

Analysis of lightning performance of 132KV transmission line by application of surge arresters

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Abstract: There are different methods for decreasing the outage rate due to lightning such as tower footing resistance reduction, increase of line insulation level, installation of additional ground and guy wires, addition of under-built ground wires, etc. limited effect or being expensive or difficult to use, are some of the reasons that make some of them impractical. But Line arresters are considered as an effective way to improve the lightning performance of transmission lines, especially in parts of line that suffer from high soil resistivity and lightning ground flash density. This paper presents results of the application of line surge arresters on the 132KV double circuit transmission line in EMTP-RV and all the practical scenarios for installation of surge arresters have been studied and compared.

1 INTRODUCTION

Lightning overvoltage is one of the major sources of equipment failure in transmission lines up to 400KV. There are different methods for decreasing the outage rate due to lightning such as tower footing resistance reduction, increase of line insulation level, installation of additional ground and guy wires, addition of under-built ground wires, etc. limited effect or being expensive or difficult to use, are some of the reasons that make some of them impractical. But Line arresters are considered as an effective way to improve the lightning performance of transmission lines, especially in parts of line that suffer from high soil resistivity and lightning ground flash density[1].

Trade off between economical aspects of implementation of surge arresters and line lightning performance is one of the major concerns of line designers and because of that it is important to design scenarios for installation of different line surge arrester configurations and study and compare their cost and lightning performance. This study can lead to optimum cost-benefit ratio.

Thanks to the development of polymer-housed metal-Oxide surge arresters, it became practical to use arresters to control line lightning performance, with reasonable price and without tower structure reinforcement[2].

This paper presents results of the application of transmission line surge arresters on the 132KV double circuit transmission line with using accurate models of line components

in EMTP-RV environment. Backflashover has been studied in this line with and without presence of line surge arrester. Several arrester installation scenarios have been introduced and their performance has been studied and compared.

At first, a brief description of test line has been presented and then, models used for modeling lightning source, tower and transmission line, tower footing resistance, insulator gap and surge arrester in EMTP-RV have been introduced and their parameters has been calculated and finally simulation results and their characterization and conclusion have been presented.

2 BRIEF DESCRIPTION OF TEST LINE

Arvandkenar-Abadan 132KV double circuit transmission line with around 53Km length is located near Mahshahr city in Khuzestan province. Average regional lightning activity from national weather bureau shows that Mahshahr city has 15.2 thunderstorm day in year. This line consists of mostly HS2-10⁷ type towers and it is used as a base for tower modeling. Other line data are briefly as follows.

Conductor: Hawk/AL, 26/3.87, 477MCM

2 Bundle per phase

Bundle spacing: 45.7cm

Diameter: 21.8mm

Total Area: 281.03mm²

DC resistance: 0.1199 Ω /Km

Conductor GMR: 0.8245cm

Shield Wire: Hawk core

1 wire per tower
 Diameter: 8.04mm
 Cross section Area: 39.46mm²
 DC resistance: 2.9 Ω/Km
Ruling span: 350m
Insulator gap length: 1350mm
Tower footing resistance: 20 ohm maximum
Soil resistivity: 100-150 Ohm.meter

Figure 1 shows Tower structure, phase and shield wire configuration.

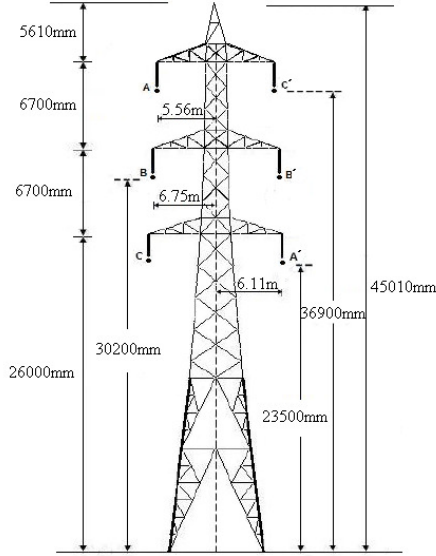


Figure 1: HS2-10^{''} type tower structure

3 MODELING

3.1 Lightning current source model

The probability distribution of crest current magnitude can be calculated approximately from equation 1.

$$P_I = \frac{1}{1 + \left(\frac{I}{31}\right)^{2.6}} \quad (1)$$

Where P_I = Probability of exceeding stroke current I , and it can be used to calculate lightning outage rate [3].

