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PERFORMANCE OF MEDIUM VOLTAGE URBAN AND RURAL DISTRIBUTION LINES FRONT LIGHTNING DISCHARGES AND INDUCED SURGES

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Abstract - This work has as objective to present the preliminary results of an analysis study of the performance of medium voltage distribution networks, front direct and induced lightning discharges. Analyzing which are the main problems that cause the biggest influence in the direct discharges to the network, in the way to define actions to reduce them.
In this stage of the study, some simplifications had been considered. However, the result shows that is possible to direct the actions for the economic solution of a series of problems, which represents the great majority of the occurrences involving lightning discharges.
As first result of this study, it was verified that the majority of the distribution problems were caused by induced surges. As the direct discharges constitute only 3 to 4% of the total amount of the lightning discharges to the ground, analyzed for a period of 100 years in a typical distribution network.

1 - INTRODUCTION

Nowadays many actions for the protection of overhead distribution lines are not well taken and without the necessary study. As a result, many of them besides of presenting high cost are not effective. This study has the purpose of leading to an efficient method for the reduction and mitigation of the effects of the lightning discharges in medium voltage overhead distribution lines.

The lightning discharges are one the main causes of interruptions of medium voltage overhead distribution lines, being the reason of great concern for the utility companies. Its destructive effects frequently extends to equipments and connected installations, with the possibility to cause personal injuries and material damages, beyond economic losses, due to out of income and the possibility of indemnities, penalties and fines applied by ANEEL (National Agency of Electric Energy). In the majority of Brazil the information of lightning discharges were restricted to isoceraunic maps, these maps were widely used by the utility companies.

With the beginning of the deregulation of the electric energy supply, some actions were been taken by the utilities for the prevention and minimization of the damages associated to the lightning discharges. However, as the lightning discharges are random events, consequently, difficult to predict, the majority of these actions does not follow a study or a detailed analysis of the problem.

By this way, in the greater part of the cases the actions were taken based on the knowledge of the engineer in charge, or based in rules defined without any effective evidence, by means of studies or by laboratory tests. As a result, the results are not the most satisfactory and do not get the correct order of cost by benefit of these actions.

Among others, the distribution network reliability depends directly on its exposition to the lightning discharges. To determine the exposition level of the line, the designer should know the number of discharges to the ground per unit of area per unit of time.

Once that the atmospheric discharges phenomena are random, this work considers that the parameter generation of the discharges follows the statistical data proposed by Anderson and Eriksson. The Monte Carlo Method is used for the incidence distribution of the discharges and the Electro Geometrical Model for the interception point of the discharge.

2 – MEDIUM VOLTAGE DISTRIBUTION NETWORK

The standard medium voltage distribution networks are subjected to incidence of direct lightning discharges and to incidence of induced surges. The majority of damages to the distribution network are caused by direct discharges. However, they can be deviated by tall structures, such as towers, buildings, high constructions, and trees.

When the lightning strikes the network directly, they commonly cause permanent damages, because they are high intensity discharges with high tax of growth. For this kind of damage, the network remains off until its repair.

Even when the lightning does not intercept the network, they induce surges that travel throughout the lines. These surges are able to cause many damages to the distribution network. For that reason, this work presents the relations between induced surges and direct discharges.

The topology of the distribution network is the major factor of influence for analysis, obtained from the results of this study. Because its density and distribution in the area make possible a greater or minor probability of incidence of direct lightning discharges.

3 – LIGHTNING DISCHARGES

An annual analysis of the area in study was adopted for the performance verification of the distribution networks, where the Monte Carlo Method and the average density of lightning discharges to ground per square kilometer per year to make an analysis of the discharge start point.

The discharges intensities are randomly drafted, according to the current method of calculation proposed by Anderson's Model, which introduces a convenient approach to the lognormal distribution of peak currents given by Anderson and Eriksson. An average current of 31kA results in a probability value of P=0.5, the probabilities becomes more reduced with the increase of the current intensities I [kA].

