Scientific
Research

Research on Evaluating Index of Lightning Protection Safety Performance of High Voltage Overhead Transmission Line

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Abstract

In order to improve the lightning protection performance of transmission lines, lightning protection management has been divided into every tower that lightning protection performance has been evaluated respectively. According to factors such as landform, span, tower type, grounding resistance, isolator type, and so on, relative ratio of tripping operation of every tower in the line has been calculated to evaluate its lightning protection safety performance, it is beneficial to operation maintenance and lightning reconstruction of transmission lines.

Keywords

1. Introduction

The ratio of lightning tripping operation of high voltage overhead transmission line is very high at all time, it always exceeds 70% of total tripping operation, and lightning tripping operation becomes the main factor that may endanger the safety of power system [1] [2].

Usually, there are few indexes to evaluate the lightning protection performance of high voltage overhead transmission line, such as lightning withstand level and ratio of tripping operation, those indexes are rude and unitary, and cannot reflect the influence of height, landform, span, tower type, grounding resistance, isolator type, and so on, of every tower.

In order to improve the lightning protection performance of transmission lines, lightning protection management has been divided into every tower that lightning protection performance has been evaluated respectively according to different parameters of every tower [3].

2. Evaluating Index of Linghtning Protect

A. *Relative Lightning Ratio*

Every tower of a transmission line has different parameters such as height above sea level, tower height, onward and backward spans of conjoint towers, distance of two overhead ground wires, so lightning ratio of every tower is different when there is thundercloud above transmission line. To reflect those differences, relative lightning ratio *k* is introduced.

$$k = \frac{S}{S_{\text{MAX}}} = \frac{\left(W + \sqrt{H}\right)D}{(W_{\text{Max}} + \sqrt{H_{\text{Max}}})D_{\text{Max}}} \tag{1}$$

Here *H* is the height above sea level of overhead ground wires, *W* is the distance between two overhead ground wires, *D* is half of sum of onward and backward spans, H_{MAX}, W_{MAX}, D_{MAX} are maximums of those parameters of all towers in a transmission line. Obviously *S* is the area of an enlarged rectangle which length is half of sum of onward and backward spans, and which width has been extended on account of the effect of height above sea level of overhead ground wires. S_{MAX} is the biggest area of those parameters of all towers. *k* equals to ratio of the equivalent area of one tower to the biggest area.

B. *Probability of Sustained Arc*

Probability of sustained arc *v* is:

$$v = [4.5\left(\frac{U}{l\sqrt{3}}\right)^{0.75} - 14]^{-2} \tag{2}$$

Here *U* is the line voltage and *l* is the length of the isolator.

C. *Withstand Level of Lightning Direct Stroke to Tower*

Withstand level when lightning is striking to tower directly is:

$$I_2 = \frac{U_{50\%}}{\left[\beta\left(R + \frac{L}{2.6}\right) + \frac{h_d}{2.6}\right](1-q)} \tag{3}$$

Here $U_{50\%}$ is 50% impulse spark over voltage of isolator, β is the shunt coefficient of overhead ground wires, *R* is the grounding resistance of tower, *L* is the inductance of tower, h_d is the height of conductor to ground, *q* is the coupling coefficient between conductor and overhead ground wire.

D. *Withstand Level of Lightning Shielding Failure*

Withstand level when lightning is striking to conductors directly is:

$$I_2 = \frac{U_{50\%}}{100} \tag{4}$$

E. *Direct Stroke Rate and Shielding Failure Rate*

There is a relationship between striking distance r_S and lightning current magnitude *I*:

$$r_S = 7.1I^{0.75} \tag{5}$$

Geometrical model of direct stroke and shielding failure is illustrated in **Figure 1**, θ is the incline angle of ground shown as line GH, GF is the centric line of a tower, B and D are overhead ground wire and conductor respectively of one side.

Draw an arc PS which center is in the point B and radius is r_S, and another arc ST which center is in the point D and radius is r_S, and a line UV which is paralleled to ground with a distance of r_S.

Obviously, if imminent lightning leader gets to arc PS, lightning may hit to the overhead ground wire, on the other hand, lightning may hit to the conductor when imminent lightning leader comes to arc ST. Direct stroke rate and shielding failure rate can be calculated by angles α and γ corresponding to arc PS and ST.