Double exponential model is used for current source modeling and its parameters has been derived from equation 2-4 [4].

$$i(t) = 1.04I_m \left(e^{-\frac{t}{T_1}} - e^{-\frac{t}{T_2}} \right) \quad (2)$$

$$T_1 = 1.365434T_R \quad (3)$$

$$T_2 = \frac{T_s}{2.282835} \quad (4)$$

Where T_s = rise time

T_R = tail time

The positive polarity lightning stroke is about 5% of all strokes and has been disregarded in this

work. Impedance of the lightning discharge path has been assumed to be 400Ω.

3.2 Tower and Transmission line model

Double circuit transmission line is modeled with frequency-dependant model in EMTP-RV. phase coupling is considered in this model.

Multistory model [5] is used for tower model. It multistoried as shown in Figure 2.

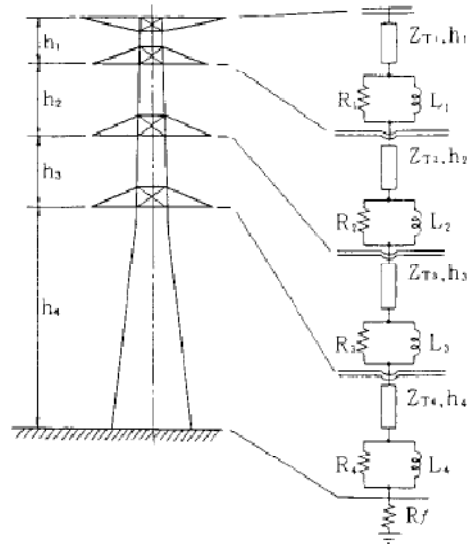


Figure 2: Multistory tower model

Tower surge impedance is calculated from CIGRE recommended equation [3] and then because of similar structure of HS2-10^{''} vertical tower and [9], the same ratio has been chosen for dividing surge impedance between upper and lower halves.

$$Z_{surge} = 60 \ln \left[\cot \left\{ 0.5 \tan^{-1} \left(\frac{R}{h} \right) \right\} \right] \quad (5)$$

Where

$$R = \frac{r_1 h_2 + r_2 h + r_3 h_1}{h}, \quad h = h_1 + h_2 \quad (6)$$

Height and radius has been shown in Figure 3.

Calculated tower model parameters and their formulas have been listed in table 1.

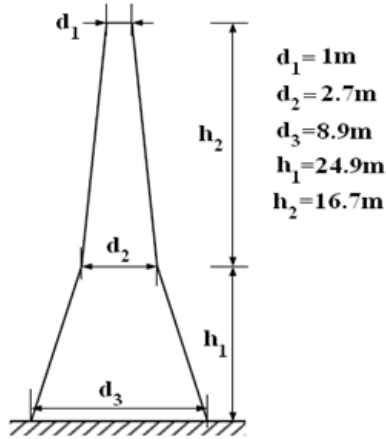


Figure 3: tower shape to calculate tower surge impedance

Table 1: Multistory tower model parameters

$Z_{surge} = 179.2$	[Ω]
$Z_{t1} = Z_{t2} = Z_{t3} = 1.19Z = 213.2$	[Ω]
$Z_{t4} = 0.81Z = 145.15$	[Ω]
$v_{t1} = v_{t2} = v_{t3} = v_{t4} = v = 300$	[m/ μ s]
$\gamma = 0.8944$	
$\tau = 2H/v = 0.28$	[μ s]
$r_1 = -(2 \times Z_{t1} \times \ln \gamma) / (h_1 + h_2 + h_3) = 2.5$	[Ω /m]
$r_2 = -(2 \times Z_{t4} \times \ln \gamma) / h_4 = 1.25$	[Ω /m]
$R_1 = r_1 \times h_1 = 14$	[Ω]
$R_2 = r_1 \times h_2 = 16.8$	[Ω]
$R_3 = r_1 \times h_3 = 16.8$	[Ω]
$R_4 = r_2 \times h_4 = 32.4$	[Ω]
$L_1 = R_1 \times \tau = 3.92$	[μ H]
$L_2 = R_2 \times \tau = 4.07$	[μ H]
$L_3 = R_3 \times \tau = 4.07$	[μ H]
$L_4 = R_4 \times \tau = 9.1$	[μ H]

3.3 Tower footing resistance model

Fast transient surges decrease the resistance of earth electrode due to soil ionization.

