Modeling and lightning performance study of compact transmission lines in EMTP-RV by application of Monte Carlo method

S. Mohajer yami*, A. Shayegani akmal, A.Mohseni, A.Majzoobi
High Voltage Institute,Tehran University,Iran
*Email:<s.mohajer@ece.ut.ac.ir>

Abstract: Techniques of line compaction have been developed with the aims of reducing the environmental impacts of transmission lines and increasing voltage level of existing ones. Because of major differences between compact and conventional transmission lines, the previous lightning performance studies on conventional transmission lines are useless in this emerging environment and these studies should be updated and differences must be considered. The calculation of the lightning performance must take into account the random nature of lightning and the random behavior of some line parameters like phase angle of power frequency voltage in every phase at the lightning stroke instance. Application of Monte Carlo method can handle uncertainties introduced by random nature of these parameters and can help to make useful predictions to estimate lightning performance of a transmission line. In this paper, the differences between compact and conventional lines are considered in the line model and line lightning performance has been studied by application of Monte Carlo method for several scenarios introduced in literature. Moment method is used to determine tower surge impedance by SuperNEC software and an approximate model has been introduced for tower modeling in EMTP-RV.

1 INTRODUCTION

Techniques of line compaction have been developed with the aims of reducing the environmental impacts of transmission lines and increasing voltage level of existing ones [1].

Compaction of overhead lines needs decreasing distance between phase to phase and that in turn could limit the span length for achieving the desired performance. Naturally reduction of the span length has a strong influence on the in-place cost of the line and offsets the saving related to the narrower Right of Way and lighter structures and because of that, compact transmission lines are recommended in regions with high tower footing resistance and Keraunic level or in congested urban areas that the land cost is high and lower visual impact is favorable [2].

Some improvement in recent technologies makes compaction of transmission lines more practical and economical. These include the widespread availability of polymer insulators with suitable mechanical ratings for use as horizontal line posts and as tension braces, along with experience leading to mechanical test standards for inter-phase spacers. Transmission line polymer-housed metal-Oxide surge arresters now offer an alternative for lightning overvoltage protection to shield wires [2].

The applicability of compaction methods requires the assessment of transmission line Lightning performance. Different tower structure, Lower insulation strength, shorter phase spacing and spans can lead to different lightning performance.

The existing models of transmission line towers are based on lattice type tower, but tubular and racket type towers have different shapes; therefore, they need to be modeled differently.

One of the key factor in determining the Backflashover in conventional transmission towers, is coupling factor between shield wire and phase conductors, but in compact transmission towers the phase configuration is totally different from conventional lines and this can strongly affect Backflashover rate in compact transmission lines and can cause different values.

Because of major differences between compact and conventional transmission lines, the previous lightning performance studies on conventional transmission lines are useless in this emerging environment and these studies should be updated and differences must be studied.

The calculation of the lightning performance must take into account the random nature of lightning and the random behavior of some line parameters like phase angle of power frequency voltage in every phase at the lightning stroke instance. Application of Monte Carlo method can handle uncertainties introduced by random nature of these parameters and can help to make useful predictions to estimate lightning performance of a transmission line.

In this paper, the differences between compact and conventional lines are considered in the line model and line lightning performance has been studied by application of Monte Carlo method. Moment method is used to determine tower surge impedance by SuperNEC software and an approximate model has been introduced for tower modeling in EMTP-RV.

2 BRIEF DESCRIPTION OF TEST LINE

Fig 1 shows the compact tower structure designed for 230KV transmission line[3]. In this paper a simple line has been introduced to study backflashover. Fig 2 shows the simulated line schematic. There are two voltage sources at the both ends of line to consider the uncertainties of power frequency voltage in the study.

