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Study on Influence of Trees around 10 kV Distribution Line

Yongcong Wu[1], Daochun Huang[1], Jiangjun Ruan[1], Yuandong Chen[2], Hanwu Luo[2], Xin Sun[2], Shubo Chen[2]

[1]School of Electrical Engineering, Wuhan University, Wuhan, China
[2]Eastern Inner Mongolia Power Ltd., Hohhot , China
Email: 362121393@qq.com

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Abstract

Considering the complexity of the geographical surroundings and the height of 10 kV distribution line, the impact of trees on the lightning performance can not be ignored. A model of lightning position judgment and overvoltage calculation based on the concept of striking distance is built. With the theory of orthogonal test, the main factors of trees' influence on lightning performance are figured out. The results indicate that the location of trees is the main factor. In practical engineering, suitable management of vegetation can improve the lightning performance and reduce the lightning failure of 10 kV distribution line.

Keywords

10 kV Distribution Line; Trees; Optimal Configuration; Orthogonal Test

1. Introduction

There are trees around the area of 10 kV distribution corridors and some even grow just below the distribution line. The height of trees can always reach 10 m - 20 m. Thus, trees may have influence on 10 kV distribution line lightning performance. Researchers have discussed the influence on lightning overvoltage [1] [2]. And the influence on 500 kV transmission line is studied. The results evidence that 10 m - 20 m trees can reduce 30% - 80% direct lightning strike. But the change of induced lightning overvoltage is not discussed and the results don't apply to distribution. Researchers have performed many tests and theoretical studies on direct lightning overvoltage and induced lightning overvoltage [3]-[6]. And striking distance is an important concept in EGM which is used to find out the lightning strike location. In this paper, the model of lightning location judgment based on the concept of striking distance is built. With the model, the lightning performance of 10 kV distribution line is quantitatively analyzed when trees are considered. The results can provide a reference for lightning protection and vegetation management of 10 kV distribution line.

2. Model

2.1. Judgement of Lightning Location

According to [6], attracting range of line, ground and trees are combined arcs that centered on relevant object

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and striking distance are radiuses. As it is shown in the **Figure 1**, B_3 B_2 C, A_1 A_2 C and DE are the corresponding attracting surface. The location of lightning leader is O. h_t and h_l are height of tree and the line. R_t, R_l, R_g are striking distance of tree, the line and the ground. L_1 is the distance between the leader and the tree. And L_2 is the distance between the leader and the line.

When $L_1 < R_t$, $L_2 < R_l$ the distance between the attracting surface and the ground H. The object which the max H_t belongs to is the lightning striking target.

$$\text{Trees:}\quad H_t = \sqrt{(R_t - L_1)^2 + h_t} \tag{1}$$

$$\text{Linw:}\quad H_t = \sqrt{(R_t - L_2)^2 + h_l}\ . \tag{2}$$

2.2. Lightning Performance Parameters

In this paper, the number of direct lightning flashover times (DLFT), induced lightning flashover times (ILFT) and dangerous current times (DCT) serve as the characteristic parameters of the 10 kV distribution line lightning performance.

Reference [7] concludes that direct lightning strike bounds to cause flashover. We define the number of direct lightning flashover times as the times that a line span suffer in a year. The number of induced lightning flashover times is defined as the times that insulators flashover caused by lightning induced overvoltage in a year. According to [8], the number of dangerous current times is defined as the sums of ILFT of a tower and the DLFT on the two line span next to the tower in a year. These parameters can serve as the assessment of the lightning performance.

2.3. Induced Lightning Overvoltage

When considering trees, lightning leader is not perpendicular to the ground as it is shown in **Figure 2**. S_1 is the horizontal distance between the vertical lightning leader and the line. S is the horizontal distance between the tree and the line. h_t, h_l are the height of the tree and the line.

The resistivity of woods can reach $1.8\times10^5\,\Omega\cdot m$. Trees are regarded as dielectric with sharp tips in this paper. Calculated datas of lightning induced-overvoltage are shown in **Figure 3**. And the results of regulation method is also given in **Figure 3** for comparison.