The equation is easily inverted to correspond to a desired level of probability P, as follow:

$$P = \frac{1}{1 + \left(\frac{I}{31}\right)^{2,6}} \quad (1)$$

$$I = 31\left(\frac{1-P}{P}\right)^{1/2,6} \quad (2)$$

Established the beginning point of the discharge and its intensity, it is necessary to make the verification of the incidence point of the discharge, observing if it intercepts directly the network or if it generates an induced surge. Many methods are possible for this task; however, the most common is the Electro-Geometrical Model.

The Electro-Geometrical model was developed from the Wagner's Model, of the lightning return speed, being updated by Armstrong, Whitehead and Love. It is characterized by a rolling sphere concept, with a radius given by the current intensity of the discharge, according to the IEEE – Std 1410 [6] formula:

$$SD = 10.I^{0,65} \quad (3)$$

Calculated the dimensions and attraction limits, it is verified if the discharge intercepts the conductors or the network. It is obtained, by this way, the number of times that the network was intercepted per year and in the study period. And, in addition, the corresponding number of times that the network was submitted to induced surges, as well as all the parameters associated with lightning discharges to the ground.

4 – SIMPLIFICATIONS AND APPROXIMATIONS

This study considers some simplifications, as the adoption of a plain surface, by the difficulty to obtain digital information of topography levels. As well as a perfectly conductive soil for the calculation of the induced surges amplitude, and a manual inclusion of tall structures, like towers, buildings, and trees. These approximations leads to a critical condition, being thus all the results are overestimated.

The manually inclusion of tall structures is possible; however these tall points are included in a higher layer in the system topology. Being thus, these points intercept the discharges, playing the role of the tall structures. This reduces the number of direct discharges for a value probably next to that obtained from the occurrence reports, made by maintenance teams of the utilities.

5 – ANALYSIS PROCESS

The analysis process is annual, that is, all the lightning discharges are drafted for a year based on the ground density of flashes to the ground per year per square kilometer, which can be assumed as random in the analysis period. The discharges are randomly distributed among the area, the intensities and growth rate of the discharge current are obtained randomly according to the statistical data of the IEEE – Std 1410.

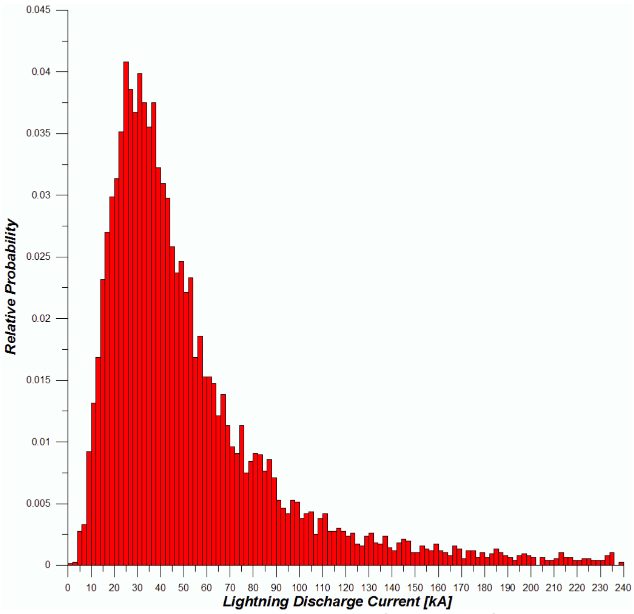

Figure 1 – Probability Distribution of Lightning Currents

The Figure 1 shows the probability distribution of direct discharges currents in a medium voltage rural distribution network.

When the position and the intensity of the lightning discharge are drafted, the Electro-Geometrical Model is applied to verify if it intercept the network. In this way, it is calculated the number and percentage of direct discharges to the network, its average current, and standard deviation associated. This process can be repeated automatically for a maximum period of 100 years, generating data for the average and standard deviation, percentage of direct discharges and corresponding current intensity.

6 – RESULTS

Three results of analysis of lightning discharges in medium voltage distribution network will be presented, respectively a rural system, an urban without considering tall structures and an urban simulating tall structure.