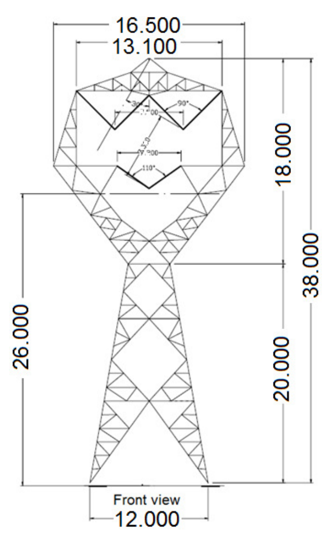

Figure 1: Suspension tower with window arrangement in tower head and inverted delta configuration.

Average regional lightning activity has been assumed to be 30 thunderstorm day in year.

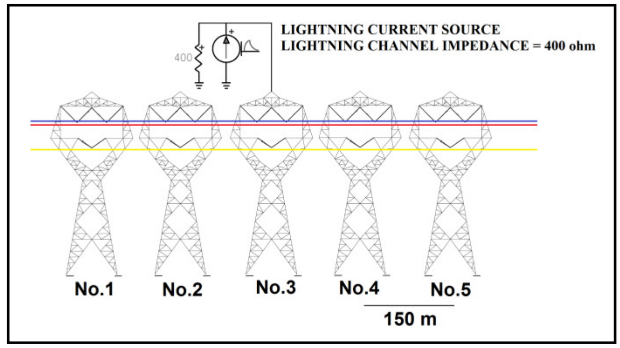

Figure 2: schematic of simulated line

Other line data are briefly as follows.
Conductor: Drake/AL,26/4.44,795MCM
3 Bundle per phase
Bundle spacing: 45.7cm
Diameter: 28.1mm
Total Area: 468.45mm^2
DC resistance: 0.0719 Ω/Km
Conductor GMR: 1.0647cm
Shield Wire: Canary core
1 wire per tower
Diameter: 9.84mm
DC resistance: 3.240 Ω/Km
Ruling span: 150m
Tower footing resistance: 20-80 ohm
Soil resistivity: 100-5000 Ohm.meter

3 MONTE CARLO

The Monte Carlo method is a well-known technique for solving either stochastic or deterministic problems; and with getting help from computers, it can be used to solve multidimensional complex problems. Application of Monte Carlo method is the usual procedure for stochastic problems [4]. It can handle uncertainties introduced by random nature of problem variables. It can help to make useful predictions from situations containing random processes like estimating lightning performance of a new transmission line [5]. This method is based on an iterative procedure that in each step uses a set of values, generated for problem variables according to their probability density function (PDF).

Lightning current crest, rise time, tail time, phase angle of power frequency voltage at stroke instance and tower footing resistance at different locations are parameters that have a random nature. Table 1 summarizes the statistical characteristics of these parameters.

Table 1: Statistical characteristics of problem random variables [5-6]

Parameter	PDF	x_m	σ
Rise time	Log-normal	$2\mu s$	$0.4943\mu s$
Tail time	Log-normal	$77.5\mu s$	$0.577\mu s$
Current crest	Log-normal	34KA	0.74KA
Footing resistance	Normal	50	5
Phase angle	Uniform	Between 0 to 360	

In probability theory, log-normal distribution has been defined as a statistical distribution of a random variable that its logarithm has a normal distribution. If X has a log-normal distribution, then Y=log(X) has a normal distribution [7].

$$\mathrm{PDF}(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{-(\ln x - \ln x_m)^2}{2\sigma^2}} \qquad (1)$$

$$\sigma \geq 0 \quad , \quad -\infty \leq \ln x_m \leq +\infty$$

Ln(x_m) and σ are mean and standard deviation of natural logarithm of X.

Figs 3-5 illustrated PDF of parameters with log-normal distribution.

