MATEC Web of Conferences **61**, 04016 (2016) DOI: 10.1051/matecconf/20166104016
*APOP2016*

# A hybrid approach to calculate the Shielding Failure-Caused Trip-out Rate

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**Abstract.** Lightning has become a big threat to the safe operation of the main transmission line. Reasonable and accurate calculation of shielding failure rate plays important role in transmission line and tower design. This paper proposes a hybrid approach to calculate the shielding failure-caused trip-out rate, based on the typical electro-geometric model and the regulation method. The case study prove the validity and correctness of this approach, by comparing with the actual operation shielding failure rate.

## 1 Introduction

The transmission line goes through the different landscapes and is exposed to nature in a long-term, it is therefore influenced and damaged by the natural phenomena easily. Lightning has become a big threat to the safe operation of the main transmission line.

Lightning shielding failure means lightning strikes on the transmission line, bypassing the lightning conductor. It is the main factor to threat the safety and reliability of EHV transmission line. The typical method to calculate the shielding failure-caused trip-out rate (SFTR) includes: regular method [1-2], electrogeometric model (EGM) [3-4], leader progression model (LPM) [5-6], and so on. Regular method is sample, but only considering the protection angle and height of tower. EMG provides a rational basis for taking account of the influence of structure height and is essentially independent of any assumptions regarding attractive distances to ground. The shortcomings of EGM is that the arc over rate and some other related the electrical characteristics are regardless. LPM is a model of lightning channel progression towards the earth is given based on the physics of discharge on long air gaps. The physical assessment of the electric field is done with the lightning lead progression, however, it does not consider the randomness of the lightning lead progression, the modelling results doesn't actually describe the actual lightning channel.

This paper proposes a new approach to calculate SFTR, based EGM and considering the electrical characteristics. Using the proposed approach to calculate a 500kV transmission line SFTR, compared with SFTR by EGM and the actual trip rate in operation, prove the effectiveness of the proposed approach.

## 2 SFTR Calculation

### 2.1 SFTR

Based on the Chinese regulation, SFTR is the number of trips which caused by shielding in per hundred kilometers, Nsf is SFTR in Eq. 1.

$$N_{sf} = N_s \eta P_\alpha P_2 \tag{1}$$

where $N_s$ is the number of lightning per year per hundred kilometer, $\eta$ is arc over rate, $P_\alpha$ is the probability of shielding strike flashover, $P_2$ is the probability of shielding lightning withstand level.

### 2.2 Calculation of $N_s$

Based on $N_g$ is the number of lightning per year per square kilometer, and it is determined by thunderstorm day $T_d$, according to IEEE Std 1243-1997 [1].

$$N_g = 0.04 T_d^{1.25} \tag{2}$$

$N_s$ is determined by Eq. 3 as follows.

$$N_s = N_g \left( (28h^{0.6} + b)/10 \right) \tag{3}$$

where $h$ is the height of tower, and $b$ is the distance between the two ground wire.

### 2.3 Calculation of $\eta$

Trip is determined by arc over rate, after the insulator flashover. The probability from the impulse flashover into power frequency arc is arc over rate η, which is described in Eq.4.

$$\eta = [4.5(\frac{U_n}{\sqrt{3}L_d})^{0.75} - 14] \times 10^{-2} \tag{4}$$

$U_n$ is the rated voltage, $kV$; $L_d$ is the insulation distance of the insulator string, $m$.

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DOI: 10.1051/matecconf/20166104016

### 2.4 Calculation of $P_2$

The different insulator flashover voltage $U_{50\%}$ is determined by the different type and number of insulator. For the different project, $U_{50\%}$ is different. The strike lightning withstand level is in Eq.5.

$$I_2 = U_{50\%}/100 \tag{5}$$

From the strike lightning withstand level, the probability of shielding lightning withstand level is $P_2$ as follows.

$$p_2 = 10^{-\frac{I_2}{88}} \tag{6}$$

### 2.5 Calculation of $P_\alpha$

EGM proposed in [4] used here to calculate the probability of shielding strike flashover $P_\alpha$. The diagram of electrical geometry model is shown in Fig.1. $D$ is the hanging point of ground line, $E$ is hanging point of conductor, $A$ is the point of intersection of the circle, whose center is $D$, and the vertical line from the tower center to horizontal. $B$ is the intersection of the two circles, center is $D$ and center is $E$, respectively. $C$ is the intersection of the circle, whose center is $E$, and the straight line of the ground attractive distance.