All the analyses are based on real distribution networks of the AES Sul Utility.

6.1 – RURAL DISTRIBUTION NETWORK

The great majority of the rural networks have a reduced length by area relation. In this way, they possess less probability of being intercepted by direct lightning discharges.

The Figure 2 presents a permanence curve for the discharges current that directly intercepted the distribution network. The values of current with 50% of probability (Median), 100kA discharge current probability and the smaller current intensity, that have 100% of probability of being exceeded, are shown.

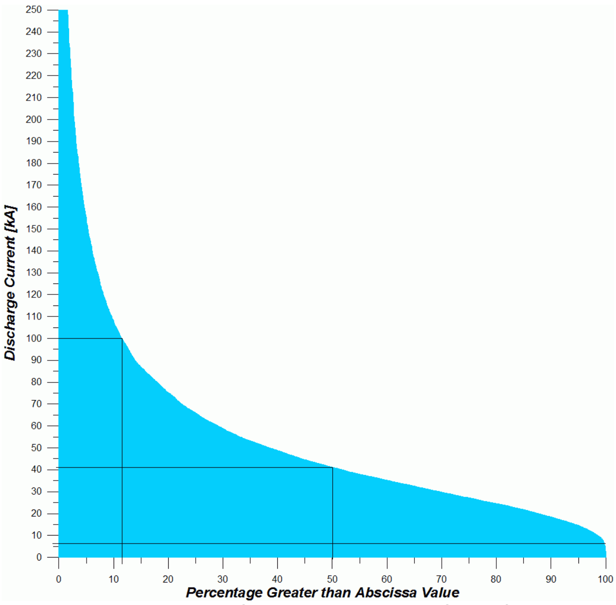

Figure 2 – Discharge Current Permanence Curve for Rural Network

The network under analysis has an area of 323.64 km² and a total length of 138.83 km. In the simulations, it was obtained a level of direct lightning discharges interception by the network of 4.02% with a standard deviation of 0.48. In this case, the average value of direct discharges current intensity is about 41kA, from the median value, according to the Figure 2.

This data had been obtained with a density of 6 discharges to the ground per square kilometer per year. In this way, for a density of 1 discharge to the ground per square kilometer per year, the network responds with a density of 9.28 discharges per 100 km per year.

As a result, in accordance with Figure 2, for 6 discharges to ground per km² per year to each 100 km of network, 27.84 discharges presents current intensity greater than 41kA, as well as 6.68 discharges exceeds 100kA of current intensity.

Although to possess capacity to indicate which percentage of the surge arresters had been exposed to discharge current with intensities greater than the nominal value, this is not object of the present study.

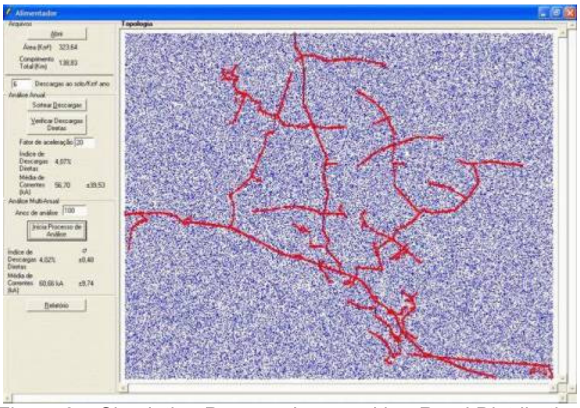
Figure 3 – Simulation Program Image with a Rural Distribution Network and 100 Years of Simulation

The Figure 3 shows a screen image of the simulation program, with the topology and results of analysis.

