region near the mesh corners is effectively used to dissipate the current.

The Fig. 8 presents the surface potential corresponding to the high voltage value in this simulation, reaching 5343 V in about 1.4 µs. Differently of the first transitory moments, in this period all the mesh is utilized to scattering the lightning surge.

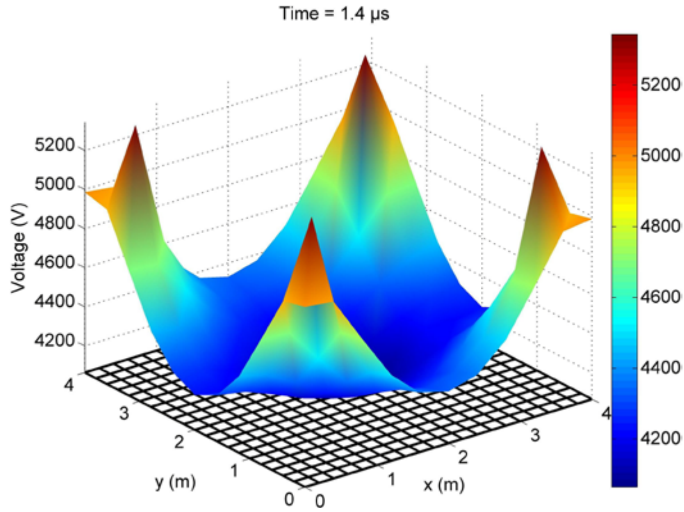

Fig. 8. Surface potential on grounding mesh in 1.4 µs reaching the maximum voltage considering a LPS with four down conductors

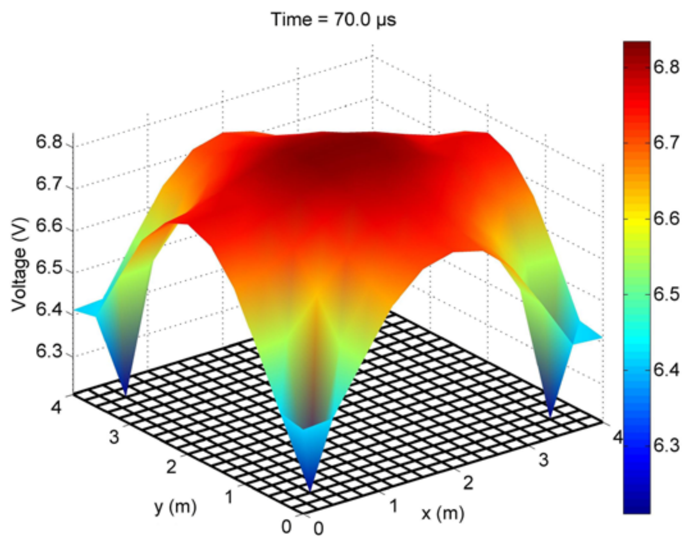

Fig. 9. Surface potential on grounding mesh in 70 µs considering a LPS with four down conductors

The last moments of the transient period can be represented by the surface presented in Fig. 9. In this figure can be seen that in 70 µs the remaining voltage on the mesh can be despised, only 6.8 V. After this time, the voltage decrease very slowly until reach zero.

In the second scenario, the air termination system is composed by only one down conductor, presented in Fig. 3b, connected in the center of the grounding, as can be seen in Fig. 2 (green square). In this simulation, in order to reduce the generated potentials, a rod was placed in the same point connection of the down conductor. The following figures, Fig 10, Fig. 11 and Fig. 12 shows the potential generated on the grounding in different instants of time for the second scenario.

Fig. 10 shows the voltage generated on the grounding in 0.1 μs. The maximum potential in this initial instant of the transitory reaches 3653 V. In comparison with the surface presented in Fig. 7, the maximum generated voltage did not preset significant alterations in terms of magnitude. Again, as in Fig. 7, only a small part of the mesh around the lightning injection point is properly used to dissipate the surge, considering the beginning of the transient.

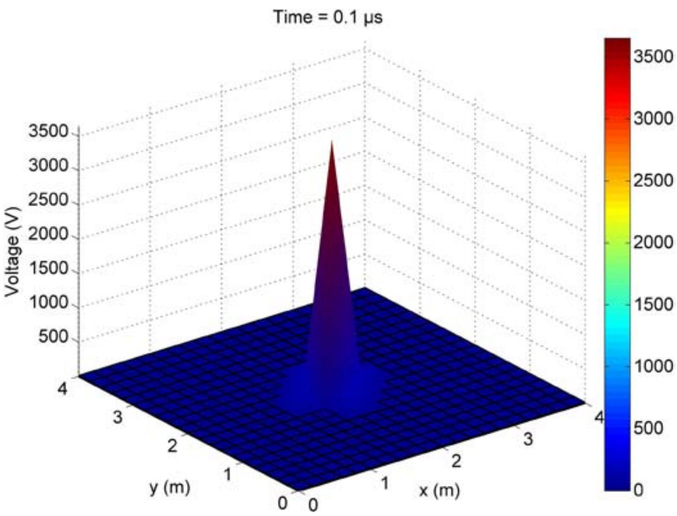

Fig. 10. Surface potential on grounding mesh in 0.1 μs considering a LPS with one down conductor and rod on the center

It can be observed in Fig. 11 that after 0.4 μs the potential reaches its highest value, about 12240 V. This magnitude is considerably higher than the maximum potential generated in the simulations considering four down conductors without rod in the LPS.