Laboratory experiments on Rod electrode which is the most common electrode, shows that earth resistance remains at the value determined by the electrode geometry and the soil resistivity until ionization onset, and then it starts to decrease in proportion with the logarithm of current until the ionization zone becomes so large that the equivalent rod geometry is no longer maintained and after that it starts to decrease inversely proportional to the square root of current [3].

Different methods have been proposed to account for these transient behaviors but the most simple and practical one is by CIGRE [3].

$$R_F = \frac{R_0}{\sqrt{1 + \frac{I}{I_g}}} \quad (7)$$

Where R_F is tower footing resistance (ohm), R_0 is tower footing resistance at low current and low frequency (ohm) and I_g is limiting current initiating soil ionization (kA) that can be calculated by

$$I_g = \frac{1}{2\pi} \cdot \frac{E_0 \cdot \rho}{R_0^2} \quad (8)$$

Where ρ = soil resistivity (ohm-meter),
 E_0 = soil ionization gradient (about 400 kV/m).

3.4 Backflashover model

In volt-time model [3], it is assumed that Backflashover occurs when tower voltage is higher than lightning impulse withstand voltage or Basic insulation level (BIL) of the insulator strings. Lightning impulse withstand voltage of the insulator string is not a unique number. The insulator string may withstand a high magnitude impulse voltage with short duration while it fail to withstand a lower magnitude impulse voltage with longer duration. A simplified expression of withstand voltage capability for an insulator string can be calculated as in 9:

$$V_{f0} = K_1 + \frac{K_2}{t^{0.75}} \quad (9)$$

Where V_{f0} = flashover voltage (kV),

$$K_1 = 400 \cdot L$$

$$K_2 = 710 \cdot L$$

L = insulator length (m)

t = elapsed time after lightning stroke, μ s.

Figure 4 shows the V-t relationship of a sample insulator.

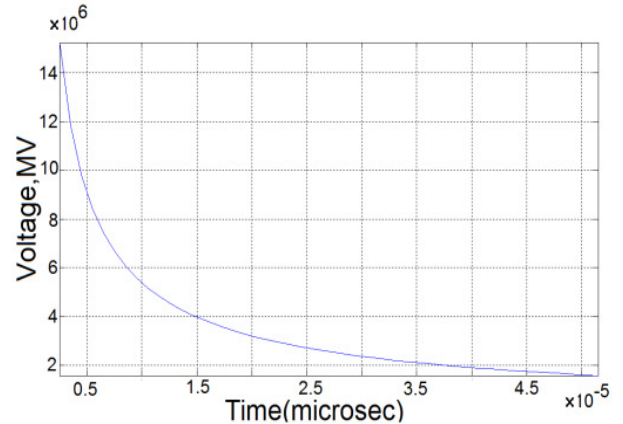


Figure 4: Volt-time model

3.5 surge arrester model

Metal Oxide surge arresters protect power equipments insulation from system overvoltages. These arresters have high resistance at the normal system operation but when facing system overvoltages, they will show low resistance. There are several models proposed in literature to describe this nonlinear behavior but in this study IEEE frequency dependant model [6] has been chosen because of its enough accuracy for lightning studies.

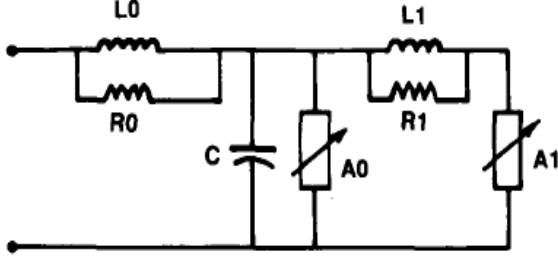


Figure 5 : IEEE frequency dependant model

The inductance L_0 in the model represents the inductance associated with magnetic fields near the arrester. The resistor R_0 is used to stabilize the numerical integration in the software. The capacitance C represents the terminal-to-terminal capacitance of the arrester.

The inductance L_1 and the resistance R_1 make a filter between the two nonlinear resistances.

