LIGHTNING PERFORMANCE OF TRANSMISSION LINE LAS CLARITAS – SANTA ELENA UP 230 KV

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***Abstract* -- The following work is calculated the lightning performance of transmission line Las Claritas – Santa Elena up 230 kV. This line has the particularity that goes through an area with high keraunic level and resistivity soil, where supports (towers or poles) are placed. When the commercial operation of the line begin, some outages by atmospheric discharges happen and to correct the situation among different actions, simulations with the ATP were carried out, considering the characteristics of each lines sections to determine which magnitudes of stroke currents produce back-flashovers, the rate of forced outages, as well as the profit of installing ZnO line arrester. The results gave a line rate of forced outages of 7 trip-outs per year (3.2 tripouts per 100 km per year) and they indicated that the installation of ZnO line arrester in the supports with high footing impedance (13% of the line length) it would achieve a reduction of 4 trip-outs per year. However, in that condition the line fulfills typical values of design and the installation of these equipments is not recommended.**

Keywords -- Rate-forced-outages, Transmission-line, Pole, Tower, Footing-resistance, Atmospheric-discharges, Line- arrester, ATP.

I. INTRODUCTION

The importance of a reliable electric supply to the border cities of Santa Elena de Guairen in Venezuela and Boa Vista in Brazil, made recommendable the installation of two continuous counterpoises in the corridor of the line Las Claritas-Santa Elena up 230 kV, during the design process of grounding system and shielding the phases, to guarantee an appropriate rate of forced outages by atmospheric discharges.

The previous analyses, determined that the line goes through a high keraunic level area, estimated in more than 120 days of thunderstorm per year and with high resistivity soil where the supports would be placed (towers or poles), around 80% of the line length has values under 20,000 Ω-m. Additionally, during the construction phase and for some environmental limitations in certain areas, peculiar configurations of grounding were built in some supports.

In the second semester of 2001, the commercial operation of the line begin and some outages by atmospheric discharges happen, indicating that new measuring of the ground impedances are necessary with the purpose of reducing with technically feasible reinforcements. Before and after executing the previous works, simulations with the ATP, were carried out considering the characteristics of each line section to determine which magnitudes of stroke currents produce back-flashovers, the rate of forced outages, as well as the benefit of installing ZnO line arrester.

II. CHARACTERISTIC OF LINE LAS CLARITAS-SANTA ELENA UP 230 kV

This point described the technical characteristics of the line, like configuration of the grounding impedances, supports, footing impedances, etc. that were used for calculations of forced outages rate by atmospheric discharges.

A. Configuration of the Grounding Impedances

By the phase of insulation design and grounding the line support, some studies [1, 2] were carried out, to verify the shielding wires behavior during atmospheric discharges. These studies are used to calculate the line tripout rate and to give the following recommendations:

- To avoid strokes incidences in phases, install the shield wires in a position that guarantees an effective shielding. That eliminated the line tripouts by shielding failures.

- The reduction of the footing impedance up 10 Ω, give a forced outages rate of 6 trip-outs per year or 3 trip-outs per 100 km per year. This is an acceptable value for transmission line with the voltages levels.

- The installation of two continuous counterpoises along the line route for the high resistivity soil.

In the Figure # 1, is showing the resistivity soil measurements along line Las Claritas–Santa Elena up 230 kV. It can be observed that around 80% of the route has smaller values than 20,000Ω-m; over 35,000Ω-m for the 20% remaining and by some specifics cases more than 80,000Ω-m.