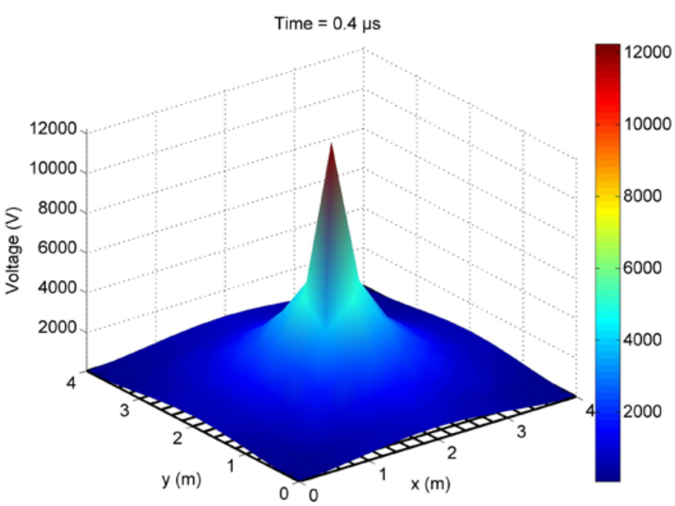

Fig. 11. Surface potential on grounding mesh in 0.4 μs reaching the maximum voltage considering a LPS with one down conductors and rod on the center

The last instants of the transitory period for the second scenario simulations can be represented by Fig. 12. Over again, in about 70 μs the potential on the grounding can be considered as zero, ending the transient period.

An important observation can be stated in relation to the mesh size used to dissipate the lightning surge. In the case of the LPS with four down conductors, the entire grounding mesh is properly utilized to scattered the surge, especially in the moment that the potential reaches its high amplitude. On the other hand, considering a single down conductor connected on the center of the mesh with rod, only the central part of the grounding is effectively used to dissipate the surge to the earth during throughout transient.

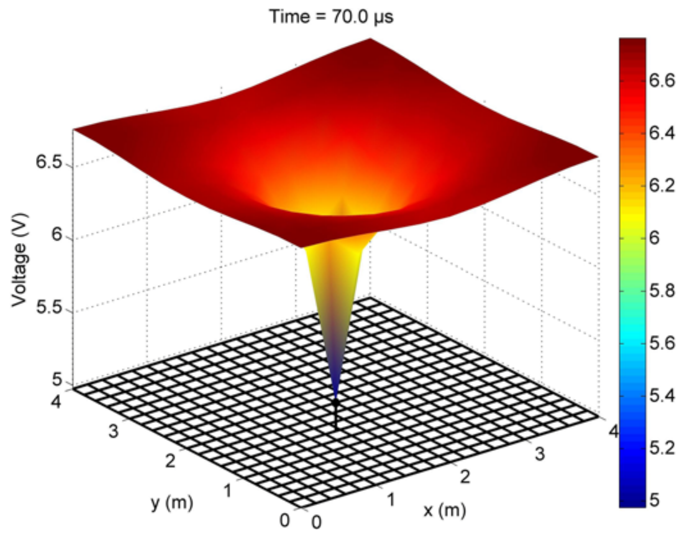

Fig. 12. Surface potential on grounding mesh in 70 μs considering a LPS with one down conductor and rod on the center

Fig. 13 shows the step potential generated on a human body considering the model illustrated on Fig. 6 for the two scenarios presented previously. In this simulation, the model presented in Fig. 6b was connected in the grounding, in order to verify the potentials generated due a current flowing from one foot to other.

In a conservative way, an approach was made considering that the potentials on the soil were the same that the produced on the grounding. In the practice, the soil surface voltages are smaller than the grounding voltages.

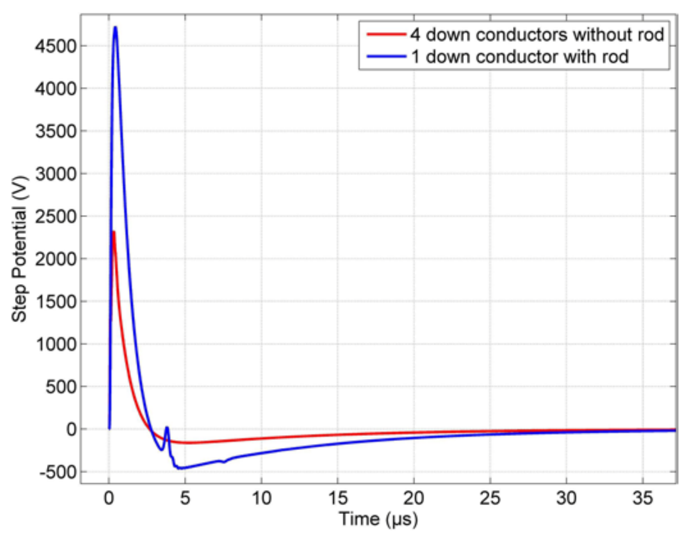

Fig. 13. Step potentials considering the LPS topologies

For the first scenario, four down conductors without rod, the bottom extremities of the body model (feet) were connected in the blue points (A B) indicated in the Fig. 2. For the second scenario (one down conductor with rod) the body feet were connected in the yellow points (C D).