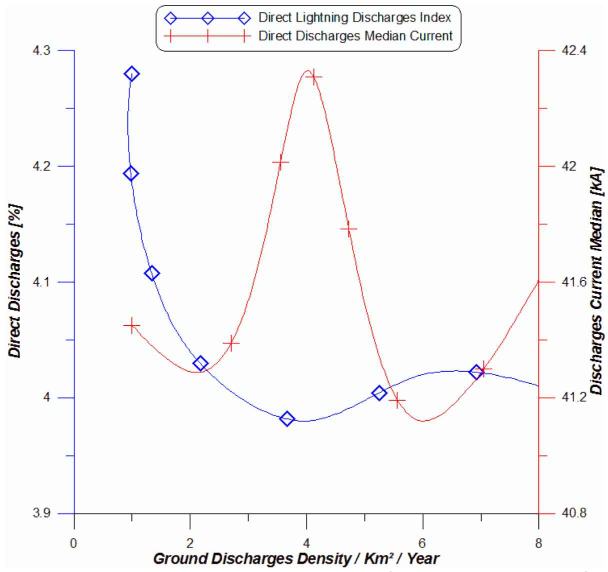

Figure 4 – Direct Discharges, Median Current by Number of Discharges to the Ground per km² per Year for a Rural Network

The Figure 4 presents the results of this circuit for different conditions of density of lightning discharges to the ground for the rural distribution network.

6.2 – URBAN DISTRIBUTION NETWORK – WITHOUT CONSIDERING TALL STRUCTURES

The great majority of the urban distribution networks possess a high relation between the total length and area. In this way possess greater probability of been intercepted by direct lightning discharges. However, in urban areas the presence of tall structures, such as towers, high buildings and trees, deviate many of the discharges that would have intercepted the distribution network.

The obtainments of data regarding elevated structures is complex and laborious, as a result the analysis program do not consider them automatically. Therefore, in terms of a first approach for the study, the urban network was analyzed without taking the presence of tall structures in consideration.
In similar way to the previous method applied to the rural network, the Figure 5 presents the permanence curve for

the discharges current that intercepted directly the urban network under analysis. The values of current with 50% of probability (Median), 100kA discharge current probability and the smaller current intensity, that have 100% of probability of being exceeded, are shown.

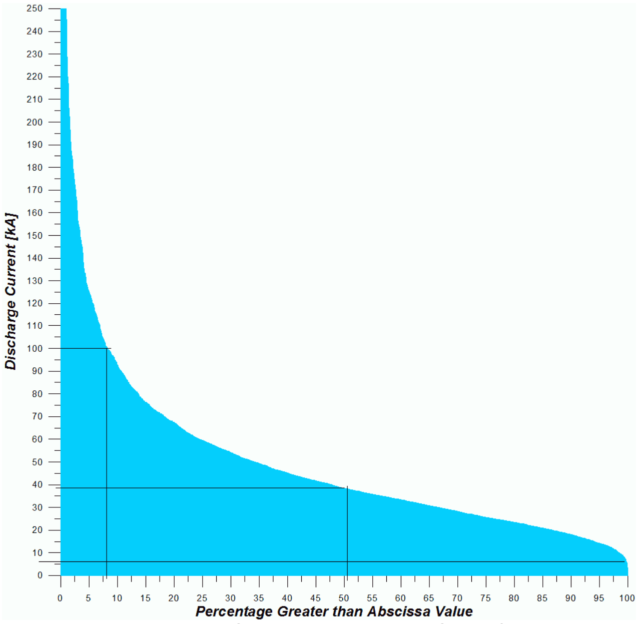

Figure 5 - Discharge Current Permanence Curve for Urban Network

This network possesses an area of 22.28 km² and 100.62 km of total length. In the simulations, it was obtained a rate of lightning direct discharges to the network of about 30.87% with a standard deviation of 4.14, in relation to the total discharges to the ground throughout the period of 100 years.

In this case, the median current intensity for the direct discharges, as shown in Figure 5, was about 39kA. These data had been obtained with a density of 6 discharges to the ground per km² per year. As a result, for a density of 1 discharge to the ground per km² per year, the system presents a density of 6.82 discharges per 100km per year.

