Application of the guideline "IEEE Std 1410-2010" in the study of the performance of the lines and grounding resistance before lightning flash.

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***Abstract* – In this document is analyzed the performance of the 13.2kV and 33kV overhead distribution lines, caused by both direct and indirect impacts of lightning. This phenomenon is one of the problems that affect the rural distribution system in the east of the Caldas department. This region is characterized for having a really high activity of atmospheric discharges. In this regard, the main goal of this paper is the study of the performance against atmospheric discharges of the performance results lines and grounding resistance, based on the "IEEE Std 1410 - 2010". Considering a real case (CHEC's MAZ30L15 circuit) allows to generate possible improvements to the system performance for overhead lines and distribution systems in this area of the country.**

Index Terms* - *Critical flashover (CFO), lightning flash, isoceraunics Level, distribution systems, grounding system

I. Introduction

LIGHTNING is the major cause of failures (temporary or permanent) of airlines in rural distribution systems [1]. The growing concern for the quality of the electric power has generated even more interest in the study of lightning discharge, and in the search of methodological guidelines to improve the performance of the overhead distribution lines against those lightnings [2] - [10].

The distribution networks are often found in areas with high densities of atmospheric discharges, therefore being subject to disruptions of the flow of energy.

In particular, Colombia presents one of the highest lightnings activities in the world due to its location. For that reason, the Central Hidroeléctrica de Caldas (CHEC S.A. E.S.P.) is looking the performance optimization of the distribution systems with 13.2 kV and 33kV voltage levels [11].

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The issues presented from random phenomena of lightning in the electric distribution airlines are usually manifested by the high inefficiency of the protection systems installed in the eastern CHEC [12]- [17].

The performance of the protection system implemented in the rural area at the east of Caldas department, has been the main cause for the majority of failures and interruptions in the service provided by CHEC in recent years. To cope with this issue, it is necessary to make adjustments to the circuit components, in aspects such as: (a) insulation, (b) grounding systems, (c) distribution transformers and (d) surge protection devices. And, as a reference it will be considered the keraunic level in the analyzed region [17].

In this work is presented the application of the "IEEE Std 1410-2010" methodological guide in the study of the performance of the distribution network against lightning. The simulations in a real circuit, displays the improvement in performance of the overhead distribution lines.

This paper is organized as follows. In Section II is described the background of the used data for the development of the research. Section III presents the implemented methodological guides. In Section IV simulation results are presented, and finally in Section V are presented the conclusions of this work.

II. Circuit Background

A. Circuit general description

The analysis of each of the elements of the system contains the main details of the current conditions of the test circuit. The analyzed data show the failure history from January 2010 to December 2012. The selected test circuit is property of CHEC (coded as MAZ30L15), and it interconnects Victoria's substation with Marquetalia's substation, which are located in Caldas department.

The TABLE I, summarizes the number of outputs of MAZ30L15 test circuit. The outputs are listed by year and the history, with a total of 122 line service outputs and 84,73 real hours of total disruption.

TABLE I
SUMMARIZE THE NUMBER OF OUTPUTS OF THE CIRCUIT MAZ30L15

Year	Number of outputs	Hours of service interruption
2010	25	3,70
2011	51	64,89
2012	46	16,14
Total	122	84,73

On the other hand, the test circuit characteristics that are the basis for the implementation of the methodology are:

- Total length: 17,87 [km]
- Shield wire: Galvanized steel 1/4"
- Phases: ACSR 4/0 AWG
- Structures: 72
- Predominant structure: H (37 structure)
- Predominant height: 12 m

With the acquisition of the distribution system parameters, it is possible to identify some of the circuit's shortcomings. Although the problems have been identified, the circuit must be adjusted to the parameters presented in the IEEE Std 1410 - 2010 and to other published studies related to the topic [4].

In Fig 1 is presented the data acquisition of the circuit that was chosen to assess the "IEEE Std 1410-2010" methodological guide, to study the performance of the rural distribution airlines against lightning. Furthermore, the Fig 1 shows the geographic location of the circuit, highlighting Marquetalia's substation (MLA) and Victoria's substation (VCT).