Direct stroke rate $\eta(r_S)$ is:

$$\eta\left(r_S\right) = \frac{\alpha}{\alpha + \gamma} \tag{6}$$

Shielding failure rate $\xi(r_S)$ is:

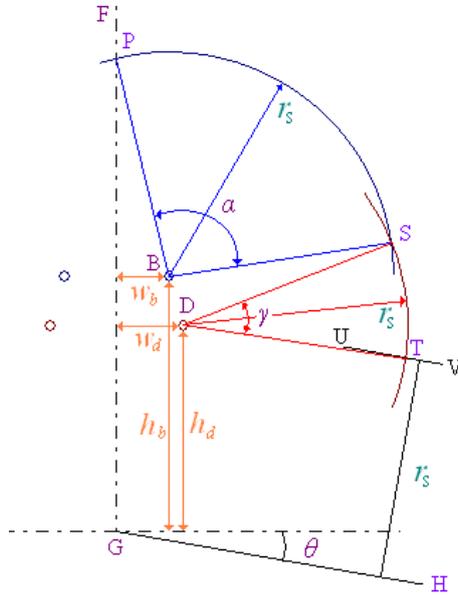$$\xi\left(r_S\right) = \frac{\gamma}{\alpha + \gamma} \tag{7}$$

Figure 1. Direct stroke and shielding failure.

Angles α and γ have a relationship with tower parameters and striking distance r_S, according to the geometrical model in **Figure 1**, they can be given as:

$$\alpha = \frac{\pi}{2} + \sin^{-1}\left(\frac{w_b}{r_S}\right) - \sin^{-1}(\frac{h_d - h_b + \sqrt{(h_b - h_d)^2 - 4(\frac{(w_d - w_b)^2 + (h_b - h_d)^2}{4} - \frac{r_S^2(w_d - w_b)^2}{(w_d - w_b)^2 + (h_b - h_d)^2})}}{2r_S}) \quad (8)$$

$$\gamma = \sin^{-1}(\frac{h_b - h_d + \sqrt{(h_b - h_d)^2 - 4\left(\frac{(w_d - w_b)^2 + (h_b - h_d)^2}{4} - \frac{r_S^2(w_d - w_b)^2}{(w_d - w_b)^2 + (h_b - h_d)^2}\right)}}{2r_S})$$
$$- \sin^{-1}(\frac{r_S - h_d - w_d\sin(\theta) - \sin(\theta)\sqrt{r_S(1 + \sin^2(\theta)) - (r_S - h_d - w_d\sin(\theta))^2}}{r_S(1 + \sin^2(\theta))}) \quad (9)$$

If $\gamma < 0$, then let $\eta = 1$ and $\xi = 0$, this indicates that shielding failure will not occur under that lightning current magnitude I and its striking distance r_S.

Middle phase will be neglected. Direct stroke rate and shielding failure rate of another side of tower can be computed by Formulas (6)-(9) in the same way, and will be added up.

For double lines on the same tower, angles α, γ_A, γ_B, γ_C, as illustrated in **Figure 2**, must be calculated, then,

$$\eta(r_S) = \frac{\alpha}{\alpha + \gamma_A + \gamma_B + \gamma_C} \quad (10)$$

$$\xi(r_S) = \frac{\gamma_A + \gamma_B + \gamma_C}{\alpha + \gamma_A + \gamma_B + \gamma_C} \quad (11)$$

F. *Ratio of Direct Stroke Tripping Operation*

Probability that lightning current magnitude exceeds I is:

$$P(I) = 10^{-\frac{I}{108}} \quad (12)$$

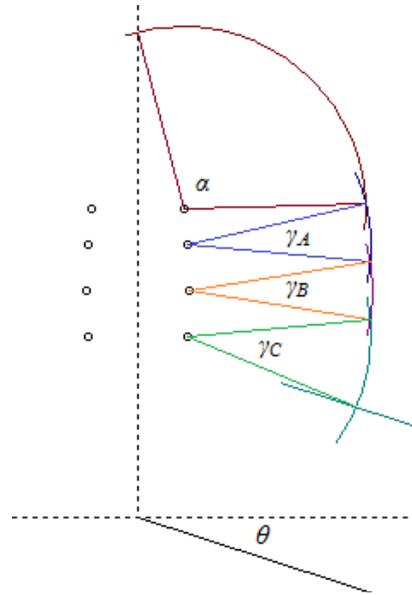So, Probability of lightning current magnitude I is:

Figure 2. Double lines on the same tower.

$$f(I) = 0.02132 \times 10^{-\frac{I}{108}} \tag{13}$$

Ratio of direct stroke tripping operation is:

$$k_1 = v \int_{I_1}^{\infty} f(I) \eta(r_s) dI \tag{14}$$

G. *Ratio of Shielding Failure Tripping Operation*
Ratio of shielding failure tripping operation is:

$$k_2 = v \int_{I_2}^{\infty} f(I) \xi(r_s) dI \tag{15}$$

H. *General Evaluating Index*
After considering the effect of tower type, height over sea level, span, ground resistance, isolator, landform, general evaluating index of lightning protection safety performance of every tower is:

$$J = k(k_1 + k_2) \tag{16}$$

By all appearances, the smaller general evaluating index of a tower is, the better lightning protection safety performance of that tower is, on the other hand, the bigger general evaluating index of a tower is, the worse lightning protection safety performance of that tower is.