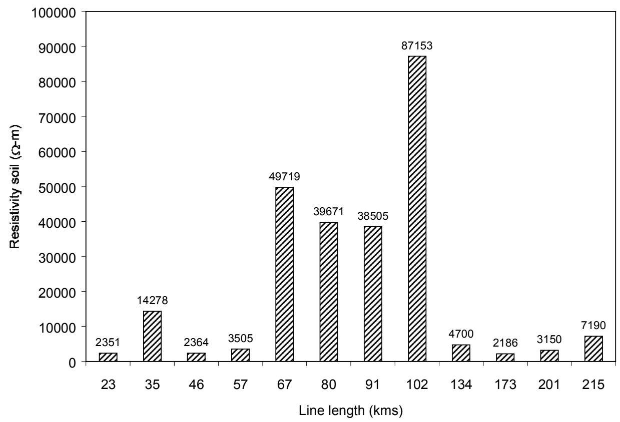


Figure # 1. Resistivity soil measurements result along line Las Claritas–Santa Elena up 230 kV.

Finally as mentioned in point #1, constructive and environmental limitations by some sections of the line, avoided the installation of continuous counterpoises and imposed the adoption of special grounding for each particular case.

B. The Supports (Tower or Pole)

The approximate line length is 215 km and used like supports a total of 4 porticos, 231 towers or lattice structures and 344 poles. The poles are used to mitigate the visual impact of the line inside the National Park "La Gran Sabana" that belong to "El Macizo Guayanés".

In the Figure # 2, the physical and geometric characteristic of the suspension tower and pole is show, which has different heights to fulfill the insulation design requirements for the line.

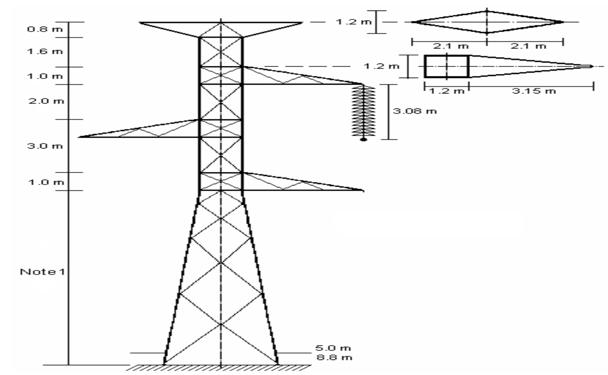
C. Supports Footing Resistance

In Figure # 3 is showing the footing resistances before and after the reinforcements to reducing the final values. In such figure is appreciated that exist zones with average by footing resistances over 20Ω due to the high resistivity soil. Then, the total line length was subdivided in 12 sections by the proximity among the values of footing resistances measured in these sections.

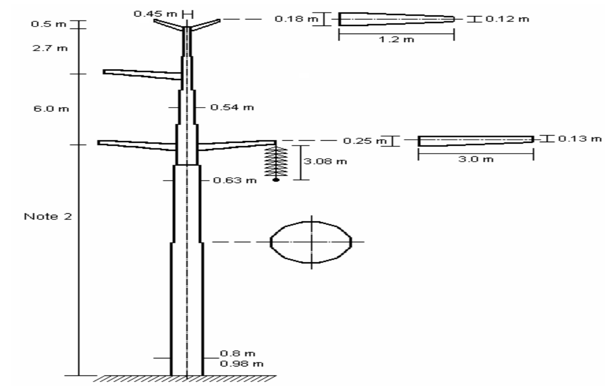
III. METHODOLOGY

To achieve the objective, the following methodology and considerations were used:

1. The line Las Claritas–Santa Elena up 230 kV was represented through mathematical models for transmission lines, footing resistances, disruptive voltages for lines insulators, sources, etc [3].
2. With ATP [4, 5] simulations, is calculating the strokes critical currents that produce back-flashovers and the phase failures sequences for supports with footing resistances among 10 to 1,000 Ω according to the measuring. The strokes will have currents magnitudes among 20 to 200 kA peak that produce an opposite voltage in the tower or pole respect to maximum power frequency voltage of phases and cause an insulation flashover as consequence by stroke impact to the line.
3. The most critical cases were selected from the previous results and ZnO line arresters placed in the phases of the impacted support according to the failure sequence. Then the simulation was repeated according the previous point.
4. Finally, the line back-flashover rate of forced outages for 120 days of thunderstorm per year was calculated for cases without and with ZnO line arresters in parallel of insulators strings.