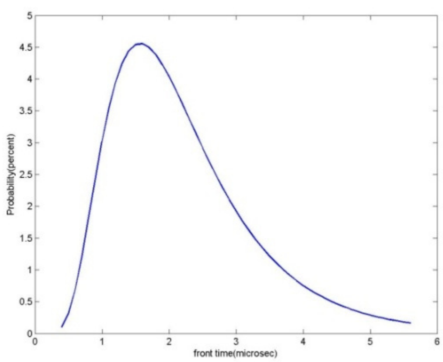

Figure 3: Log-normal distribution of lightning current rise time

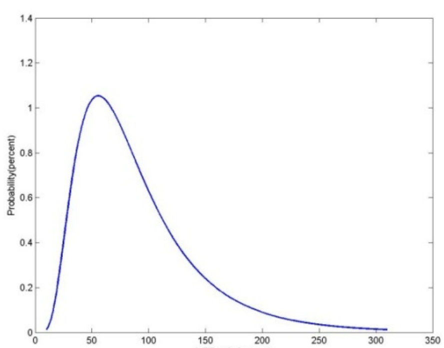

Figure 4: Log-normal distribution of lightning current tail time

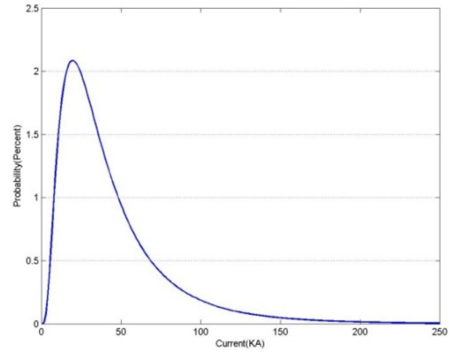

Figure 5: Log-normal distribution of lightning current crest

4 MODELING

4.1 Lightning current source model

The probability distribution of crest current magnitude can be calculated approximately from equation 2.

$$P_I = \frac{1}{1 + (\frac{I}{31})^{2.6}} \qquad (2)$$

Where P_I is probability of exceeding stroke current I, and it can be used to calculate lightning outage rate[5].

CIGRE model is used for current source modeling that is one of the standard models of surge in EMTP-RV.

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.

4.2 Tower and Transmission line model

First of all, tower surge impedance must be determined and then this impedance can be used to model tower. SuperNEC is using the moment method to solve electromagnetic field around thin wires in the frequency domain and in this paper; it has been used to determine tower surge impedance. To determine tower surge impedance in time domain, Fourier transform and inverse Fourier transform have been used in this software.

Tower needs to be decomposed into thin wire elements, and some simplification must be applied along with frequency settings and description of source of current. Fig 6 shows the arrangement of numerically analyzed setup of simplified tower structure of this paper. Validation of this technique is verified in numerous papers [8-10].

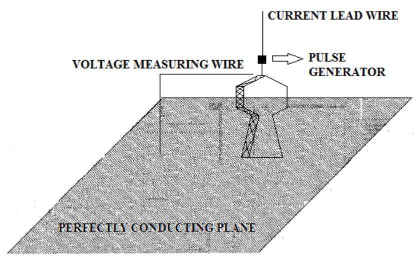

Figure 6: arrangement of analyzed setup

Figs 7 and 8 are injected current waveshape and calculated top voltage of tower respectively, tower surge impedance can be obtained by dividing maximum value of voltage and maximum value of current and in this case, 125 ohm is its result. A constant parameter transmission line model is used to represent tower and it has been divided to two parts. The top part is for upper part of tower and the bottom part is for lower part of tower. Unfortunately there is not any accurate model for this kind of tower structure yet, but Multistory tower model [11] can be used as an idea for developing different accurate compact tower models.

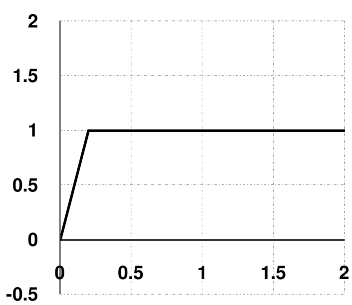

Figure 7: Injected current

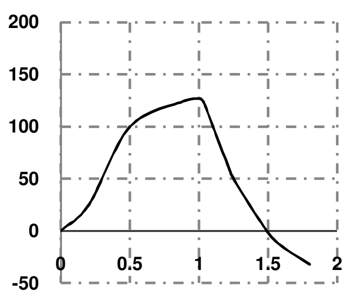

Figure 8: Tower top voltage

4.3 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 [5].