Supposed that J_{MAX} is the maximum of evaluating indexes of all towers in a transmission line, relative evaluating index can be defined as:

$$J_r = \frac{J}{J_{\text{Max}}} \times 100 \tag{17}$$

Relative evaluating index expressed by percentage is very intuitionistic, and it is easy to give a taxis to all towers in a transmission line according to relative evaluating index.

3. Evaluating Software

Based on MS Visual Basic 6.0, evaluating software of lightning protection safety for high voltage overhead transmission lines is developed, it includes six component: lines edit, tower edit, isolator edit, evaluating analysis, graph show, and version information.

Line edit component inputs and manages lines information and all parameters of every line. Tower edit com-

ponent manages tower type and its main parameter. Isolator edit component manages isolator type, save 50% impulse spark overvoltage and length of every isolator (**Figure 3**).

Figure 4 shows the interface of the evaluating result. Result includes relative lightning ratio, ratio of direct stroketripping operation, ratio of shielding failure tripping operation, general evaluating index, relative evaluating index and taxis. All parameters of a transmission line and evaluating result can be exported to an Excel document.

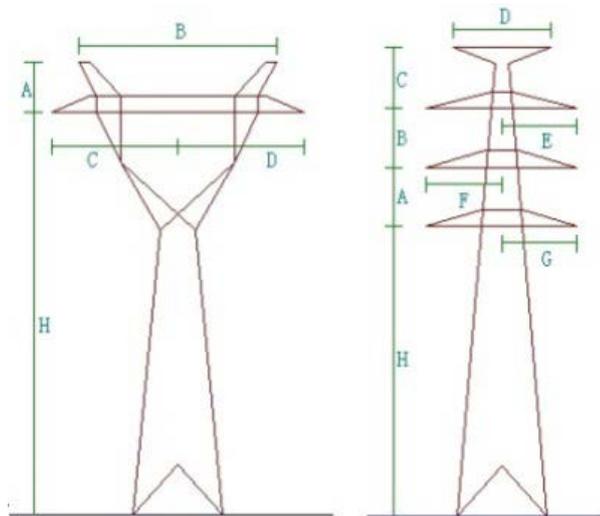**Figure 5** shows height and span of atransmission line.


Figure 3. Tower main parameter.

杆号	杆塔类型	海拔高度	档距	接地类型	接地电阻	地形	安装避雷器	绝缘子	故障记录	落雷概率	绕击跳闸率	反击跳闸率	综合指标	相对综合指标	排序
85	ZY1-36	310	1316	NJD-236	25	丘陵		FXBW4-220/100		0.5382	0.0322	0.2065	0.1285	47.693	40
86	SJ2-21	328	249	NJD-237	30	丘陵		FXBW4-220/100		0.2841	0.0093	0.2156	0.0639	23.725	109
87	ZY1-33	429	575	NJD-235	25	丘陵		FXBW4-220/100		0.3738	0.0273	0.2030	0.0860	31.947	90
88	ZY1-36	415	413	NJD-237	30	丘陵		FXBW4-220/100		0.3527	0.0322	0.2270	0.0914	33.938	85
89	ZY1-30	437	527	NJD-235	20	丘陵		FXBW4-220/100		0.3546	0.0225	0.1746	0.0699	25.939	103
90	ZY1-36	507	407	NJD-237	30	山顶		FXBW4-220/100		0.3858	0.0460	0.3243	0.1428	53.035	35
91	SJ1-27	534	558	NJD-237	30	山顶		FXBW4-220/100		0.4076	0.0255	0.3134	0.1381	51.289	36
92	ZY1-36	671	450	NJD-233	20	山顶		FXBW4-220/100		0.2384	0.0460	0.2621	0.0735	27.270	99
93	ZY1-27	693	93	NJD-232	15	山顶		FXBW4-220/100		0.3929	0.0255	0.2016	0.0892	33.120	87
94	SZ201-30	857	796	NJD-236	25	山顶		FXBW4-220/100		0.5544	0.0321	0.2850	0.1758	65.267	22
95	SZ201-42	753	366	NJD-237	30	山顶		FXBW4-220/100		0.6895	0.0604	0.3303	0.2693	100.00	1
96	SZ201-42	763	1139	NJD-237	30	山顶		FXBW4-220/100		0.6586	0.0604	0.3303	0.2573	95.520	4
97	ZY1-27	727	292	NJD-237	30	山顶		FXBW4-220/100		0.3011	0.0255	0.3134	0.1020	37.883	73
98	SZ201-48	709	378	NJD-236	25	山腰		FXBW4-220/100		0.8429	0.0599	0.2489	0.2603	96.653	3
99	SJ1-27	652	1495	NJD-237	30	山顶		FXBW4-220/100		0.7801	0.0255	0.3134	0.2644	98.155	2
100	ZY1-36	671	308	NJD-235	25	山顶		FXBW4-220/100		0.3951	0.0460	0.2950	0.1347	50.020	37
101	ZY1-36	625	592	NJD-237	30	山顶		FXBW4-220/100		0.4564	0.0460	0.3243	0.1690	62.731	24
102	ZY1-30	618	473	NJD-237	30	山顶		FXBW4-220/100		0.3157	0.0321	0.3169	0.1102	40.904	57
103	ZY1-30	593	269	NJD-236	25	山顶		FXBW4-220/100		0.3394	0.0321	0.2850	0.1076	39.961	62
104	ZY1-30	615	540	NJD-236	25	山顶		FXBW4-220/100		0.4843	0.0321	0.2850	0.1536	57.010	30

