Backflashover Study of Arvandkenar-Abadan 132KV Double Circuit Transmission Line by Monte Carlo Method with Accurate Components Modeling

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Abstract: The evaluation of the power system overvoltages is necessary for the selection of dielectric strength of power equipments. Lightning overvoltage is one of the major sources of equipment failure in transmission lines up to 400KV. Since the backflashover is the main part of lightning performance of high voltage transmission lines with presence of shield wires, this study has focused on Backflashover study in 132KV Double Circuit Transmission Line. In this paper, Backflashover has been studied with application of Monte Carlo method by using accurate models of transmission line, tower, grounding system and physical model of breakdown in insulator gap, in Arvandkenar-Abadan 132KV Double Circuit Transmission Line as a case study.

1 INTRODUCTION

The predication of the power system overvoltages is essential for the selection of dielectric strength of power equipments[1].

Lightning overvoltage is one of the major sources of equipment failure in transmission lines up to 400KV. Flashover due to lightning overvoltage can be divided into the Backflashover rate (BFOR) and the shielding failure flashover rate (SFFOR)[2]; with presence of shield wires and for high voltage transmission lines, it can be claimed that BFOR is the main part of lightning performance. This study has focused on Backflashover.

Backflashover occurs when lightning stroke terminates on the overhead ground wire or tower. The lightning discharge makes a transient voltage that travels through tower and reflects to the tower top from tower footing resistance. Voltages across tower crossarms are built up by these multiple reflections. If these voltages equal or exceed the insulator withstand capability, flashover occurs [3].

The calculation of the lightning performance must take into account the random nature of lightning and the random behaviour 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 for estimating lightning performance of a transmission line [4-5].

In this paper, Backflashover has been studied with application of Monte Carlo method by using accurate models of transmission line, tower, grounding system and physical model of breakdown in insulator gap, in Arvandkenar-Abadan 132KV Double Circuit Transmission Line as a case study.

At first, a brief description of test line has been presented and Monte Carlo method has been explained, then, models used for modeling lightning source, tower and transmission line, tower footing resistance and insulator gap in EMTP-RV have been introduced and their parameters has been calculated and finally simulation results and their characterisation 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 Khozestan 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 HS2-10" 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: 281.03mm^2
DC resistance: 0.1199 Ω/Km
Conductor GMR: 0.8245cm
Shield Wire: Hawk core
1 wire per tower
Diameter: 8.04mm

Cross section Area: 39.46mm^2
DC resistance: 2.9 Ω/Km
Ruling span: 350m
Lightning outage rate: 3 per 100Km per year
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.

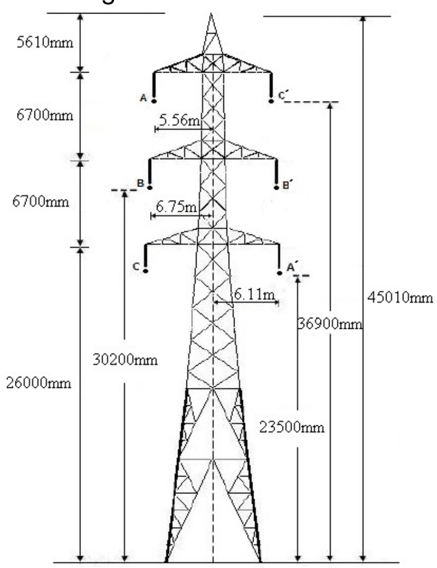

Figure 1: HS2-10" type tower structure

3 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 [2]. 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 and phase angle of power frequency voltage at stroke instance are parameters that have a random nature. Table 1 summarizes the statistical characteristics of these parameters.

Table 1: Statistical characteristics of problem random variables [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
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.
Figures 2-4 illustrated PDF of parameters with log-normal distribution.