For slow-front surges, this R-L filter has very little impedance and the two non-linear sections of the model are in parallel. For fast-front surges the impedance of the R-L filter becomes more significant. This results in more current in the non-linear section named A_0 than in the section named A_1 .

$$L_1 = 15 \left(\frac{d}{n} \right) \mu H \quad (10)$$

$$R_1 = 65 \left(\frac{d}{n} \right) \text{ Ohm} \quad (11)$$

$$L_0 = 0.2 \left(\frac{d}{n} \right) \mu H \quad (12)$$

$$R_0 = 100 \left(\frac{d}{n} \right) \text{ Ohm} \quad (13)$$

$$C = 100 \left(\frac{n}{d} \right) \text{ pF} \quad (14)$$

Where d : is the estimated height of the arrester in meters (from catalog data)

n : is the number of parallel columns of metal oxide in the arrester

The non-linear V-I characteristics A_0 and A_1 can be estimated from the per unitized curves given in Figure 6.

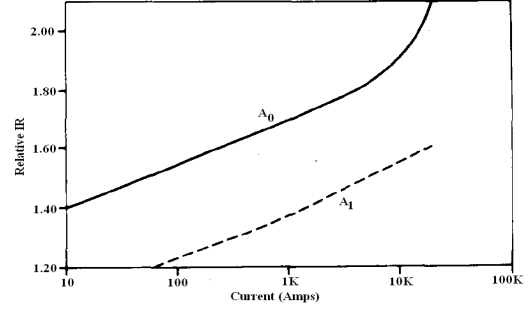


Figure 6 : V- I Relationships for Non-Linear Resistor Part of Model

For A_0 , the

$$\text{Discharge, KV} = [\text{Relative IR in p.u. for } A_0(i)] * [V_{10}/1.6] \quad (15)$$

Likewise for A_1 , the

$$\text{Discharge, KV} = [\text{Relative IR in p.u. for } A_1(i)] * [V_{10}/1.6] \quad (16)$$

Where V_{10} is discharge voltage for 10kA current with 8/20 μ s waveshape per kV.

Table 2 shows line arrester specification used for this simulation.

Table 2 : SIEMENS 3EL5 108-0LK23 specification[7]

Height(d)	1.53 m
Parallel column(n)	1
Maximum value of Residual voltage at discharge current 8/20 μ s and 10 kA(V_{10})	308kV
Maximum value of Residual voltage at discharge current 30/60 μ s and 2kA	259kV
Maximum Continuous Operation Voltage	86 kV

4 SIMULATION AND RESULTS

Simulation has been done with accurate components modeling in EMTP-RV software. Figure 7 shows the schematic of test line. Figure 8 shows the induced voltage on insulator without surge arrester for standard lightning current of - 100 kA that as it can be observed, flashover occurs across insulator. Figure 9 shows the same situation for insulator but with surge arrester installed at the upper phase. For installation of surge arresters a comprehensive plan must be studied to consider all scenarios. Figure 10 illustrates all the different practical scenarios for installation of insulators. Scenarios with the same number of surge arrester per tower have been compared in Figures 11-15. Finally, in Figure 16 lightning currents causing flashover in all scenarios, have been shown graphically.