2.4. Parameters

According to IEEE, the striking distance is expressed as:

$$R_l = 6.72 I^{0.8} \tag{1}$$

$$R_t = K_g R_l\ . \tag{2}$$

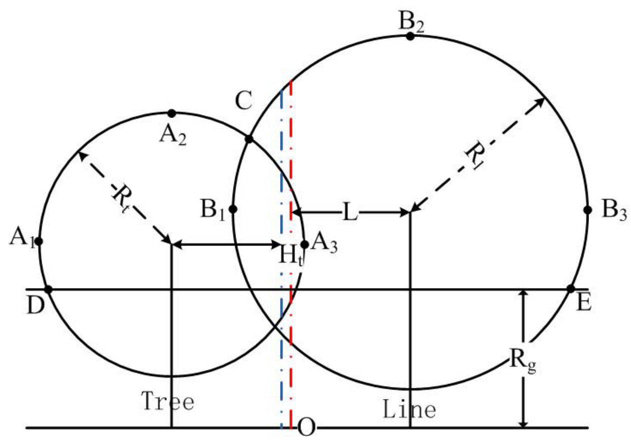

Figure 1. Judgement of lightning strike location.

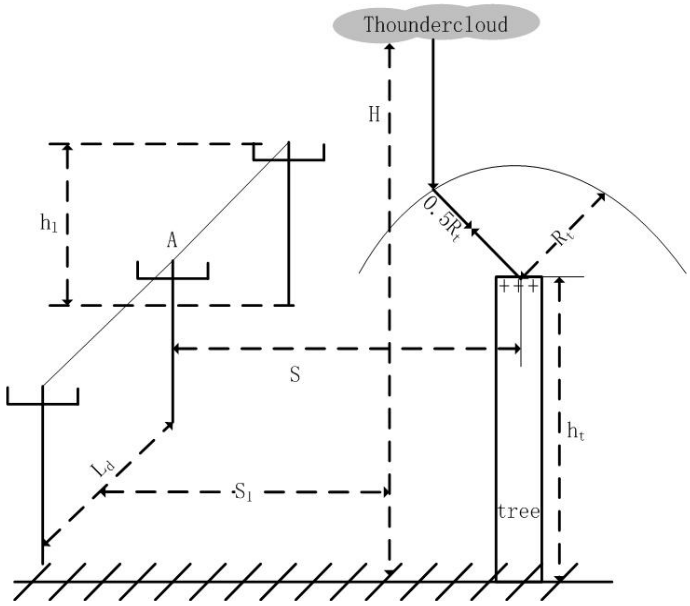

Figure 2. Lightning location and strikiing distance.

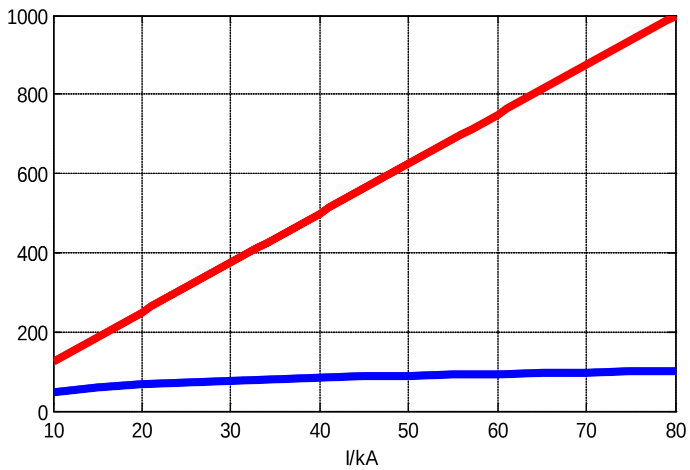

Figure 3. Results of induced-overvoltage (kV).
$h_l = 10.2m, h_t = 12m, S_1 = 20m, S = 25m$.

I: amplitude of lightning current, R_l, R_l are the striking distance of the line and the tree.
Reference [9] provides lightning current parameters:

$$\lg P = -I/88 . \quad (3)$$

Thunderstorm day Td = 40. Average surface density of lightning is 0.07. H_l = 10.2 m, impulse discharge voltage of insulator $U_{50\%}$ = 230 kV, line span L_0 = 100 m.