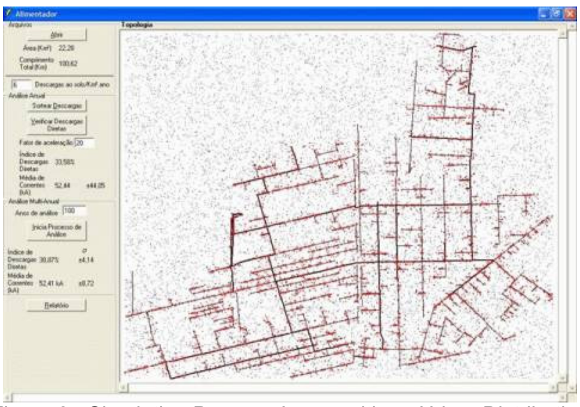

Figure 6 - Simulation Program Image with an Urban Distribution Network and 100 Years of Simulation

Therefore, in accordance with Figure 5, for 6 discharges to ground per km² per year to each 100 km of network, 20.44 discharges presents current intensity greater than 39kA, as well as 3.27 discharges exceeds 100kA of current intensity. The Figure 6 shows a screen image of the simulation program, with the topology and results of analysis.

The Figure 7 presents the results of this circuit for different conditions of density of lightning discharges to the ground for the urban distribution network.

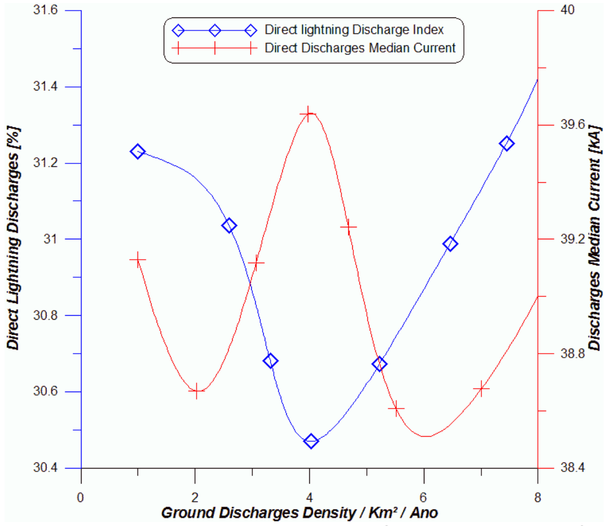

Figure 7 - Direct Discharges, Median Current by Number of Discharges to the Ground per km² per Year for an Urban Network

6.3 – URBAN DISTRIBUTION NETWORK – SIMULATING TALL STRUCTURES

The tall structures simulation implies in the manual inclusion of diverse points along the network. With this artifice, the obtained results are more close to the real urban cases. This has as objective to incorporate the natural shield supplied by trees, towers, high buildings, among others.

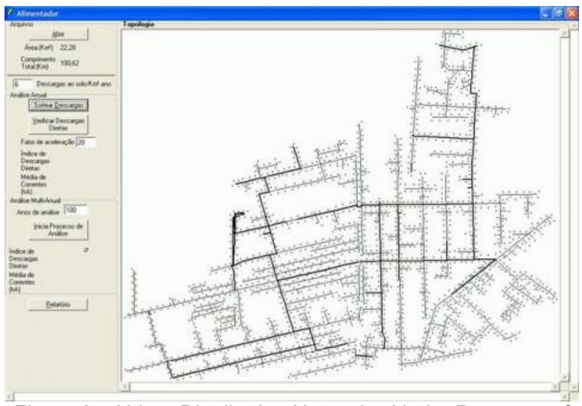

Figure 8 – Urban Distribution Network with the Presence of Simulated Tall Structures

In the case shown in Figure 8, the tall structures had been inserted with average spacing of 10m for the lines, 40m between two consecutive structures, and with height little superior to the network, around 15m. The Figure 8 presents the topology of the urban network detaching the points of tall structures.

This network possess the same area and length of the urban network simulated previously, however, it considers the presence of tall structures. In this way, in the obtained simulations the average rate of direct discharges to the conductors, trough 100 years, is about 2.24% with a standard deviation of 1.17. This case presents the median value of direct discharge current of 12kA.

These data had been obtained with a density of 6 discharges to the ground per km² per year. As a result, for a density of 1 discharge to the ground per km² per year, the system presents a density of 0.24 discharges per 100km per year.