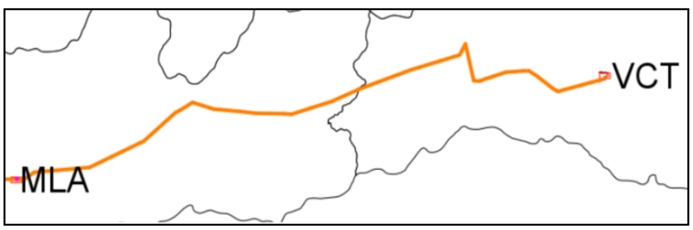

Fig 1. Circuit MAZ30L15, located in the department of Caldas, and that makes up a part of the facilities of CHEC S.A E. S. P

Other relevant data are:

- 224.7 m of the circuit have no earth wire, which correspond to 1.25 % of the line.
- 85 line insulators are deteriorated due to flashovers and other factors. 58 guy wire are in a state of disrepair.
- 58 guy wire templates are in poor condition.

In addition, from the technical inspection of the test circuit grounding resistance it was found that 19% of the structures (14) have the grounding systems in good condition and have a resistance lower than 10Ω. 59% of the structures (42) are in poor condition and have a resistance greater than 10Ω. Finally the 22% of the structures (16) do not have grounding resistance.

B. Ground resistivity of the test circuit

The ground resistivity data are the key factor in designing a good grounding resistance. In general, the ground leads electric current, some with more or less electrical conductivity than others.

The land resistivity varies widely around the world. It changes dramatically within small areas, being mostly influenced by the type of soil, water content, amount of electrolytes (minerals and dissolved salts) and temperature.

In the test circuit, the ground resistivity measurement is made by the WENNER method. As shown below, this is one of the key parameters for the calculation of the resistance grounding resistance.

Fig. 2 shows the results of the ground resistivity study in the MAZ30L15 test circuit. It was determined that 57% of the structures have a resistivity less than 300 [Ω-m], whereas the 39% of the structures have a resistivity between 300 - 1000 [Ω-m], and only 4% of them have a resistivity greater than 1000 [Ω-m].

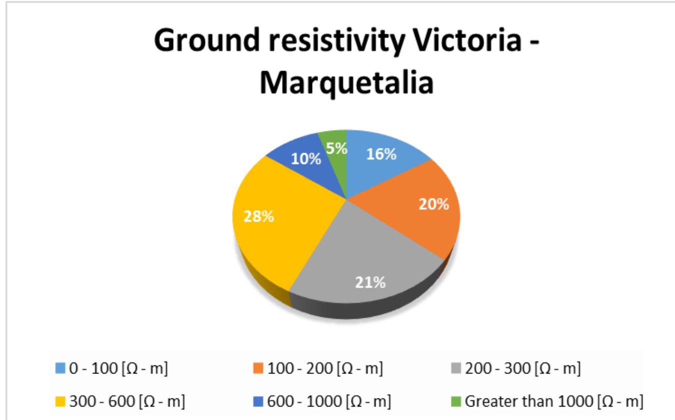

Fig. 2. Results of the study of field ground resistivity in MAZ30L15.

C. Grounding resistance

An important POINT in the data acquisition is the inspection of the grounding resistance current state. Therefore, the inspection results are presented in Fig. 3 , where is clear that the 59% of the structures require changes of the grounding resistance configuration, 22% of the structures have no grounding resistance, and only 19% of the structures have a suitable grounding resistance. As a conclusion, the current state of grounding resistance is the major cause of the failures of the test circuit.

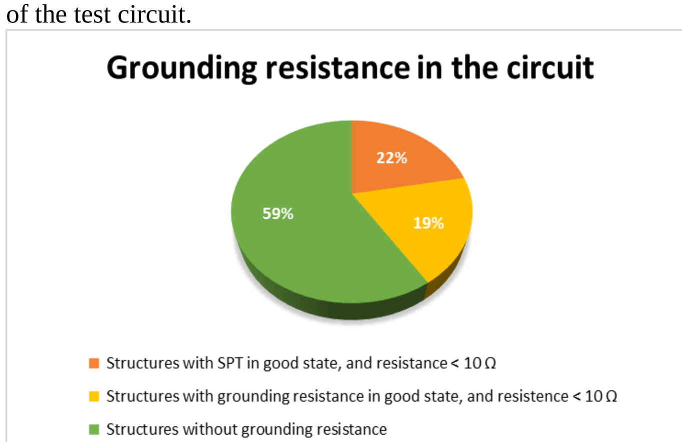

Fig. 3 the results of the study of grounding resistance MAZ30L15.