3. Influence on Lightning Performance

In this section, simulations are carried out with trees that the height is between 5 m and 40 m. The K_g is set to be 0.95. we focus on the trees that located within 50 m from the line or the tower, N_a, N_b, N_c are the simulation datas of DLFT, ILFT and DCR without trees. If N is the relevant simulation value of DLFT, ILFT and DCR, relative value N/N_a, N/N_b, N/N_c are used to describe the changes of lightning performance. In the diagram, the x-y coordinate plane describe the location of the trees that is relative to the line or the tower.

3.1. Influence on DLFT

Firstly, we can get $N_a = 0.0314$ without considering trees. It is equivalent to 31.4/(100 km·a),which means the direct lightning flashover times of 100 km distribution line reach 31.4 times in a year. The center of the diagram is the middle of the line span. (0,0) is the location of the tower, and the y axis shows the result of N/N_a. The direction of the line is the same as the arrwo in **Figure 4(a)**.

Simulation results are shown in **Figure 4**. When the height of trees $h_t > 5$ m, trees can keep $N/N_a < 1$. It indicates that trees can reduce the DLFT. When the height of tree between 5 m and 12 m, the shape of the simulation diagram is convex. It evidences that the closer to the line the poorer the protecting effect of the tree is. Taking 10.2 m trees for example, trees locating 25 m from the line can reduce 5% of the direct lightning strike but only 2% when the distance is 10 m.

When ht > 20 m, the results are significantly different from that of 5 m - 12 m trees. Trees can best protect the distribution line. The simulation datas show that the decrease of DLFT can reach 50% - 70% when h_t = 20 m - 30 and the shielding effect is significant.

3.2. Influence on ILFT

We can get $N_b = 0.0012$/a without considering trees. It is equivalent to 1.2/(100 km·a),which is the ILFT of