Note 1. Heights in meters 12.1; 15.1; 18.1; 22.1; 25.1; 27.1 and 33.1.



Note 2. Heights in meters 27.1; 24.1; 21.1; 18.1 and 15.1.

Figure # 2. Tower and Pole up 230 kV.

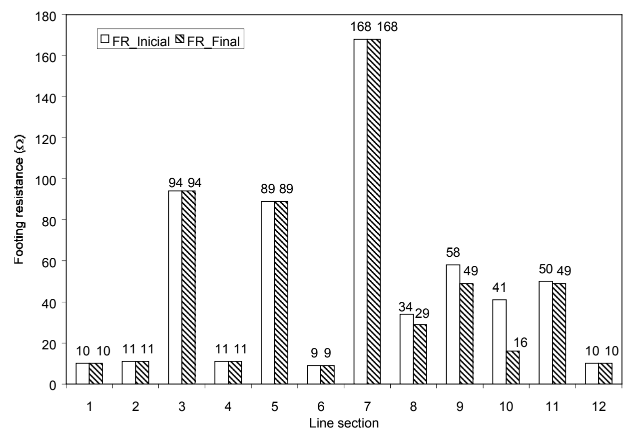


Figure # 3. Footing resistance measurements result along line Las Claritas–Santa Elena up 230 kV.

A. Considerations about the Line up 230 kV

After the revision and evaluation of the topographical transmission route line, were obtained the averages of conductor's heights to earth and the spans length among supports for each line section. These were grouped in sections towers when it is defined by an initial and final pole, and sections poles among an initial and final tower respectively. Then, the sections supports were classified in high or low and the spans in long or short due to the different supports heights by route line. The previous mention was necessary to consider the change of the conductor's position in the supports and the extreme conditions for lightning attraction. The result gives a 4 study's cases, whose supports heights and spans lengths are indicated in the Table # I.

Table # I
Heights of supports and spans lengths up 230 kV

Support type	Support height (m)	Span length (m)
Low post	24.3	157
High post	36.3	574
Low tower	30.9	264
High tower	47.5	505

B. Determination of the Stroke Current with the ATP

To determine the stroke current (I_{stroke}) required to cause a back-flashover at least in one string of insulators, 10 detailed spans were modeled for each line section and support (tower or pole), including a lumped model for the footing resistance, the string of insulators and in some cases ZnO lines arresters (S/A). Additionally, a source for power frequency voltage of phases and a source to inject the stroke currents are included, as showing in Figure #4.

C. Disruptive Voltage of the Insulators Strings

When the atmospheric discharge impact the line support, it will cause that the insulators string can be stressed by the voltage difference between the support and the phase. In the case of overcoming the disruptive voltage of the insulators strings, the fault of the insulation will take a place. To calculate the disruptive voltage, the following equation were used [6, 7]:

$$T_r = L_c * [0.4 + (0.71 / t^{0,75})] \quad (1)$$

where:

T_r = Disruptive voltage of the insulators strings, (MV).
L_c = Length of the insulators strings, (m).
t = Time to crest of stroke current wave, (μs).

D. Calculation of the Line BackFlashover Rate of Forced Outages

The line under study has a different characteristic (supports, heights, footing resistances, etc.) along their route. To evaluate the behavior, it was subdivided in several sections that on average have similar characteristics. Then, the total line back-flashover rate of forced outages can be obtained, as the sum of the calculations of the forced outages rates of each line section, through using the following equation [6, 7]:

$$N = (72*10^{-6})(b + 4*h^{1.09})*Ni*Pi*L \quad (2)$$

where:

b = Separation among shield wires, (m)
h = Average height of shield wires, (m).
Ni = Days of thunderstorm per year.
Pi = Probability of exceeding stroke current ($P(I_{stroke})$).
L = Length of the line or section, (Km).
N = Rate of line or section trip-outs per year.