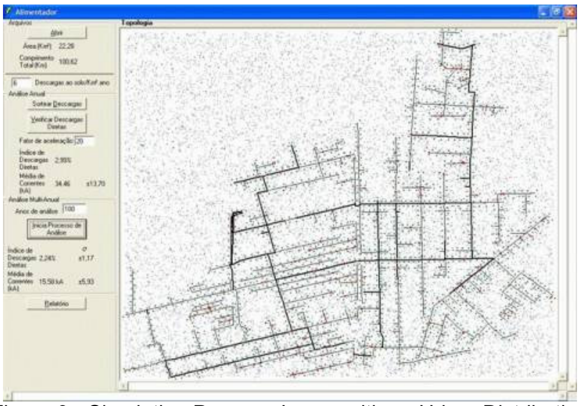

Figure 9 - Simulation Program Image with an Urban Distribution Network, 100 Years of Simulation and Simulated Tall Structures

Therefore, for 6 discharges to ground per km² per year and to each 100 km of network, 0.73 discharges present current intensity greater than 12kA. As well as discharges with current above 100kA of current magnitude were not found, what proves the effectiveness of the shield effect, provided by tall structures, in the system performance against lightning discharges. The Figure 9 shows a screen image of the simulation program, with the topology and results of analysis.

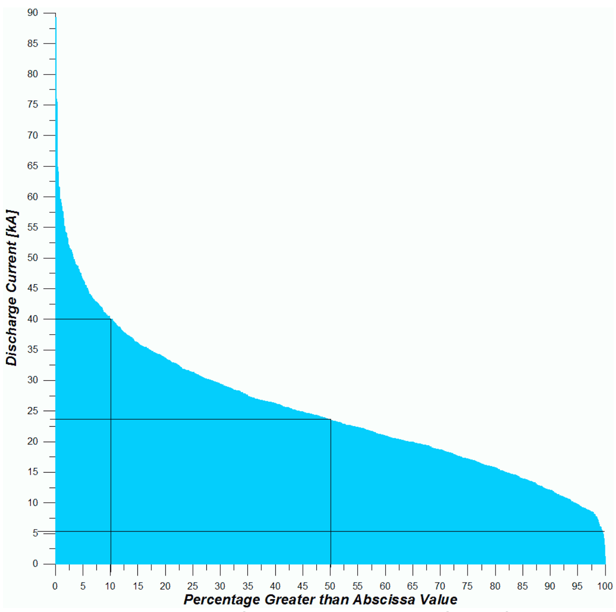

Figure 10 - Discharge Current Permanence Curve for Urban Network with Simulated Tall Structures

In the cases shown in Figures 8 and 9, the amount and localization of the tall structures causes a relatively high shielding effect on the network, where only low intensity discharges can reach the network. Another case with the tall structures nearest to the network, however more spaced between it, about 80 to 200 meters, are also simulated. This new case corresponds to an urban area with a lower density of constructions or structures. Figure 11 shows the topology of this case.

The Figure 10 presents the permanence curve for the discharge currents that have intercepted the network for the case of the Figure 11. The values of current with 50% of probability (Median), 100kA discharge current probability and the smaller current intensity, that have 100% of probability of being exceeded, are shown.

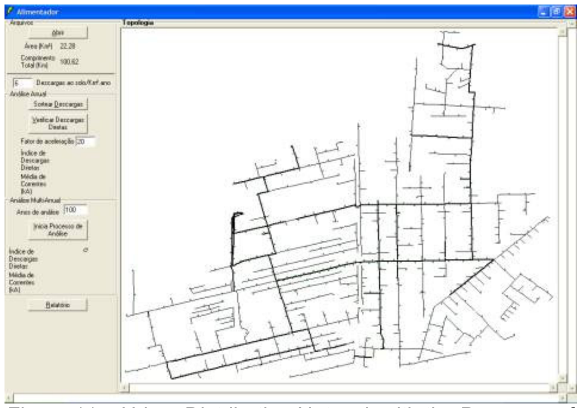

Figure 11 – Urban Distribution Network with the Presence of Simulated and Less Concentrated Tall Structures

In this case, in the obtained simulations the average rate of direct discharges to the conductors, trough 100 years, is about 15.43% with a standard deviation of 3.36. This case presents the median value of direct discharge current of 23kA.