Analyzing the Fig. 13 can be stated that the topology with four down conductors (red line) presents small values of step potentials in comparison with the LPS with only one down conductor with rod (blue line). The maximum step potential in the blue line 4724 V is approximately the double value of the voltage generated in red line 2327 V. In both cases after about 2.7 µs the voltages achieve zero.

The behavior of touch potentials generated in the human body can be analyzed with base on the Fig. 14. In this simulation it was considered that one hand of a person was in direct contact with the down conductor in the moment that a lightning reaches the LPS. The touch contact point was adopted as 1.5 m high in the down conductor above the soil surface for both LPS topologies.

In the scenario considering a LPS with four down conductors, the touch potential was measured between the hand, represented by right RC parallel circuit in Fig. 6a, and the feet located in one of the mesh external corner.

In the simulations considering one down conductor with rod, the difference of potential was measured between the hand contact point and the gray point indicated in Fig.2.

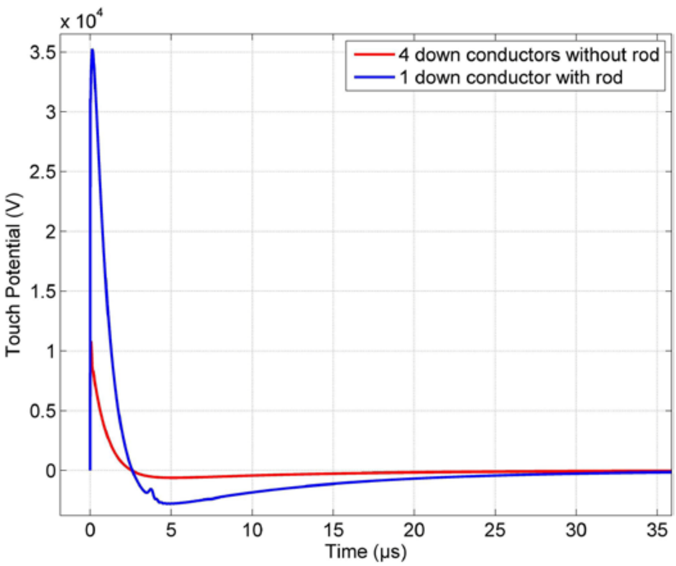

Fig. 14. Touch potentials considering the LPS topologies

Analyzing the Fig. 14 it can be seen that the touch potential for the LPS with one down conductor (blue line) presents a higher voltage value, about 35270 V, than the four down conductor configuration (red line) that reaches 10830 V in the peak value. Approximately in 2.5 µs the voltages achieve zero.

Several other points along the grounding mesh were measured in the simulations, but the objective was present some worst cases in terms of the highest step and touch potentials.

Table 1 summarizes the maximum potentials determined in the performed simulations.

TABLE I: MAXIMUM POTENTIALS GENERATED IN THE SIMULATIONS

LPS configuration	Maximum potentials (V)		
	Mesh	Step	Touch
Four down conductors	5343	2327	10830
One down conductor	12240	4724	35270

V. CONCLUSIONS

This paper presents a study case about the performance of a Lightning Protection System that will be built to protect sentry boxes located in beaches with sand soils. The main focus of the work was to establish which LPS topology presents the best cost effective, ensuring the people safely in terms of the lowest potentials generated due a lightning surge, reaching the mentioned structure.

To achieve this goal, two simulations sets considering different topologies of the LPS were performed in ATP. The LPS was composed by an air termination system, down conductor system and earth terminations system.

In the first set of simulations, the developed model was composed by an arrester connected with 4 down conductors that leads the surge to the grounding mesh without rods. In the second group of simulations, the arrester is linked with only one down conductor that leads the lightning surge to the grounding mesh with a central rod.

With base on the simulation results, it can be stated that the configuration with four down conductors presents smaller voltage values (mesh, step and touch potentials) than the configuration with only one down conductor, as can be seen in numerical values in Table 1.

Additionally, in the case of one down conductor the entire mesh is not effectively used to dissipate the surge to the earth. Is this case, a significant part of the grounding is not properly used, beyond to have the worst efficiency in terms of safely.

Then, amongst the LPS topologies modeled the configuration with four down conductors and mesh grounding without central rod was chosen to be built.

This study does not exhaust the problem in question. Other LPS topologies can be modeled showing efficiency as good as the proposed solution. Finally, the procedure and the methodology presented here can be used as base for future projects with the same purpose.

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