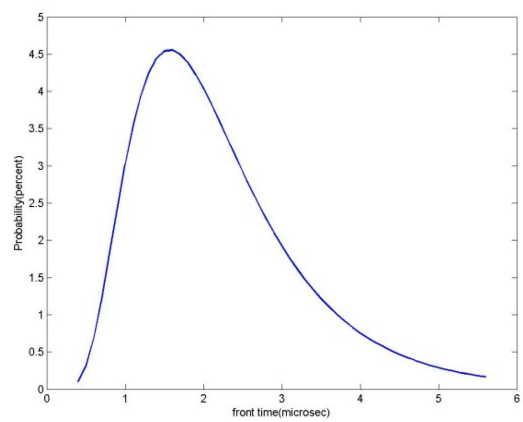

Figure 2: Log-normal distribution of lightning current rise time

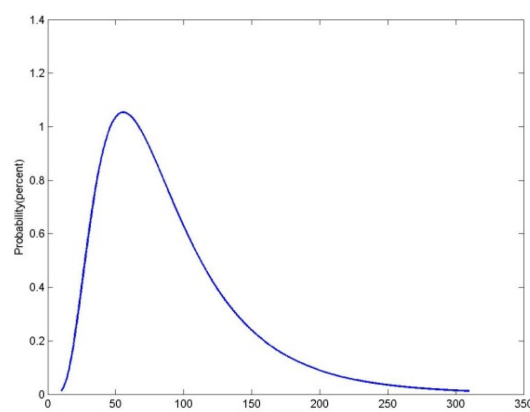

Figure 3: Log-normal distribution of lightning current tail time

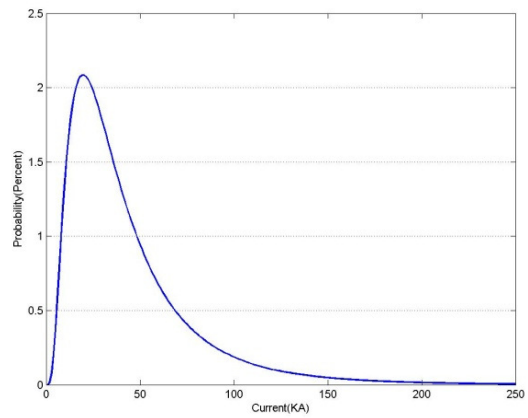

Figure 4: Log-normal distribution of lightning current crest

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[6].

Double exponential model is used for current source modeling and its parameters has been derived from equation 3.

$$i(t) = 1.04 I_m (e^{-\frac{t}{T_1}} - e^{-\frac{t}{T_2}}) \qquad (3)$$

$$T_1 = 1.365434 T_R \qquad (4)$$

$$T_2 = \frac{T_s}{2.282835} \qquad (5)$$

Where T_s is rise time and T_R is tail time[8].

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

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

Multistory model [9] is used for tower model. It multistoried as shown in Figure 5.

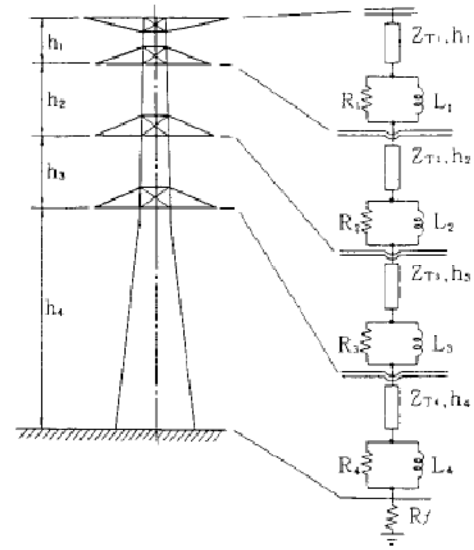

Figure 5: Multistory tower model

Tower surge impedance is calculated from CIGRE recommended equation [6] 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.

$$Z_{surge} = 60 \ln \left[\cot \left\{ 0.5 \tan^{-1} \left(\frac{R}{h} \right) \right\} \right] \qquad (6)$$

Where

$$R = \frac{r_1 h_2 + r_2 h + r_3 h_1}{h} \quad , h = h_1 + h_2 \qquad (7)$$

Height and radius has been shown in Figure 6.

Calculated tower model parameters and their formulas have been listed in table 2.