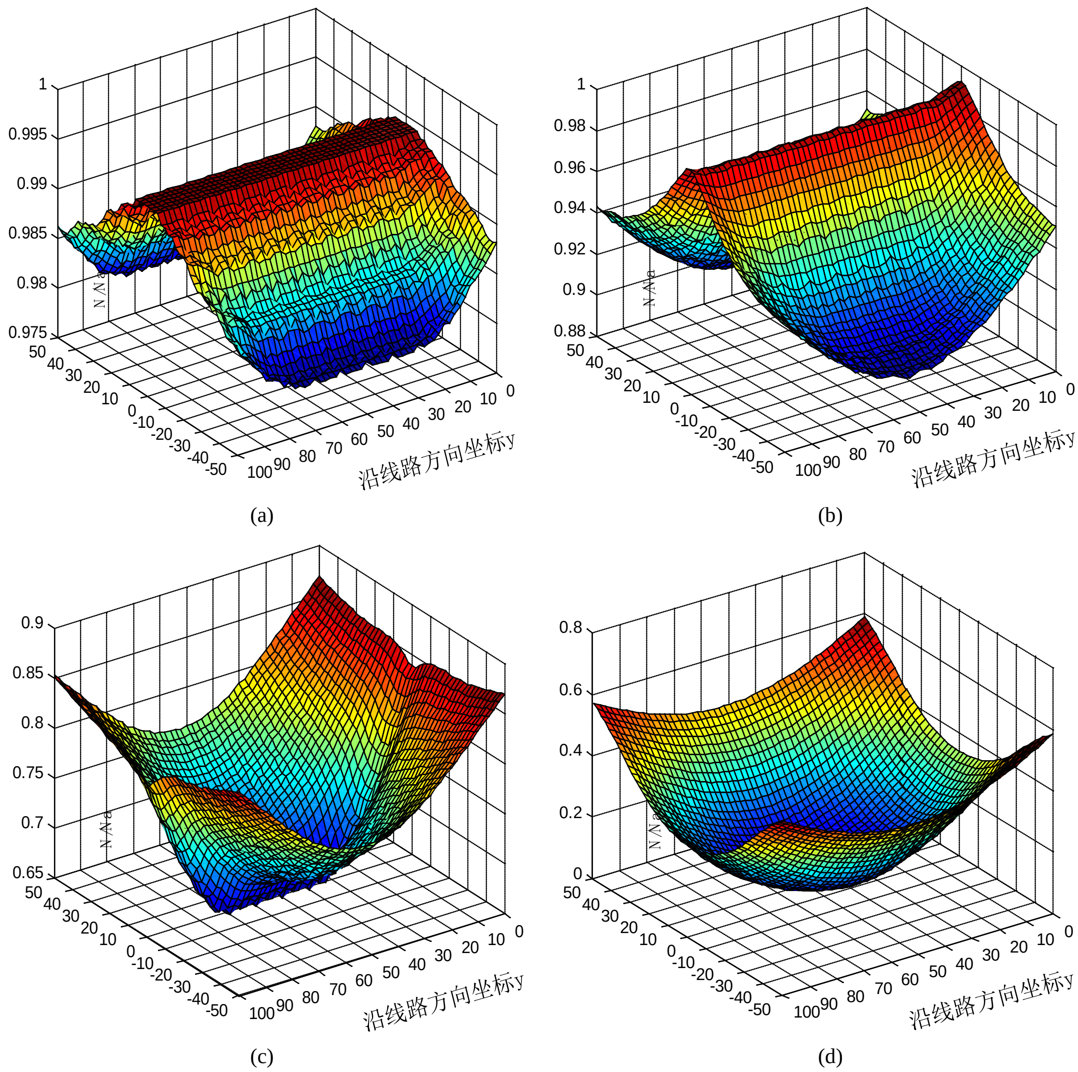

Figure 4. Simulation results of N/N_a. (a) h_t = 5 m; (b) h_t = 12 m; (c) h_t = 20 m; (d) h_t = 40 m.

100 km distribution line.

The simulation results are shown in **Figure 5**. The center (0,0) of the result diagram is the location of the tower and the y axis shows the simulation results of N/Nb. The direction of the line is the same as the arrow in **Figure 5(a)**.

The simulation results in **Figure 5** shows that $N/N_b > 1$.They evidence that trees taller than 5 m can increase the ILFT. There are many maxima scattered in the diagram. Comparing with the other location, trees locating at these point may increase more threat to the insulation.

When ht > 30 m N/Nb is obviously segmented. The closer to the tower, the more significantly the induced lightning flash over rate increase. Trees can increase the ILFT more than 10 times. It means that trees can increase the threat of lightning induced overvoltage.

4. Orthogonal Test on Optimal Configuration of Greenbelts

According to the analysis above, trees have opposite influence on DLFT and ILFT. Thus different location and h_t of the tree may lead to different influence on the total flashover times of distribution line. Finding out the best management of trees can protect the line from direct lightning strike and reduce the ILFT increase. In this sec-