Different methods have been proposed to account for these transient behaviors but the most simple and practical one is by CIGRE [5].

$$\mathrm{R_F} = \frac{R_0}{\sqrt{1 + \frac{I}{I_g}}} \quad (3)$$

Where $\mathrm{R_F}$ 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

$$\mathrm{I_g} = \frac{1}{2\pi} \cdot \frac{E_0 \cdot \rho}{R_0^2} \quad (4)$$

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

4.4 Backflashover model

Insulation coordination is usually based on insulator behavior caused by standard impulse voltage (1.2/50 microsec). It is important to be able to determine the insulation performance when stressed by non-standard lightning impulse. Leader propagation model [5] is used to represent backflashover model, as it can be observed in fig 1, the minimum distance between insulator and tower is less than insulator length in this tower structure, then minimum distance between insulator and tower has been chosen as air gap length. Air gap length in this case is 2.1m.

5 SIMULATION AND RESULTS

Backflashover study of test line has been done with accurate components modeling with EMTP-RV. Lightning current has been injected into No. **3** tower in fig 3 and the four other towers have been modeled to account for reflection from adjacent towers.

Convergence criteria are reached when PDF of rise and tail time of flashover current fit in their theoretical functions. Although their PDF cannot fit their theoretical functions precisely but their trendlines can fit exactly to their associated theoretical figures. 10000 random samples have been chosen to study line behavior against different scenarios of lightning. For random variable generation, a program has been written in MATLAB environment.

The number of flashes to the line per 100Km per year has been calculated according to [12] and 83 strokes to line per 100Km per year has been achieved and with 10000 random lightning strokes, it can be claimed that the lightning performance of the line is observed for over 100 years. It can give an excellent image from every line lightning performance.

Figs 8-10 show statistical distribution of flashover current rise time, tail time and current crest respectively.