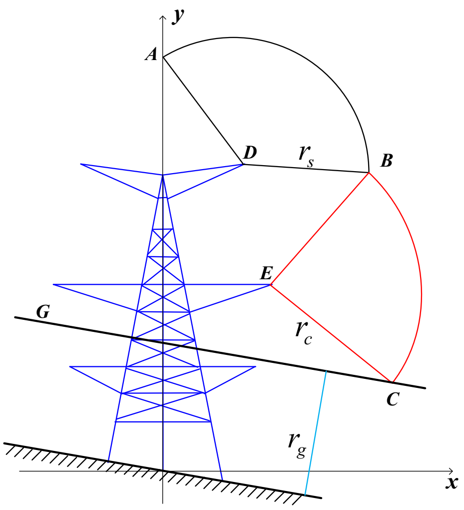



**Figure 1.** Diagram of electrical geometry model.

From the IEEE Std. 1243-1997 [1], the attractive distance can be calculated as in Eq.7- Eq.9.

$$r_s = 10I^{0.65} \tag{7}$$

$$r_c = 1.63\left(5.015I^{0.578} - 0.001U_{ph}\right)^{1.125} \tag{8}$$

$$r_g = \begin{cases} \left[3.6 + 1.7\ln\left(43 - h_{c.av}\right)\right] I^{0.65}, & h_{c.av} < 40m \\ 5.5I^{0.65}, & h_{c.av} \geq 40m \end{cases} \tag{9}$$

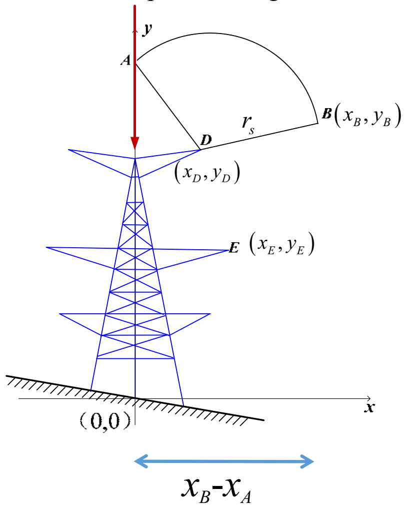
where $I$ is lightning current, $r_s$ is the attractive distance from lightning to ground line; $r_c$ is the attractive distance from lightning to conductor; $r_g$ is the attractive distance from lightning to ground; $U_{ph}$ is the instantaneous voltage when lightning striking; $h_{c,av}$ is the average height of the phase conductor, which can be obtain in Eq. 10.

$$h_{c.av} = h - \frac{2}{3}S_d \tag{10}$$

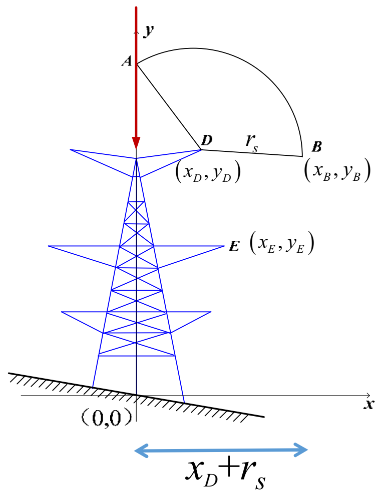
where $S_d$ is sag of conductor.

In Figure.1, the striking point is on the ground line, if the lightning leader progression reaches Arc $AB$ first. The striking point is on the conductor line, if the lightning leader progression reaches Arc $BC$ first. The thundercloud discharge to earth, if the lightning leader progression reaches Straight $CG$ first. Arc $AB$ is protection arc, and Arc $BC$ is exposure arc.

When angle of lightning progression is 0°, lightning current perpendicular to x axis. In Fig. 1, $y_B < y_D$, and the projection of protection surface on x axis is longer than $(x_B - x_A)$, as shown in Eq. 11 and Figure.2.




(a)The protection arc when $y_B \geq y_D$.




(b)The protection arc when $y_B < y_D$.

**Figure 2.** Diagram of the protection arc.

$$l_{AB} = \begin{cases} x_B - x_A, & y_B \geq y_D \\ x_D + r_s, & y_B < y_D \end{cases} \tag{11}$$

Coordinate of point $C$ can be obtained by solving equations of straight $CG$ and the circle of center $E$.

$$y = kx + b \tag{12}$$

where $k = \tan\theta_g, b = r_g/\cos\theta_g, \theta_g$ is ground inclination.

The circle of center $E$ can be described in Eq. 13:

$$(x - x_E)^2 + (y - y_E)^2 = r_c^2 \tag{13}$$

Simultaneous circular and linear equation, get the coordinate of $C$.

$$\begin{cases} x_C = (-b_1 + \sqrt{b_1^2 - 4ac}) / (2a) \\ y_C = kx_C + b \end{cases} \quad (14)$$

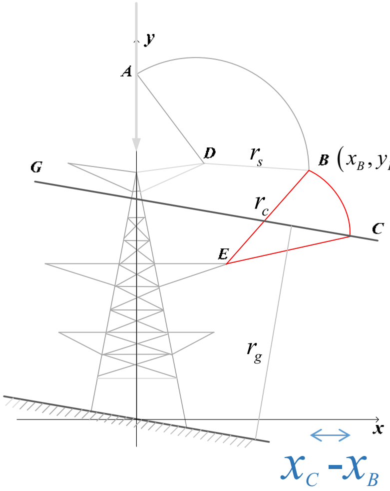
a, b1 and c can be calculated by the Eq. 15-17.