Figure 4. Interface of evaluating result.
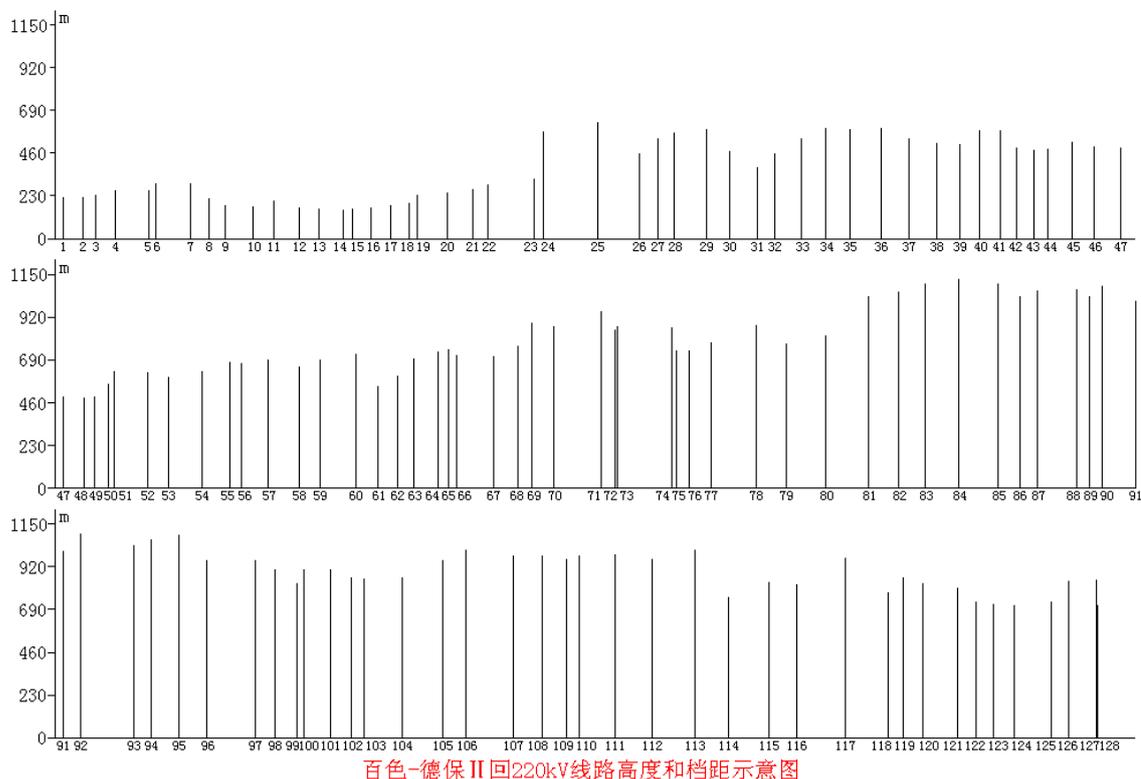
Figure 5. Height and span of a transmission line.

4. Conclusions

By introduction of relative lightning ratio, the effect of tower parameters, such as height above sea level, tower height, onward and backward spans of conjoint towers, distance of two overhead ground wires can be numerated, and that is easy to reflect the difference of every tower.

Tower type and incline angle of ground have a distinct influence to direct stroke rate and shielding failure rate, and are main parameters of the difference.

Relative evaluating index of of every tower is very intuitionistic and is beneficial to operation maintenance and lightning reconstruction of transmission lines.

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