These data had been obtained with a density of 6 discharges to the ground per km² per year. As a result, for a density of 1 discharge to the ground per km² per year, the system presents a density of 2.22 discharges per 100km per year.

Therefore, in accordance with Figure 10, for 6 discharges to ground per km² per year and to each 100 km of network, 6.68 discharges present current intensity greater than 23kA. As well as discharges with current above 100kA of current magnitude were not found, what proves the effectiveness of the shield effect provided by tall structures.

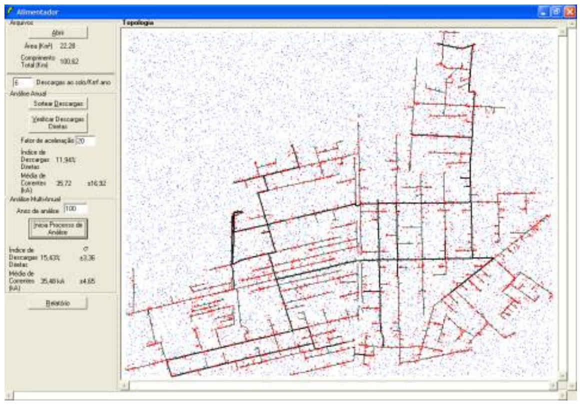

Figure 12 - Simulation Program Image with an Urban Distribution Network, 100 Years of Simulation and Less Concentrated Simulated Tall Structures

The Figure 12 presents a screen image of the simulation program, with the topology and results of analysis.

7 – CONCLUSIONS

The carried studies demonstrate that a low number of direct lightning discharges intercept the urban distribution network, mainly when the circuits are naturally shielded by tall structures. In the cases analyzed, between 2% to 16% of the lightning reaches directly the urban distribution network. For a density of 1 discharge to the ground per square kilometer per year, between 0.24 and 2.22 discharges intercept the network per 100 kilometer per year.

In complementary way, the amplitude of the average discharge currents that intercept the network stays between 12 and 23kA. As a result, the main factor of study for the performance improvement of urban distribution systems, front lightning, is induced surges.

In these cases, the presence of surge arresters and transformers should be carefully investigated before taking any standard protection practices, mainly when it is in mind that the protection of “better quality” is individual by equipment.

In this study, with the adopted simplifications, the urban distribution networks without shielding had suffered with a bigger amount of discharges, as direct as induced, because they present a greater density of network by area than the rural ones. However, as tall structures had not been considered, it is necessary to observe that the number of direct discharges in these cases is overestimated.

Based in the median current intensities obtained, it is possible to affirm that direct discharges intercepting the network implies in dielectric failure of the system, and in the failure of transformers, when considering the transformers insulation quality.

Observing the reduction in the discharges current intensity provided by tall structures, it is considered inadequate the application of indiscriminate indemnity politics without the presence of firm evidence, through correlated events in the network.

The studies demonstrated that the majority of direct discharge currents stay below 40kA at urban systems, with 10% of probability of being surpassed. According to Figure 10, the average discharge current is of the order of 25kA. This implies in the use possibility of surge arresters rated for these magnitude, as a result, with lower cost.

Otherwise, for rural networks and urban networks with low natural shielding or tall structures, 10% of the discharge currents have magnitude greater than 100kA. However, this does not imply that the surge arresters for those networks must have rated capacity to support 100kA or more, whereas, for a density of 1 discharge per square kilometer per year, around 1.1 discharges per 100km intercept the network with intensity greater than 100kA.

This high current is equally divided in both directions of the intercepted network, and the process of traveling waves thus established is responsible for a series of insulation failures, until a set of surge arresters is reached.

On the other hand, the average discharge current is about 40kA, according to Figures 2 and 5, what partly confirms the values of discharge current used in the type, routine, and reception tests of medium voltage surge arresters.

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