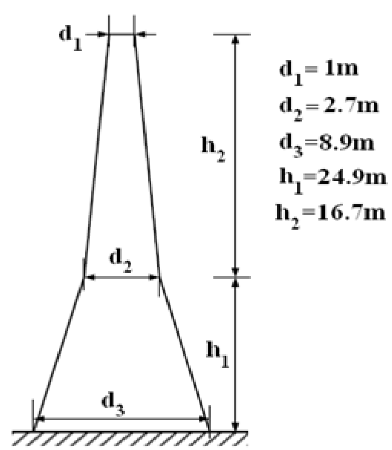

Figure 6: tower shape to calculate tower surge impedance

Table 2: 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/μs]
$\gamma = 0.8944$	
$\tau = 2H/v$=0.28	[μs]
$r_1 = -(2 \times Z_{t1} \times \ln \gamma)/(h_1 + h_2 + h_3) = 2.5$	[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]
$L_1 = R_1 \times \tau = 3.92$	[μH]
$L_2 = R_2 \times \tau = 4.07$	[μH]
$L_3 = R_3 \times \tau = 4.07$	[μH]
$L_4 = R_4 \times \tau = 9.1$	[μH]

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[6].

Different methods have been proposed to account for these transient behaviors but the most simple and practical one is by CIGRE [6].

$$\mathrm{R_F} = \frac{R_0}{\sqrt{1 + \frac{I}{I_g}}} \quad (8)$$

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

$$\mathrm{I_g} = \frac{1}{2\pi} \cdot \frac{E_0 . \rho}{R_0^2} \quad (9)$$

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.

Comprehensive physical analyses of discharge showed that discharge development always consists of three different phases : corona inception, streamer propagation and leader propagation. Therefore, the time-to-breakdown, t_b , can be expressed as a sum of three components.

$$T_\mathrm{b} = t_i + t_s + t_l \quad (10)$$

Where t_i is the corona inception time, t_s , is the time for streamers to cross the gap or meet the streamers from the opposite electrode and t_l is the leader propagation time[6].

By taking into account the high rate of rise of the applied voltage, the corona inception time, t_i can be neglected without introducing noticeable error.

For streamers

$$\frac{1}{\mathrm{t_s}} = 1.25\left(\frac{E}{E_{50}}\right) - 0.95 \quad (11)$$

Where E is maximum value of the average gradient reached in the gap before breakdown and E_{50} at 50% flashover voltage (U_{50}).

Time for leader propagation, t_l , is normally calculated on the basis of the knowledge of the velocity, which depends on the applied voltage, and leader length.

It has been shown that for all the configurations examined, the most satisfactory results has been obtained with the help of equation. (12)[10].

$$\frac{dl}{dt} = \mathrm{v_l} = 170. D. \left(\frac{u(t)}{D - l} - E_0\right) e^{0.0015\frac{u(t)}{D}} \quad (12)$$

Where l is leader length (m), $u(t)$ is actual voltage (absolute value) in the gap and D is gap length.

But with some practical simplifications [11], the following formula was introduced as a "best fit" to the volt-time curves for standard lightning impulses.

$$\frac{dl}{dt} = \mathrm{k}u(t)\left[\frac{u(t)}{D - l} - E_0\right] \quad (13)$$

Table 3 summarizes the practical parameters for different configuration and polarity.

Table 3: Parameter E and K for different configuration and polarity [6].

configuration	polarity	k	E_0
Air gaps, post and long rod insulators	+ -	$0.8 . 10^{-6}$ $1 . 10^{-6}$	600 670
Cap and pin insulators	+ -	$1.2 . 10^{-6}$ $1.2 . 10^{-6}$	520 600

5 SIMULATION AND RESULTS

Backflashover study of test line has been done with accurate components modeling with EMTP-RV software. Figure 7 shows the schematic of simulated line in EMTP-RV. Each phase line has an ac voltage source on both ends to account for the superposition of the phase voltage on the induced surge voltage. Lightning current has been injected into No. **2** tower and the two 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. With tradeoff between reaching convergence criteria with minimum error and the simulation time, 2000 random lightning current has been chosen.