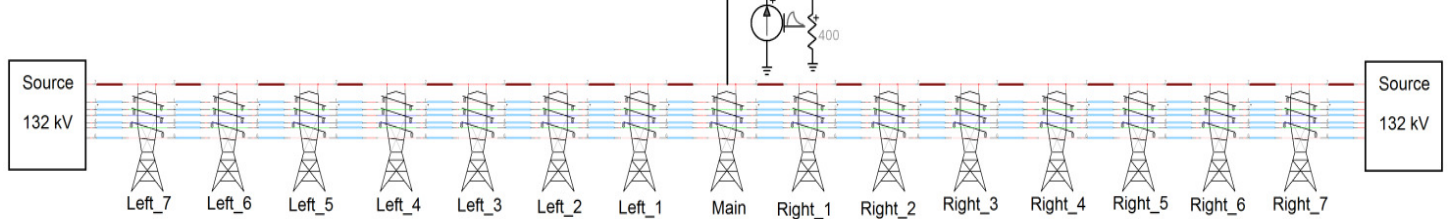


Figure 7: Simulated line schematic

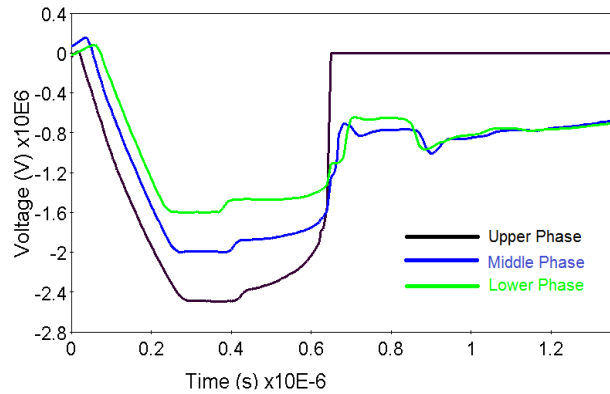


Figure 8 : insulator induced voltage without arrester

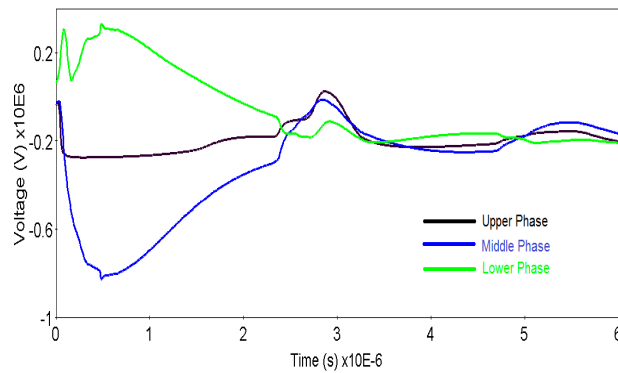


Figure 9 : insulator induced voltage without arrester

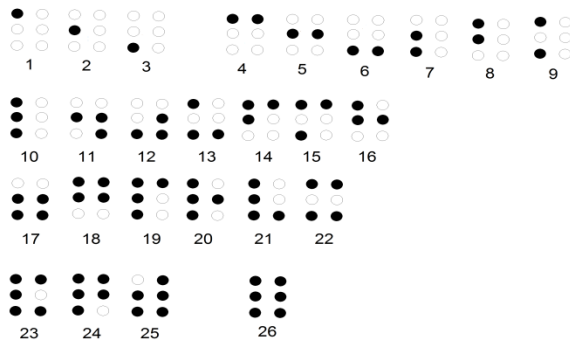


Figure 10 : installation scenarios

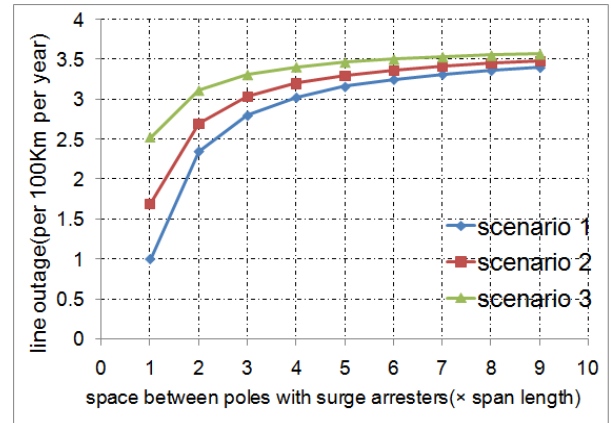


Figure 11 : Scenarios with one arrester

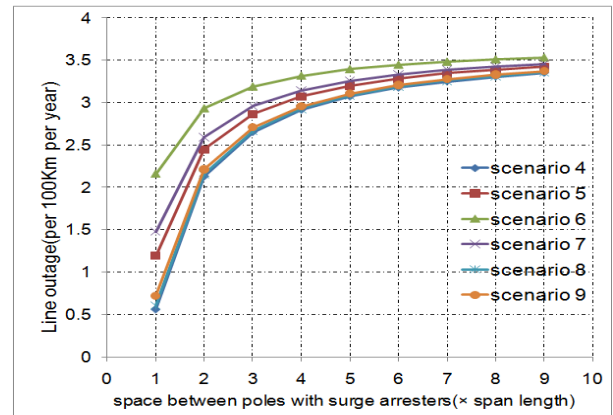


Figure 12 : Scenarios with two arresters

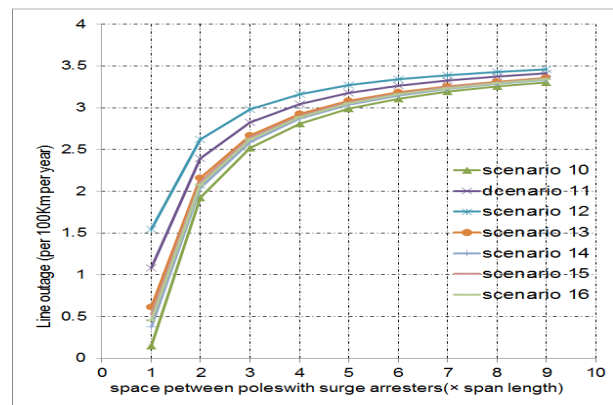


Figure 13 : Scenarios with three arresters

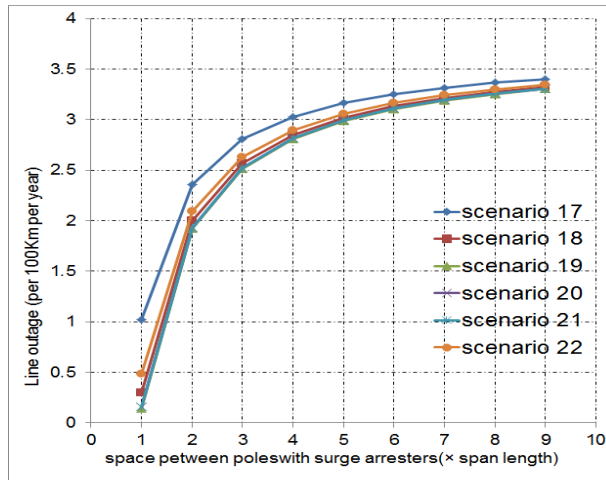


Figure 14 : Scenarios with four arresters

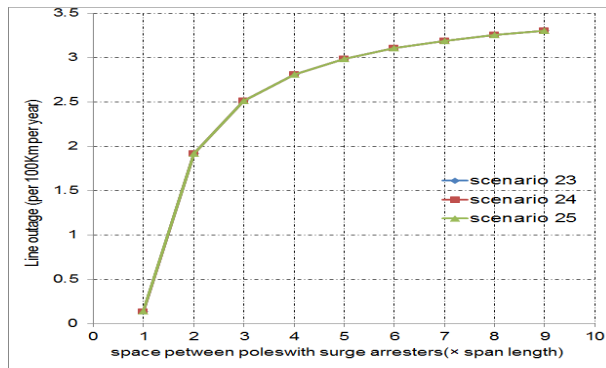


Figure 15 : Scenarios with five arresters

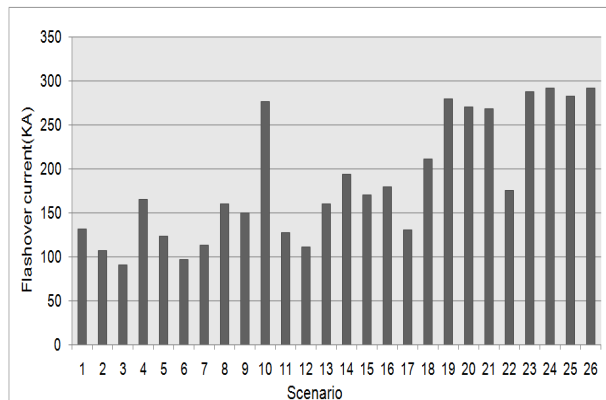


Figure 16 : Lightning current flashover in all scenarios

5 CONCLUSION

Simulation showed that standard lightning current of -77kA can cause flashover across insulators of the line without surge arrester, this current results 3.7 line outage per 100km per year, but with installing surge arrester, this line can withstand lightning currents up to -292kA

that probability of having this lightning current, is practically zero.

As shown in Figure 16, scenarios 1, 4 and 10 are the most efficient among other installation scenarios; as it is obvious in Figures 11-16, inefficient strategies for installing surge arresters can waste a lot of money even with more arresters per tower.

The study has shown that, as expected, a different level of improvement can be reached by installing arresters at all or only some of the line phases. The improvement of lightning performance can be very significant when arresters are installed at two phases, but even with the installation of a single arrester per tower at the upper phase, a significant reduction of the total flashover rate can be achieved.

There are, however, some parts of this work that require a deeper study. For example, all simulation has been done with this assumption that tower footing resistance is constant; this parameter could be variable according to its probability density function. In this kind of studies Monte Carlo method can be used to handle uncertainties related to parameters of problem.

6 REFERENCES

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