In this sense, it is possible to say that the grounding resistance is the major cause of the failures of the test circuit.

III. The Implemented Methodology

The configuration changes are based on the parameters specified in the guides "IEEE Std 1410 –2010" and IEEE Std 80 - 2000", and the information is supplemented with the MVMT® simulation software as a mean to verify the performance of each of the proposed configurations. Therefore, the main approach of this study is oriented to methodically apply these procedures to a real circuit of the Colombian electrical system.

The implementation of the methodology guide involves the study of a considerable amount of information, such as: (a) the probability of occurrence of faults, (b) the density of atmospheric discharges on the circuit, (c) the number of flashovers [direct / indirect] a year and (d) the total circuit failures per year.

In this study, each one of the circuit components is analyzed in order to optimize the traditional rural distribution system. The attention is focused on the grounding resistance performance given its relevance in the described system. In this sense, the following elements depend on a proper functioning of the grounding resistance:

- Shield wire.
- Distribution arrester.
- Transformers.

For those elements the resistance must be of magnitude less than 10 [Ω], because it is essential for its proper functioning. Specially, for the ones where it will be installed overvoltage discharges. Meanwhile, there are situations for which it is difficult to have a low value of grounding resistance. Then, it is recommended to fulfill the step and contact voltages stipulated in IEEE Std 80-2000.

IV. Simulation Results

A. *Airlines Performance Results*

The application SOFTWARE used to evaluate the atmospheric and meteorological circuit conditions is based on the IEEE Std 1410-2010. This application allows to obtain more accurate data on the possible causes of MAZ30L15 circuit output.

Fig. 4 presents the software interface (main screen) used to evaluate the circuit. This interface allows the user to enter the values of the main aspects of the circuit, such as: length of the circuit, keraunic level, the average resistivity of the ground, discharge voltage of the SPD, predominant insulators, among others.

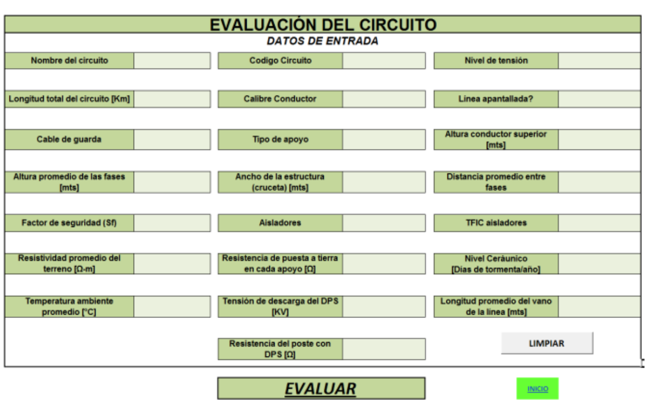

Fig. 4.Graphical Environment for the entry of initial parameters of the circuit.

Now, in TABLE II is shown the diagnosis of the circuit current conditions, with regard to the amount of lightning discharges with direct and indirect impacts.

TABLE II
CURRENT CONDITIONS OF THE TEST CIRCUIT

Phenomenon	Flashover/Year
Flash over by direct flash	15
Flash over by nearby stroke	2
Total	17

The implemented process simulates the performance of the overhead distribution lines against lightning for the MAZ30L15 circuit.

The equivalent configuration of the test circuit presents the following data:

- The average distance between structures is 251.77 [m]
- The average resistance of the grounding resistance is 27.35 [Ω].
- The Flashover by nearby stroke when there is no SPD in the entire MAZ30L15 circuit section is 62 [Flashover/100km/year].

The data are obtained from the circuit and from the software mentioned above (see Fig. 4).

B. *Grounding Resistance Performance*

Given the high cost of the grounding resistances and the lack of effectiveness of the materials used as grounding conductor, it is necessary to implement an optimal procedure of this resource. For this purpose the MVMT ® software is employed, which allows to evaluate different configurations of the grounding resistance, including varying the type of material. Moreover, the implemented process simulates the performance of the grounding resistance to efficiently dissipate the fault current due to lightning.