The probability of exceeding the stroke current (I_{stroke}) can be calculated in approximate form by means of the following expression [6,7]:

$$P(I_{stroke}) = 1/(1 + (I_{stroke}/31)^{2.6}) \quad (3)$$

with $2 \text{ kA} < I_{stroke} < 200 \text{ kA}$.

IV. Approaches and Used Models

The point described the approaches and some used models.

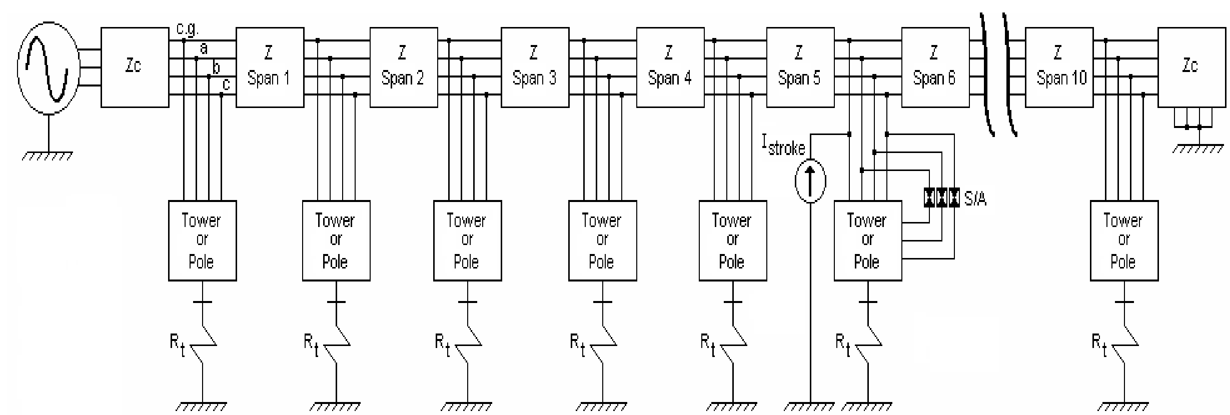


Figure # 4. Outline model used in ATP of the line up 230 kV.

A. The Line up 230 kV

The line spans were represented with the model of not balanced distributed parameters (R, L and C) and calculated a frequency of 500 kHz [3]. The span length and height of the support will depend on the line section under study, as was indicated in the Table # I.

B. The Atmospheric Discharge

This was represented with a double ramp type source of current whose peak magnitude is reached in a time of crest and then fall to 50% of that magnitude in a tail time of 50μs [3]. Table # II, indicated the time to crest of the wave in function of the current magnitudes for the atmospheric discharge and the disruptive voltage for insulators strings calculated with the equation (1) [6,7].

Table # II
Time to crest of current for atmospheric discharge and disruptive voltage for insulators strings

Atmospheric discharge current (kA)	Time to crest of the wave (μs)	Disruptive voltage of the insulators strings up 230 kV (kV)
20	0.5	4910
50 - 100	1.2	3139
150 - 200	2.0	2532

C. *The Insulators String up 230 kV*

These are a series-parallel combination of capacitances that represent the voltages distribution with regard to the support and the leakage current along the insulator string as show in Figure # 5. The effective length is 2.33 m and 3.16 m with line end fitting. To simplify the representation, the equivalent capacitance was determined, giving a value of 3.94 pF [4].

The dielectric strength of the insulator string was represented through a voltage controlled switch [3, 4]. This switch closes their contacts when the voltages difference between the support and the phase conductor overcomes the disruptive voltage as consequence of the atmospheric discharge. The disruptive voltage of insulator string was indicated in Table # II.

D. The Supports (Tower or Pole) up 230 kV

The supports were represented by transmission lines, with impedances calculated from the support sections geometry connecting in series with footing resistance. The propagation time in the pole or the tower, was calculated as the relationship between the height or sections length and the 90 or 70% of the speed of the light when travel in a medium different to the vacuum [3, 4, 5]. Figure # 6, shown the models for tower and pole and is indicated the equation (cone or cylinder) used to calculate the impedance of their sections.