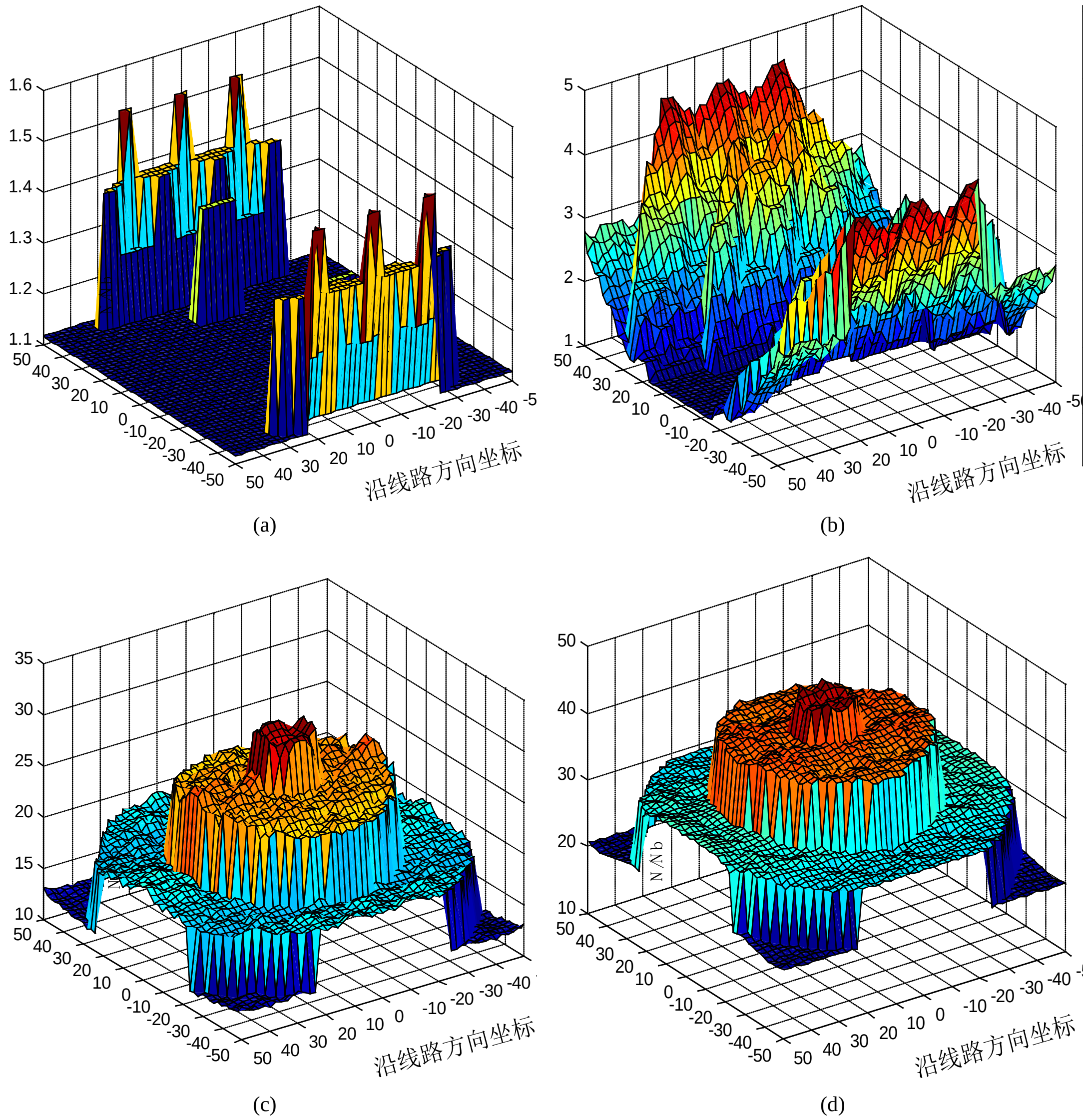

Figure 5. Simulation result of N/N_b. (a) h_t = 5 m; (b) h_t = 12 m; (c) h_t = 30 m; (d) h_t = 40 m.

tion, orthogonal test is USED to study the influencing factors of the impact of trees. In the urban area, trees are always appearing in greenbelt form. Thus, greenbelt serves as a proxy in the study.

Orthogonal test is a scientific method that is based on probability theory, mathematical statistics and practical experience. Orthogonal test is USED to find out the best management of trees and 10 kV distribution line.

4.1. Factor and Level

According to the theory of orthogonal test, striking distance factor K_g, difference between h_t and h_l, location of the greenbelts S, and the length of the greenbelts are regarded as 4 factors. Each factor includes 5 levels. Factors and levels are shown in **Table 1**. The scheme is arranged according to $L_{25}(5^6)$.

4.2. Results

The simulation and range analysis result are shown in **Table 2**. To DLFT, the range of K_g is the largest, which indicates that K_g is main influence factor of DLFT. Meanwhile, the range of L reach 0.44 which means L is also the factor that cannot be ignored. According to this analysis method, to ILFT, K_g is still the main factor. And distance S becomes the second most important factor.

To DCT, Kg is not the main factor. And S becomes the main influence. It means that the increase of ILFT is similar to decrease of DLFT when Kg changes. And the rational location of greenbelts can improve the lightning performance of 10 kV distribution line.

Striking distance factor is not steerable in engineering and the height difference is not the main factor. The optimal location of trees is figured out in different condition. The simulation data are shown in **Figure 6**.

The simulation results of **Table 2** and **Figure 6** indicate that the length of greenbelts and the location is the main factors that influence the impact of trees. N/N_c should keep small enough so that the 10 kV distribution

Table 1. Orthogonal factor level.

Factor	1	2	3	4	5
A: Factor, K_g	0.92	0.94	0.96	0.98	1.00
B:height difference, Δh (m)	−3	−1.5	0	1.5	3
C: distance between trees and line, S (m)	5	15	25	35	45
D:Length of trees, L (m)	40	80	120	160	200

Table 2. Range analysis.