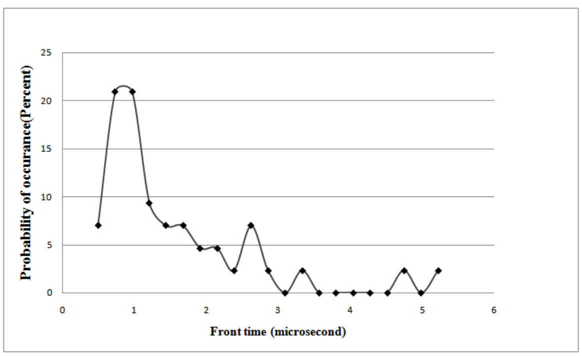

Figure 9: Statistical distribution of flashover current rise time

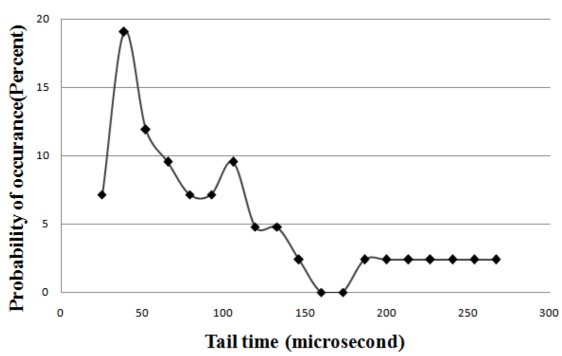

Figure 10: Statistical distribution of flashover current tail time

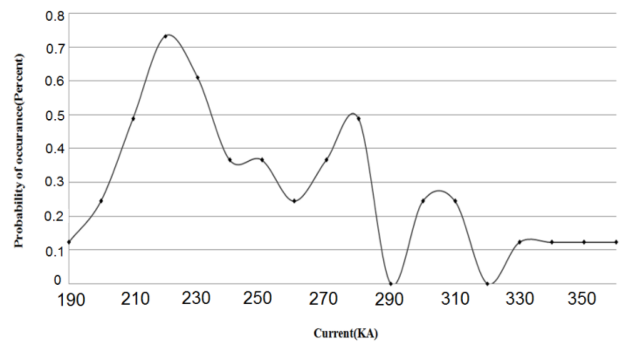

Figure 11: Statistical distribution of flashover current amplitude

6 CONCLUSION

Simulation results show that 40 out of 10000 samples of lightning current have had destructive effect on transmission line and the observed range of destructive currents in this simulation will not happen in practice. It has been observed in this simulation that shorter span can improve lightning performance significantly and the other improving factor is shorter phase to ground wire distance, it can increase the coupling factor and this increased coupling factor, decrease the induced voltage and eventually improve line lightning performance.

Shorter air gap length can lead to weaker line, but in this case, improving factors in this design cover negative effect of shorter air gap length.

Lower tower footing resistance has been observed that can reduce insulator failure significantly as it has been anticipated.

Finally, it can be said that Modern compact lines can achieve reduced visual impact by using a combination of short spans, rigid insulators and inter-phase spacers that reduce the height of the line along with improved lightning performance.

7 REFERENCES

[1]R.rosa, M.Ochoa, J.Bonilla, G.Enriquez, “contribution to lightning research for transmission line compaction”, *IEEE Transactions on Power Delivery*, Vol. 3, No. 2, April 1988

[2] W.A.Chishlom, J.G.Anderson, A.Phillips, J.Chan, “Lightning performance of compact lines”,International symposium on lightning protection,9-13 Nov,2009,Brazil

[3]J.H.M.Fernandes, R.P.Guimaraes, J.F.Nolasco et al ,” Eletronorte and the Challenge of Long-distance Transmission in Brazil”, B2-111, CIGRE 2008

[4]J. A. Martinez, F. Castro-Aranda, P.Martin-Munoz, ”Lightning studies of transmission lines using the EMTP” ,Session 2004,CIGRE,C4-302

[5]CIGRE WG 33-01: “Guide to Procedures for Estimating the Lightning Performance of Transmission Lines”, Technical Brochure, October 1991.

[6]J. A. Martinez, F. Castro-Aranda, “Lightning performance analysis of transmission lines using the EMTP”, Proceedings of IEEE Power Engineering Society General Meeting 2003, pp 295-300.

[7]R.A.johnson, ”Probability and statistics for engineers”,7th edition, Prentice Hall,2004

[8]M. Ishii and Y. Baba, “Numerical electromagnetic field analysis of tower surge response,” *IEEE Trans. Power Delivery*, vol. 12, no. 1, pp.483–488, Jan. 1997.

[9]Y. Baba and M. Ishii, “Numerical electromagnetic field analysis on measuring methods of tower surge impedance,” *IEEE Trans. Power Delivery*,vol. 14, no. 2, pp. 630–635, Apr. 1999.

[10]Y. Baba and M. Ishii, “Numerical Electromagnetic Field Analysis on Lightning Surge Response of Tower with Shield Wire”, *IEEE TRANSACTIONS ON POWER DELIVERY*, VOL. 15, NO. 3, JULY 2000

[11]M. Ishii, T. Kawamura, T. Kouno, E. Ohsaki, K. Muromi, T. Higuchi, “Multistory Transmission Tower Model for Lightning surge Analysis”, *IEEE Transaction on Power Delivery,* Vol. *6,* No. 3, July 1991, pp.1327-1335

[12]IEEE WG on lightning performance of transmission lines, “A Simplified Method for Estimating Lightning Performance of Transmission Lines”, *IEEE Transaction of power apparatus and system,* No. 4. April 1985