E. The Footing Impedance

These were represented like a lumped resistance with a value among 10 to 1,000 Ω by each study's cases to cover all different values of footing impedances measuring along the line.

F. ZnO Line Arresters up 230 kV

These equipments were simulated like an approach of their non lineal characteristic of voltage versus current, in parallel with a capacitance to represents the voltage distribution and current leakage of the insulation [3]. The nominal voltage is 172 kV, with a MCOV of 140 kV and a residual voltage of 544 kV when it discharges a current of 10 kA for a front of wave of 8/20 μs [8].

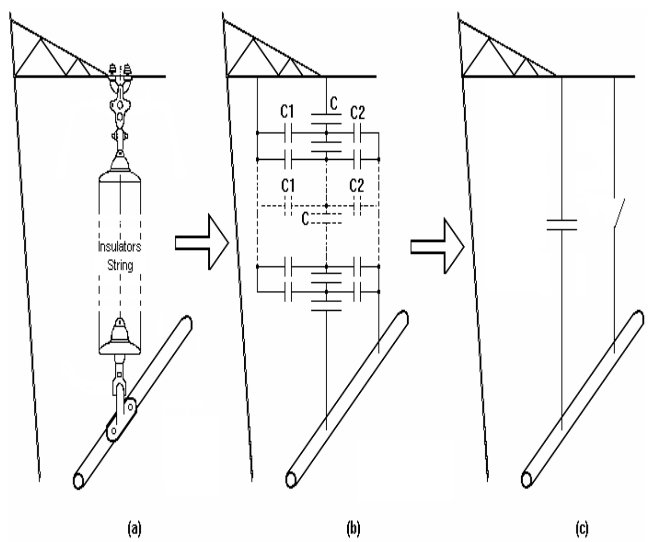


Figure # 5. Model used for string of insulator up 230 kV.

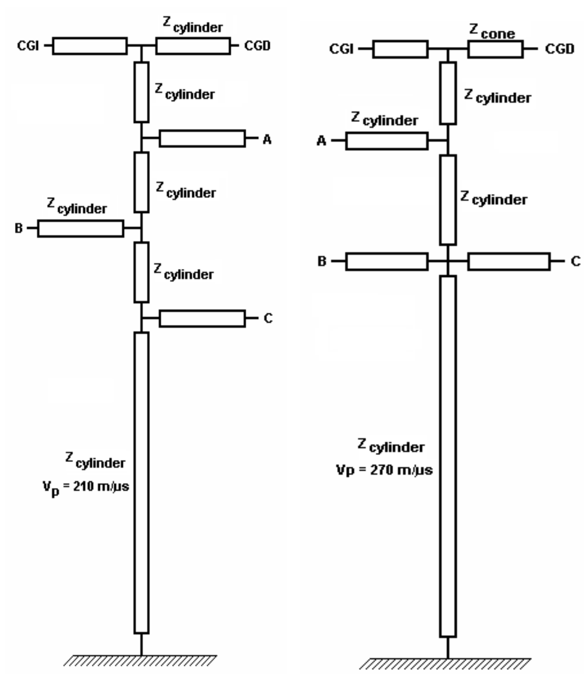


Figure # 6. Models used for tower and pole up 230 kV.

V. RESULTS ANALYSIS

The most important aspects for the different simulated cases are the following:

- A similar failures tendency was appreciated for the different supports (towers and poles), with high dependence of the footing resistances value that influences directly the first phase failure (high, low or all). The higher supports fail before the lower and required strokes with current of 150 kA in a case with a footing resistance of 20 Ω. Table # III, included a results summary for strokes current that produces back-flashover in the line and their corresponding value of footing resistances.