Knowing that the average resistivity of the ground in this area of the country is 300 [Ω-m], it is recommended reviewing different options of materials for the grounding resistance configuration, which give a good performance at low cost.

The RA6-010 standard developed by Empresas Públicas de Medellín (EPM) is the reference for CHEC SA ESP regarding grounding. In that document are presented 11 different configurations to improve the performance of the circuit, much of this condition provides the effective protection against system failures due to atmospheric nature.

The characteristic of this type of disposition (circular) around the structure base ensures that contact and step voltages generated by failure are below the permissible voltage for the human being. Although these dispositions comply with the limits for ground potential rises, they do not present the magnitude of resistance required by IEEE Std 1410-2010. For that reason, it is important the alternative study that meets the required parameter.

Fig. 5 shows the configuration N° 10 of the norm RA6-010 [18], which is the most suitable choice given the low cost and the resistivity for the region where is located the circuit.

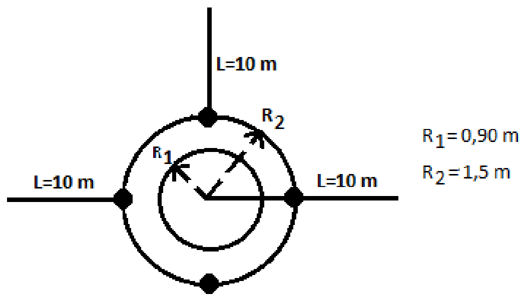

Fig. 5. Disposition of grounding resistance EPM.

Fig. 6. Exhibits the configuration implemented in this study, where are used alternative materials that allow to have a low value of grounding resistance.

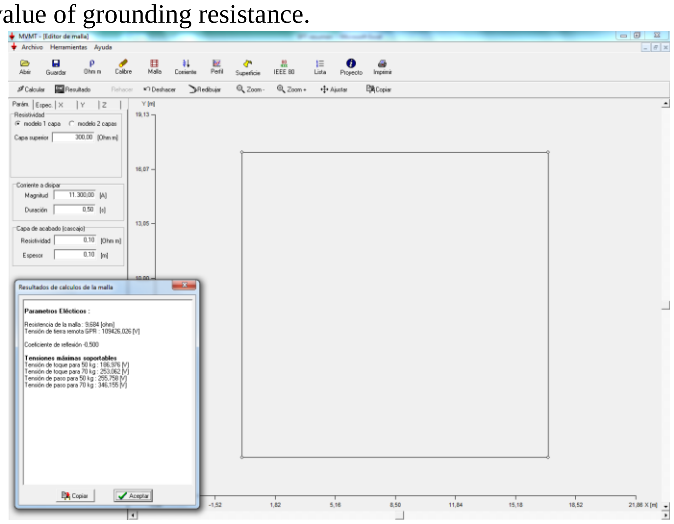

Fig. 6. Graphical Environment for the income of the configurations.

TABLE III presents certain configurations proposed by EPM, where are specified some important elements of the implementation, including the magnitude of grounding resistance. For this particular case, the resistances are taken depending on the most suitable resistivity for the analysis.

TABLE III
CONFIGURATION PROPOSED BY EPM

Case	Ground resistivity [Ω - m]	Nº or the electrode	Lenght conductor of mesh [m]	Counterweight Length [m]	Artificial ground	Resistance [Ω]
1	100	2	15,07	0	No	13
4	200	4	15,07	5	Si	19
10	300	4	15,07	10	Si	16
11	600	4	15,07	10	Si	28

One of the main features that can be observed in the above TABLE III, is that regardless of the configuration their proposals have not been adjusted to standard values, in order to provide effective protection against failures by atmospheric conditions (resistance).

On the other hand, TABLE IV shows the results obtained after simulating of different base configurations, and it is possible to notice the acceptable behavior in each one of them.

TABLE IV
VARIATIONS OF THE CONFIGURATION OF THE PROPOSAL OF THE SPT

Case	Ground resistivity [Ω - m]	Nº or the electrode	Counterweight Length [m]	Artificial ground	Resistance [Ω]
1	100	3	5	No	9,684
2	200	3	10	No	9,776
3	300	4	15	No	9,684
4	400	4	15	Si	12,912
5	600	4	15	Si	16,339

The proposed configuration options vary in the size of its counterweight and the number of buried rods (electrodes). In addition, options 4 and 5 require the use of artificial ground (sodium bentonite), to obtain a grounding resistance within the established parameters.