For random variables generation according to their PDF, a program has been written in MATLAB environment and 2000 random number according to associated PDF has been generated for each parameter.

The number of flashes to the line per 100Km per year has been calculated according to [12] and 40 strokes to line per 100Km per year has been achieved and with 2000 random lightning strokes, it can be claimed that the lightning performance of the line is observed for 50 years. It can give an excellent image from every line lightning performance.

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

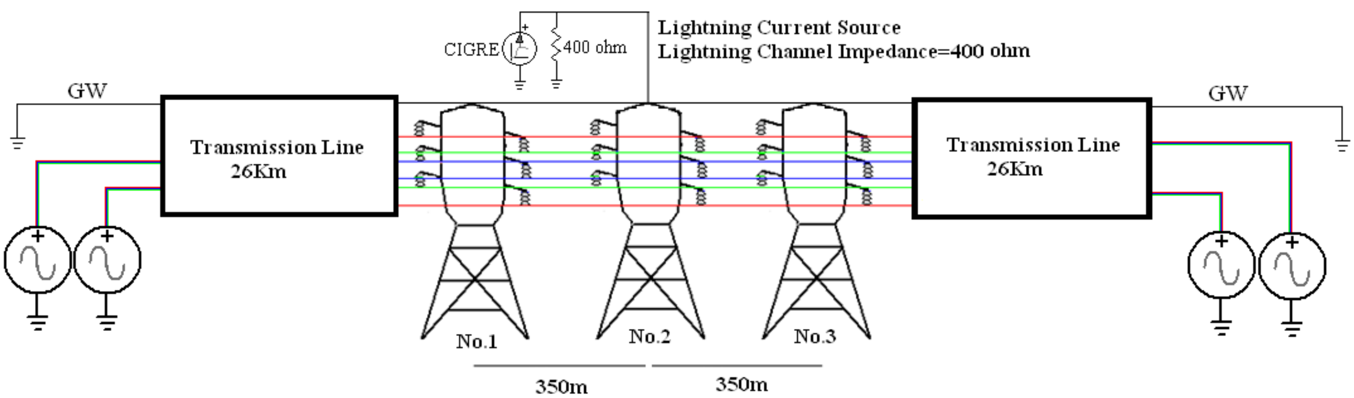

Figure 7: Simulated line schematic

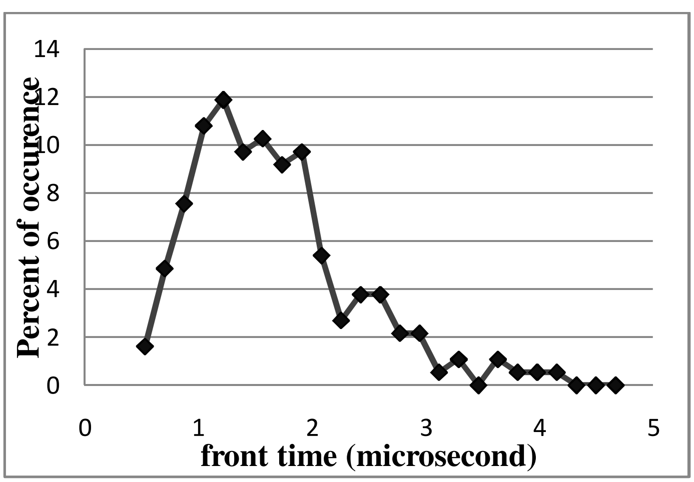

Figure 8: Statistical distribution of flashover current rise time

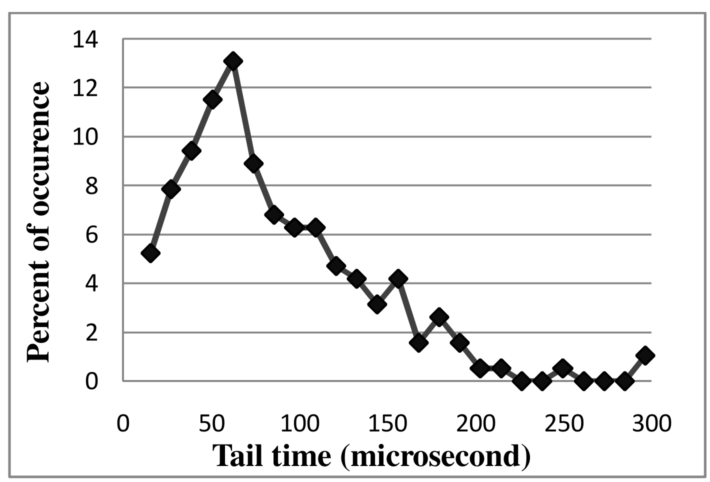

Figure 9: Statistical distribution of flashover current tail time

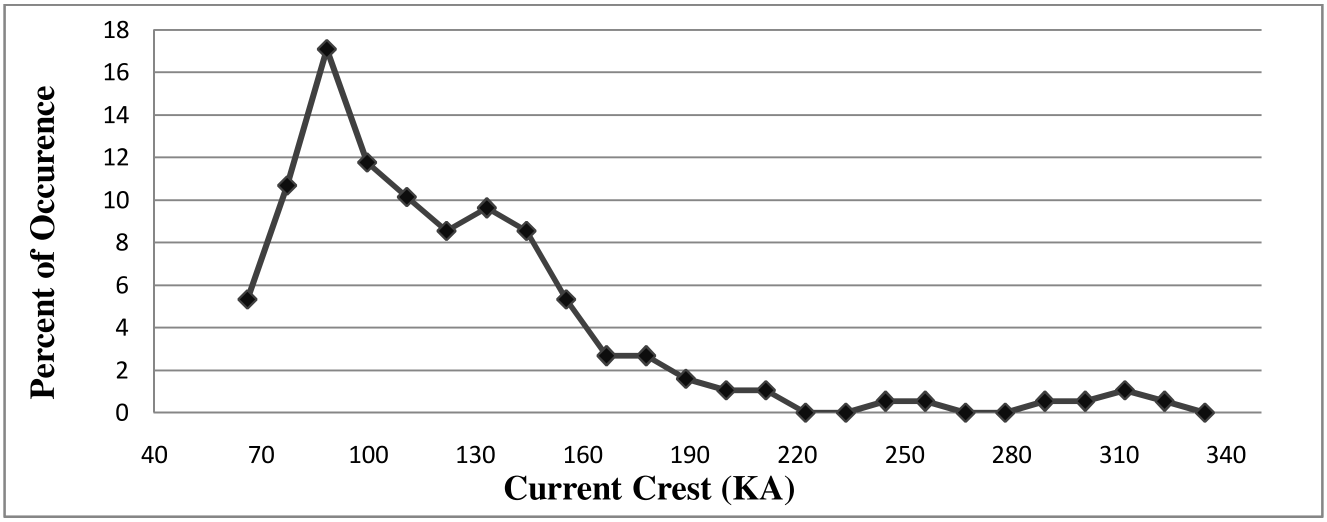

Figure 10: Statistical distribution of flashover current amplitude

6 CONCLUSION

185 lightning strokes from 2000 random lightning strokes cause flashover in upper phase insulator. It means that 9.25 percent of lightning strokes can cause backflashover and for 40 strokes in 100Km per year, 3.7 line outage has been achieved. This value is 23 percent more than the outage rate calculated by conventional methods.

As shown in Figures 8 and 9, statistical distribution of rise and tail time of flashover current fit in log-normal PDF and it means that convergence criteria have been met. More random data can increase similarity between these figures and theoretical figures of 1 and 2.

Figure 10 shows that at the beginning of flashovers, with increase of current amplitude, waveshape dependence of flashovers starts to decrease; but after -95KA this dependence becomes zero and for currents above this value, flashover occurs for every waveshape. Declining trend of flashovers after -95KA arise from lower probability of upper current amplitudes. At the dependence zone of flashovers to current amplitude, shorter rise time and longer tail time can cause flashover at the lower current amplitude.

The presented study as well as the obtained results can be used by power utilities to predict the lightning performance of transmission lines with every voltage level and therefore it can be used as an useful tool for the design of cost-effective transmission lines in electric power systems.

7 REFERENCES

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