Table # III
Stoke currents and its occurrence probability to produce back-flashover in the line according to the footing resistances of the supports

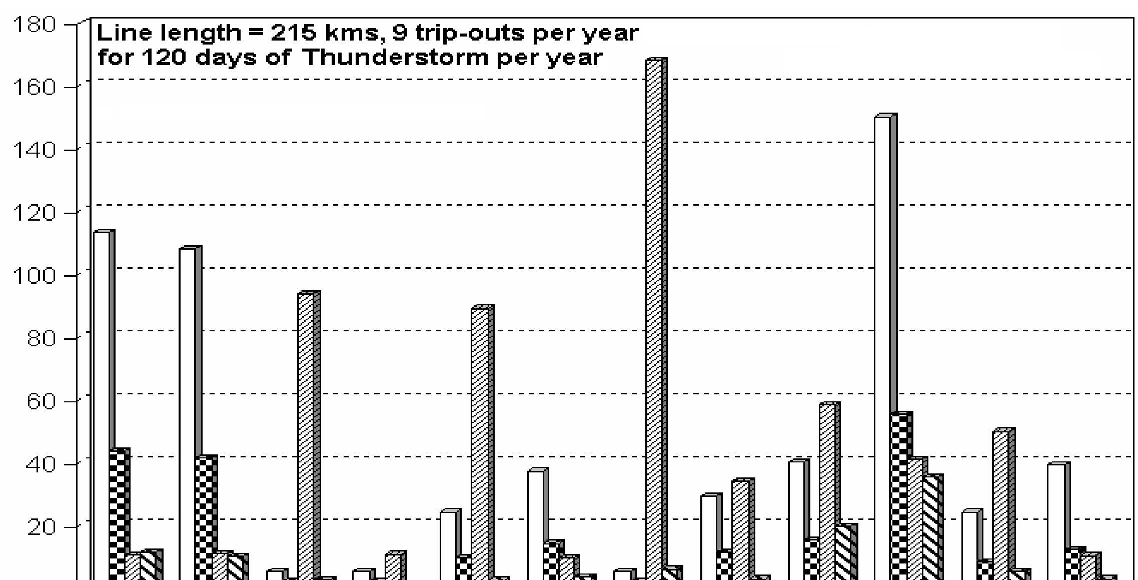
Footing resistance values (Ω)	Atmospheric discharge current [I_{stroke}] (kA)	Occurrence probability of I_{stroke} (%)
10 up 35	150	1.63
36 up 50	100	4.54
51 up 150	75	9.14
151 up 1000	50	22.39

- For the most critical cases, the installation of ZnO line arresters in all phases avoids back-flashover failures in the line. That condition gives a zero probability of failures by a stroke, excluding only the case with damages in the line arresters.

- The total line back-flashover rate of forced outages for 120 days of thunderstorm per year, using the supports footing resistance (initial and final values) showing in Figure # 3, the reported results on Table # III and the equation (2) respectively, give a reduction from 9 to 7 annual trip-outs or 3.2 trip-outs per 100 km per year. This represents a 23% decrease in the forced outages rate due the footing impedances reinforcements that reduced the resistance.