Factor		*I*	*II*	*III*	*IV*	*V*	R
	N/N_a	4.86	4.77	4.62	4.29	3.99	0.87
A	N/N_b	15.83	18.11	21.49	49.95	74.63	58.79
	N/N_c	5.08	5.02	4.94	5.16	5.16	0.22
	N/N_a	4.62	4.53	4.56	4.30	4.52	0.31
B	N/N_b	31.32	28.31	30.31	48.14	41.92	19.83
	N/N_c	5.13	4.99	5.05	5.14	5.24	0.24
	N/N_a	4.43	4.60	4.46	4.57	4.48	0.13
C	N/N_b	18.19	44.14	43.59	38.87	44.06	25.94
	N/N_c	4.69	5.19	5.21	5.23	5.23	0.53
	N/N_a	4.73	4.52	4.58	4.42	4.29	0.44
D	N/N_b	38.10	42.25	38.24	27.71	33.71	14.53
	N/N_c	5.37	5.24	5.23	4.86	4.85	0.52

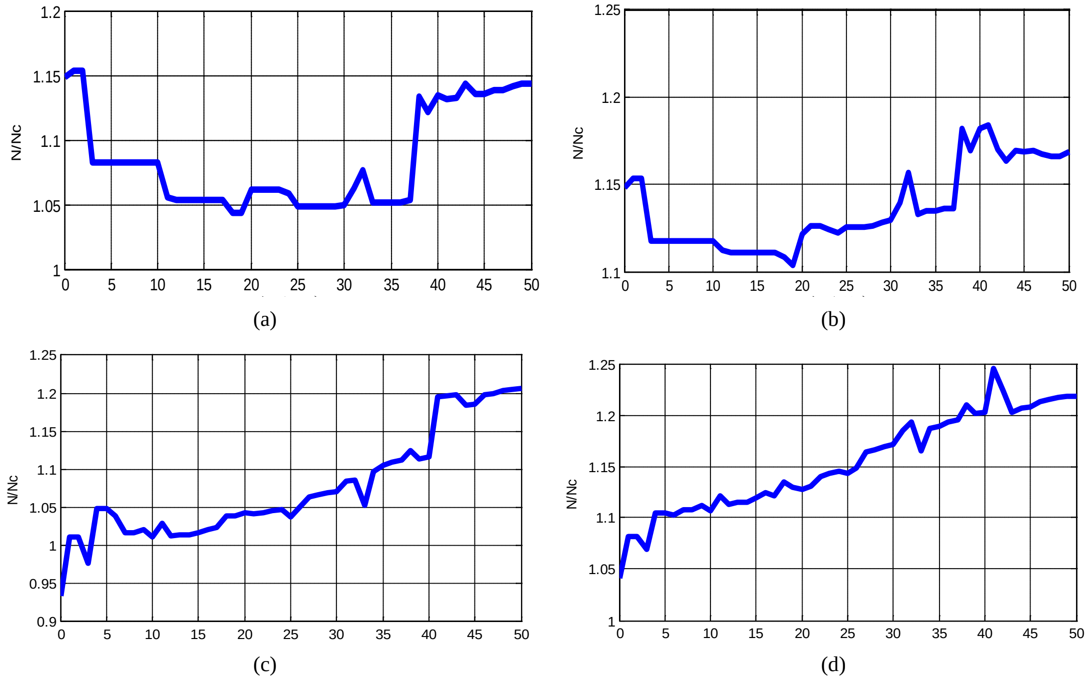

Figure 6. Simulation datas of N/N_c (DCT). (a) $\Delta h = 1m, K_g = 0.95, L = 200m$; (b) $\Delta h = 1m, K_g = 0.95, L = 100m$; (c) $\Delta h = 1m, K_g = 0.98, L = 200m$; (d) $\Delta h = 1m, K_g = 0.98, L = 100m$.

face fewer failures. More simulation evidences that greenbelts can reduce N/N_c up to 20% if the location is suitable ($N/N_c < 0.8$). To condition (a) in **Figure 6**, the best location distance S = 12 m - 38 m. To condition (b), the best distance S = 12 m - 18 m. To condition (c) and (d), trees closer to the line may lead to better protecting effect.

5. Conclusion

In this paper, a feasible scheme of quantitative analysis about trees' influence on 10 kV distribution line lightning performance is proposed. The results can provide a reference for lightning protection and nearby vegetation management of 10 kV distribution line.

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