$$a = 1 + k^2 \quad (15)$$

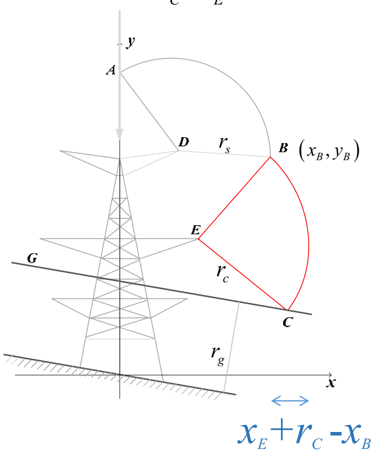
$$b_1 = -2x_E + 2k(b - y_E) \quad (16)$$

$$c = x_E^2 + (b - y_E)^2 - r_c^2 \quad (17)$$

From Figure.1, because of $y_C < y_E$, the projection of Arc $BC$ on $x$ axis is longer than $(x_C - x_B)$, $l_{BC}$, the projection of Arc $BC$ on $x$ axis, is calculated as in (18). The diagram of exposure arc is shown as in Figure.3.




(a)The protection arc when $y_C \geq y_E$.




(b)The protection arc when $y_C < y_E$.

**Figure 3.** Diagram of the exposure arc.

$$l_{BC} = \begin{cases} x_C - x_B, & y_C \geq y_E \\ x_E + r_c - x_B, & y_C < y_E \end{cases} \quad (18)$$

$P_\alpha$ is the probability of shielding strike flashover. When angle of lightning progression is 0°, $P_\alpha$ is as follows.

$$p_\alpha(I) = l_{BC} / (l_{AB} + l_{BC}) \quad (19)$$

From the calculation result of $N_s$, $\eta$, $P_\alpha$ and $P_2$, $N_{sf}$ in Eq. 1 can be obtained.

## 3 Case Study

A 500kV transmission line in operation in the Southwest China is as an example here, there are a total of 340 towers in the transmission line. The example here is a selection of the tower number is #N227 to #N340 , SFTR of these tower is calculated by the proposed calculation method. 50% of these towers are located in the plateau, which is higher than 3000 meters. The average thunderstorm days $T_d$ of the transmission line are up to 80 days. The mountain slopes of each tower is obtained from the GoogleEarth software, and assumed the positive slope is at the right side of the tower, the negative slope is at the left side of the tower. Insulator flashover voltage $U_{50\%}$ is 2520kV.

The calculation result of SFTR is shown in Figure.4 and Figure.5. The Figure.4 is the SFTR of the right side of towers, which is mentioned above that assumed the positive slope is at the right side of the tower. The Figure.5 is the SFTR of the left side of towers. The maximum SFTR of two sides of one tower is the SFTR for this tower, which is shown in Figure. 6. The largest SFTR for the towers in the example is 0.1778 times/100km per year, the calculation result is close to the statistics operating SFTR in last two years, which proves the validity and correctness of this approach.

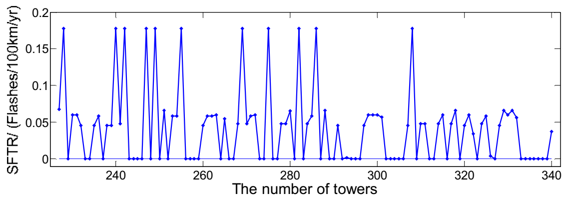



**Figure 4.** SFTR of the right side of towers.

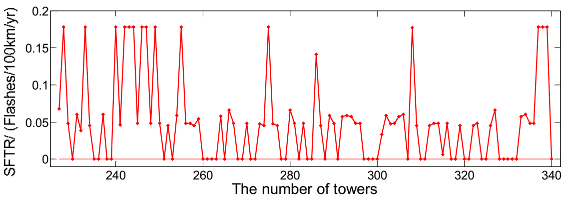



**Figure 5.** SFTR of the left side of towers.

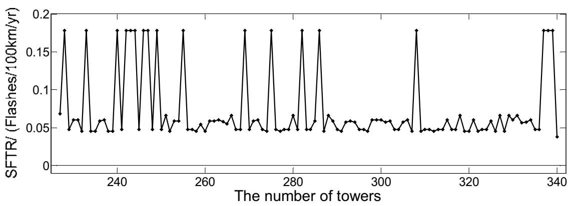



**Figure 6.** SFTR of the towers.

## 4 Conclusion

Transmission line fails by lightning has been a big threat to safe operation in power system. Shielding failure is most lightning strike type in all of the world. Reasonable and accurate calculation of shielding failure rate plays important role in transmission line and tower design. This paper proposes a hybrid approach to calculate the shielding failure-caused trip-out rate, based on the typical electro-geometric model and the regulation method. The case study prove the validity and correctness of this approach, by comparing with the actual operation shielding failure rate.

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