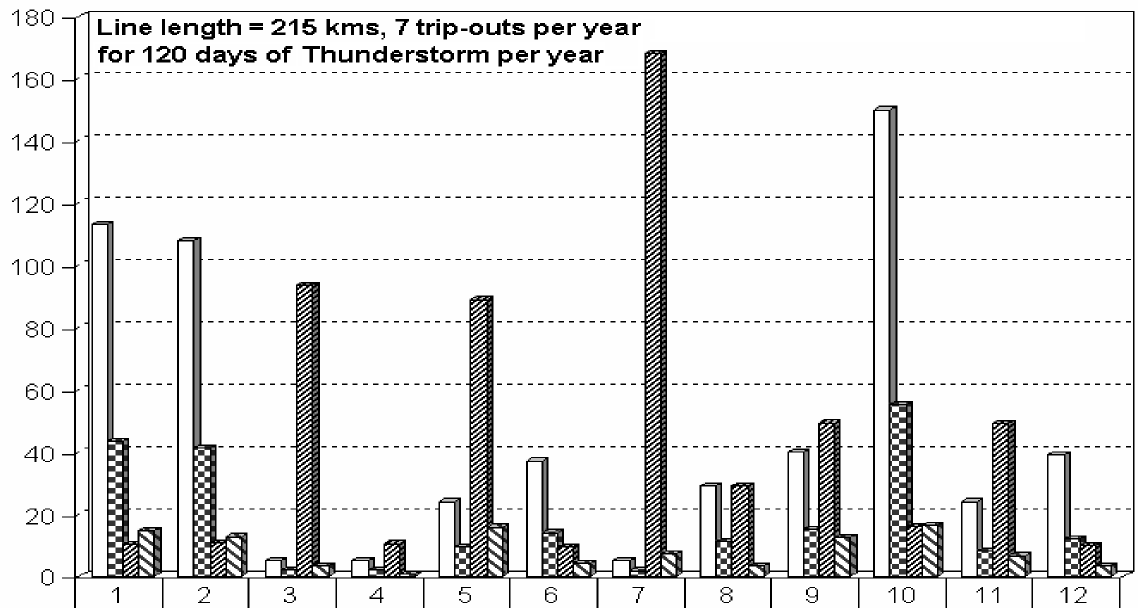
- Finally, the total line back-flashover rate of forced outages for 120 days of thunderstorm per year, considering the installation of the ZnO line arresters in the lines sections (3, 5, 7 and 9) with footing resistances up 50 Ω, give a total of 4 annual tripouts or 1.9 tripouts per 100 km per year. This represents a 43% decrease in the forced outages rate when comparing the cases without and with ZnO line arresters.

- Figures # 7 and 8, showing a results summary for line rate of forced outages in function of, number of supports, section line length, footing resistance (initial and final values) and their contribution in percentage of total tripouts. In these can be appreciated that the reinforcements were carried out in the sections 8 to 11, achieving reductions between 2 and 61% in footing resistance.



	1	2	3	4	5	6	7	8	9	10	11	12
# of Supports	113	108	5	5	24	37	5	29	40	150	24	39
Length (km)	43.3	41.1	1.9	2.0	9.2	13.9	1.8	11.3	15.1	55.3	8.0	12.1
Grd-Resist. (Ω)	10	11	94	11	89	9	168	34	58	41	50	10
Fault in % total	11.3	9.8	2.5	0.5	2.2	3.3	5.7	2.6	19.4	35.1	5.0	2.6

Figure # 7. Line forced outages rate for initial condition of footing resistance.



	1	2	3	4	5	6	7	8	9	10	11	12
# of Supports	113	108	5	5	24	37	5	29	40	150	24	39
Length (km)	43.3	41.1	1.9	2.0	9.2	13.9	1.8	11.3	15.1	55.3	8.0	12.1
Grd-Resist. (Ω)	10	11	94	11	89	9	168	29	49	16	49	10
Fault in % total	14.5	12.6	3.2	0.6	15.7	4.3	7.3	3.3	12.4	16.2	6.5	3.4

Figure # 8. Line forced outages rate for final condition of footing resistance.

VI. CONCLUSIONS

The main conclusions are the following:

- The footing impedance improvements in line Las Claritas - Santa Elena up 230 kV, allow a considerably reduction of the resistance values in the supports (towers and poles).
- Some supports maintain high values of footing resistances (up 50 Ω) as consequence of high resistivity soil and the technical limitations encountered during the reinforcements work.
- The line back-flashover rate of forced outages for 120 days of storm per year, decreased from 9 to 7 annual tripouts or 3.2 tripouts per 100 km per year, as a result of the footing impedances reinforcements that reduced their resistance.
- The total line forced outages rate, is considered appropriate, according to the values of design used for the level of voltage.
- The installation of ZnO line arresters in the supports with high footing resistances values (13% of total line length) give a reduction to 4 tripouts per year for forced outages rate. However, this line fulfills the typical values of design and therefore the installation of ZnO line arresters is not recommended.
- At last, EDELCA load dispatch reported 6 failures for back-flashover during the commercial operation of the year 2002 for the line Las Claritas–Santa Elena up 230 kV once made the reinforcements in the footing impedances.

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