It is also confirmed that the new configurations of the grounding resistance have as maximum margin a magnitude of 64 [Ω], in a fault clearance time of 5 [s] in which the contact and step voltages can be tolerated by the human body.

Finally, it is concluded that is possible to use the ACSR conductor 2/0 AWG instead of the traditional bare copper conductor 4 AWG. This is a lower cost material (which could prevent its stealing), and therefore becomes an important alternative in the implementation of grounding in CHEC SA ESP.

Moreover, one of the elements to be evaluated given its relevance in the design of the grounding resistance is the grounding conductor, which must meet the criteria specified in IEEE Std 80 [15]. To validate the performance of this element, is simulated the grounding resistance behavior to changes in the type of used material in the grounding conductor. In this simulation, the fault current employed is 11.33 [kA] due to an induced voltage by a lightning discharge.

Fig. 7. shows the circuit grounding resistance obtained from the software. Similarly, Fig. 8 shows the results of the simulation process implemented to validate the type of material for the grounding conductor. Where it is possible to observe that the conductor with the best performance is the Alumoweld 7 # 7, and therefore it is an alternative to the usual copper conductor.

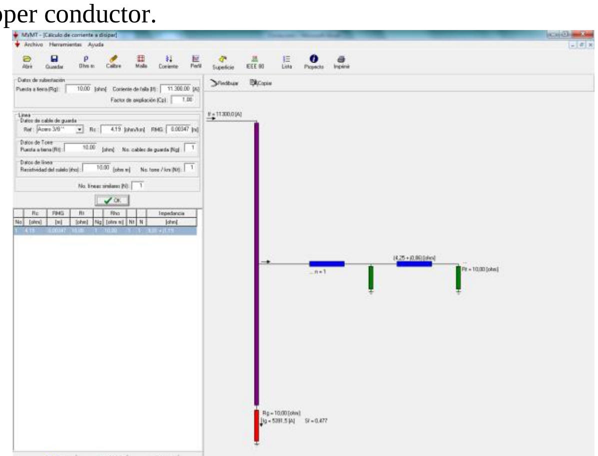

Fig. 7. Circuit diagram of the grounding conductor of grounding resistance.

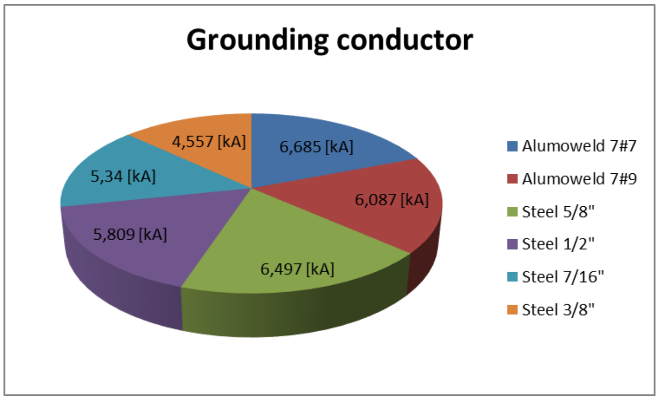

Fig. 8. Simulation results for different types of material the grounding conductor of grounding system MVMT®

V. Conclusions

The characterization of rural overhead distribution circuits in the eastern CHEC, gives the possibility to apply the proposed methodology to other circuits with similar features. This generates a suitable solution for many of the problems commonly found in the 13.2 and 33 kV distribution systems that are property of CHEC.

The most important findings of this work are summarized as follows:

- The proposed grounding resistance allows to improve the efficiency of shield wire and the surge arresters operation.
- The proposed approach to optimize the distribution system takes into consideration most of the system components in the western area of CHEC SA ESP. As a consequence the proposed methodology meets the stipulations of the studies and research found in the literature.
- The implementation of the overvoltage protection system induced (arresters in conjunction with an appropriate grounding resistance), will provide a major improvement by reducing the number of faults in the MAZ30L15 circuit.
- The proposal of the grounding resistance modification used in CHEC SA ESP seems an efficient solution for the system, as it is designed according to the needs of an effective protection against lightning.

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